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Review

Global Policy Review on Embodied Flows: Recommendations for Australian Construction Sector

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Abstract: There has been a call for the construction industry to become more energy efficient in its planning and activities, to reduce greenhouse gas emissions to help combat climate change. The Australian Building Codes Board has implemented ‘Energy Efficiency’ standards through the National Construction Codes to direct the industry towards net zero emissions goals. However, the Board has maintained a focus on operational flows considerations despite this only being a part of the total expenditure in a building lifecycle. Embodied flows, the energy output, and emissions from harvesting, manufacturing, transporting, and manufacturing materials for a building have not been included as a part of the current standards despite their growing share in the outputs of construction. A qualitative document analysis using data from academic articles and industry publications was performed to identify the context in embodied policy development. Findings reveal an abundance of different legislations and initiatives globally, recommending techniques that may effectively achieve embodied flow reductions. The results highlighted that Australia needs to capitalize on the potential reductions in overall energy and emissions from construction. Other regions have provided a strategic and legislative basis for the industry to emulate.

Keywords: Australia; construction; embodied flows; policy; review

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1. Introduction

Sustainable production and consumption have become a necessity and a priority, globally and within Australia, as humans are confronted with climate change and associated natural crises in modern-day society [1,2]. Most industries and sectors are evolving and adopting environmentally responsive materials, methods, and processes to mitigate anthropogenic greenhouse gas (GHG) emissions globally, to preserve the environment and prevent catastrophic societal failure [3–5]. As one of the largest global GHG emitters, the construction industry is also changing its conventional practices through policy changes and other legislative frameworks to help mitigate climate change [6–8]. Currently, most construction industries in developed and developing countries have their sustainability policies and practices established aiming at emissions reductions and preserving the environment [3,9–13]. Many of the existing policies developed for construction industries emphasize reducing operational energy and emissions in buildings during the use phase, although its only part of the energy used and emissions generated from buildings during their life cycles [14–18].

As one such measure to enforce change within its policies, the Australian Building Codes Board (ABCB) has adopted ‘Energy Efficiency’ standards as a part of the ‘National Construction Code’ (NCC) [19]. The ABCB is a government representative involved in developing and maintaining a safe and high-standard building industry and has outlined sustainability as a high-level goal for the Building Codes of Australia (BCA) in 2006 [19].

Since then, the BCA and the Plumbing Code of Australia (PCA) have combined to create the NCC, which provides the minimum requirements for Australian states and territories.

Volume One and Two of the NCC have a set of 'Energy Efficiency' minimum standards that have adopted tools such as Green Star Rating Tool, Nationwide House Energy Rating System (NABERS) energy for offices, and GHG emissions modelling as a way of verifying compliance to these standards [19].

The current standards on 'Energy Efficiency' sections have an impact on the operational flows of a building project, which typically comes from the building's design, including energy and emissions from heating, lighting, ventilation, and cooling [20–23]. The energy and emission flows associated with building materials and construction practices used for construction of buildings have been neglected from the NCC volumes [10,24].

This continuous emphasis and commitment on operational flows over the years has made significant contributions towards reducing its share in the total energy and emission flows of a building, leading to the rise in embodied energies' share in this total output [25–28]. Hence, in the recent decade, the emphasis has been shifted to embodied flows associated with building design and construction phases [9,25,26,29–34].

Globally the construction industry contributes 30 to 50 percent of raw materials [35,36] and 18 percent of worldwide carbon (CO₂) emissions, with electricity, water, waste, and materials being the most significant sources of CO₂ output from the sector [37–39]. As the built environment in Australia grows and thrives in economic performances contributing up to 9 percent of the country's gross domestic product (GDP) as of 2021, the efforts to reduce these embodied flows should parallel [25,37,40].

Embodied flows are generated from building design and the construction stage and are associated with materials and methods used. When considering building materials used, raw material acquisition and manufacturing stages contribute significantly to embodied flows as the processes use fossil-fuel operated heavy machinery and other operations [21,30,31,41–43]. These exploitations of raw materials have extreme negative effects on the natural environment, causing land degradation and erosion, creating toxic waste, and emitting excessive amounts of GHG [44,45]. Transportation also accounts for a significant share of embodied flows associated with these materials [46,47]. It has been suggested that the construction sector might tackle these emissions by optimizing supplier and client logistics, ensuring maximum efficiency in each load of resources delivered, resulting in minimal capacity wasted and less unnecessary travel to and from sites [48,49]. Hence, the need for regulatory policies and support for builders to improve their material supply management has been recognised in the current literature [50–52].

The erection of a building during the construction process typically uses energy sourcing from machinery, equipment, generators, electricity, and fuel consumption [13]. The daily site activities can include mechanical plants such as excavators, compactors, cranes, pilers, and drillers, which typically use different types of fossil fuel, including diesel, petrol, gas, crude oil, and electricity [53–55]. Use of these fossil fuels during building erection leads to significant contributions of GHG emissions, which are considered as embodied flows of the building itself [33,54,55]. The erection stage of the project is also generally the creator of waste, which has been seen as an indirect embodied flow creator [50,56]. If not appropriately managed through environmentally responsive approaches, waste can lead to further energy use and emissions generation [13,25,44,56–60].

There were early discussions in 2003 and 2017 surrounding a potential widening of the NCC's scope to include manufacturing policy to improve the industries' reuse and recycling [61,62]. However, still no changes have been made as of the 2022 amendment of the codes [2]. The growing market can outline the opportunity for the industry to promote use of environmentally responsive materials [63].

The modern emphasis on creating green cities and suburbs has been increasing in Australia as government incentives and policies have encouraged builders to adopt more environmentally responsive materials and methods to mitigate embodied flows [2,64,65]. While Australia is trending in the right direction, some research cites further motivation as

a required incentive for builders to become more active participants in working towards sustainability goals [47].

Australia's researched transition into sustainability has been challenged by some examiners, with the belief that a 'passive government' has permitted builders to have a lack of accountability regarding the energy efficiency and sustainability of their design and construction. This is due to regulations not being audited, being too lenient, and not considering the total life cycle of the building's energy use [65]. Cost and time factors can also affect a builder's decisions regarding efficient design and building. The client's needs may not prioritize sustainable design if it can negatively impact their budget or timeline requirements [25,66,67].

The Australian government has committed to the international treaty on climate change, the 2016 Paris Agreement, which is legally binding and aims to limit global warming by reducing GHG emissions [2,68]. The Paris agreement is a worldwide arrangement by each nation to keep the world's average temperature from rising above two degrees Celsius over the pre-industrial levels [69]. Each nation is expected to set its own goals with the treaty and Australia is committing to having net zero emissions by the year 2050 [24,69]. This has been the incentive for many industries, including construction globally and within Australia, to influence change that can have positive impacts on mitigating climate change [70,71].

Energy efficiency frameworks, codes, and regulations are among the most efficient measures to minimize carbon emissions from the construction industry [3,10,11]. While the policy is viewed as the base for initiating change, the code's implementation and effectiveness are pivotal in continuing the push toward a more sustainable future in the construction industry [72]. Currently, there is the NCC, a performance-based code from the ABCB in Australia. It sets the minimum performance and general requirements for construction designs and activities in many categories. The states and territories in Australia each individually provide the NCC legislative effect as the framework for the construction industry [19].

In overall, few studies have been conducted with a focus on the Australian codes and regulatory framework surrounding embodied energy output [2,10]. In Europe [32,73,74] and in India [75–78], there has been much more academic discussion around the topic. These studies have suggested the inclusion of embodied energy requirements in efficiency policies for the nations within their case studies.

Australia's current policies in the NCC on energy efficiency have improved the landscape of environmentally conscious building designs. Table 1 below exhibits the current scope of NCC on energy efficiency.

The ABCB's 2022 outcome report [19] identified the reduction of greenhouse gases and lowering energy bills as their intended aims for low-energy buildings. The report shows that the ABCB still appears to be undecided regarding adding construction phase regulations to their framework despite "a number of comments" calling for them to be included. The reason being that it would broaden the scope of the NCC's existing sustainability goal. Further government intervention regarding the policy around the green building within Australia has also been backed by researchers in the field [47,65], as embodied flows are currently not being regulated within the national code.

The Green Building Council Australia (GBCA) has predicted that if nothing is done to the existing policy, the percentage of built environment embodied flows will climb from 16 percent in 2019 to 85 percent of all construction life cycle emissions by 2050 [40]. This would be due to the targeted decrease in operational flows percentage contributions and the lack of policy surrounding embodied energy [29]. The current first volume of the NCC 2022 includes 'Section J: Energy Efficiency', which provides the minimum performance requirements for the Australian construction industry to follow in building classes of 2 to 9. Energy performance requirement one (JP1) focuses on energy use and reflects on the Council of Australian Governments (COAG) verdict that a building can decrease its greenhouse gas emissions. Adhering to the goal of the requirement means that the building

must be capable of reducing energy and obtaining energy for building services through low emission sources. Volume two of the NCC provides building codes for NCC building class 1 and 10 buildings. Energy efficiency codes are included in Section 3.12, where the objective is stated to “reduce greenhouse gas emissions”.

Table 1. Summary of national construction code energy efficiency requirements and standards.

National Construction Code Volumes	Scope	Description
Volume one—Section J: Energy Efficiency	Part J1 Building Fabric Part J3 Building Sealing Part J5 Air Conditioning and Ventilation Systems Part J6 Artificial Lighting and Power Part J7 Heated Water Supply Part J8 Facilities for Energy Monitoring	Provides the minimum performance requirements for the Australian construction industry to follow in the construction of buildings with the NCC building classification of 2 to 9. Provides three verification methods to measure compliance with JP1, the ‘NABERS Energy for Offices’ model, the Green Star rating tool, and greenhouse gas emission modelling in comparison to a reference building [19].
Volume two	Part 2.6 Performance provisions—Energy efficiency Part 3.12.1 Building fabric Part 3.12.2 External glazing Part 3.12.3 Building sealing Part 3.12.4 Air movement Part 3.12.5 Services	Provides building codes for NCC building class 1 and 10 buildings. Energy efficiency performance provisions are included in Part 2.6 and codes are included in Section 3.12, where the objective is stated to “reduce greenhouse gas emissions”. Volume two provides the option of employing NatHERS to verify compliance or fulfilling the code’s specified performance solutions like R-value and glazing responsibilities to meet requirement Part 2.6 [19].

Currently, there is a noticeable gap for the embodied energy and emissions policy for the construction sector in Australia. Ref. [10] states that “the current building code for Australia—known as the National Construction Code—has no mechanism for enforcing EE/EGHG (embodied energy/embodied greenhouse gas) emissions targets”, majorly disregards the raw material, manufacturing, transport, and construction phases of a project’s life cycle in their legislation, despite an abundance of research highlighting embodied energies influence and the gap in framework globally, as well as within Australia [65,79,80].

This study aims to investigate how building policies and codes can be improved to improve embodied flow efficiency in construction processes in Australia.

To achieve the aim, the following objectives have been established.

1. To identify processes within the construction phase that have high energy consumption and has the potential to be reduced.
2. To investigate relevant codes and standards, if any, on effectiveness in reducing energy consumption.
3. To provide recommendations for improvements on the current codes, such as the NCC, based on global initiatives and policies.

The following section presents the research method used in this study, data collection, and analysis techniques used to achieve the aim mentioned above and objectives.

2. Materials and Methods

The study followed a policy analysis and a document analysis to answer the research question in the previous section, “How can building codes and standards be improved to decrease embodied flows in construction practices in Australia?”.

Data were gathered from published academic articles and industry publications, including but not limited to journals, conference proceedings, and industry reports, which have covered existing policies for reducing embodied flows of construction sectors globally. The International Energy Agency's (IEA) Policy Database was searched to identify existing policy mechanisms in-force and pertaining to buildings. An initial list of existing policies was then used to conduct further investigations via web search. Policies from national levels of administration were considered for the analysis.

The policy review adopted a similar method to [10,81,82]. The policy information was extracted and compared to identify the objectives, coverage, and effectiveness of each selected country. Academic and industry publications were used to gather further data on policies and measure their effectiveness. This research method was chosen as it would allow for greater exploration in the investigation of surrounding ideas and provide a broader range of potential discussions to support the findings. The qualitative data was analyzed using contextual components, document analysis, and literature reviews. The observation and interpretation of patterns and themes throughout the research were critical to developing insightful and evidence-formed answers to how building codes can be improved with energy efficiency within the scope.

The analysis of current policies' effectiveness was used to develop recommendations for policy enhancements for reducing embodied flows in the Australian construction sector, answering the established research question.

The proposed research methodology is presented as illustrated in Figure 1. The National Construction Code only features an operational energy policy and entirely disregards the embodied energy expenditure during the construction and procurement phases of the project life cycle. This gap recognizes the Australian construction industry codes regarding embodied energy is minimal and do not investigate the improvements that adding a construction phase policy could have on reducing energy consumption.

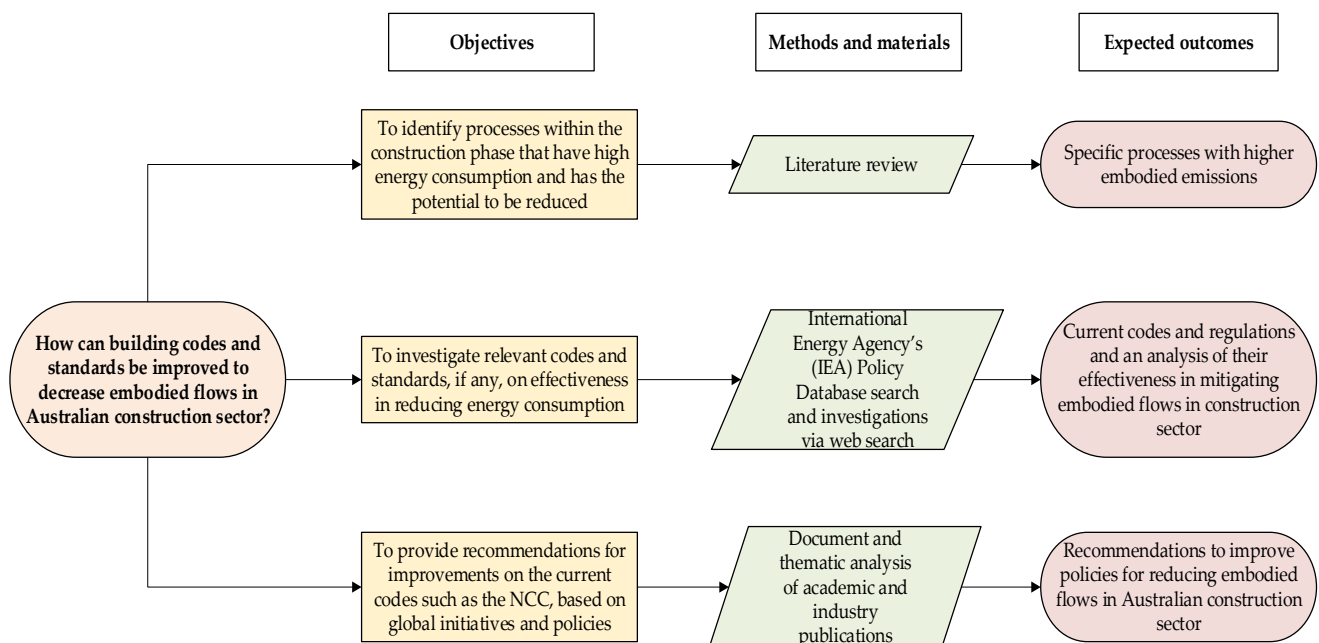


Figure 1. Research methodology showing the objectives, data sources used, and the outcomes of the study.

This gap allows for the formation of the research question, "How can building codes and standards be improved to decrease embodied flows in construction practices in Australia?" The aims and objectives have been produced to allow for detailed and concise research that addresses the overall research question.

Background information was explored to provide context to the research and its significance, as it delivered key information that uncovered relevant themes surrounding the overall topic. A literature review was conducted on the current literature based on the construction industry, energy efficiency, and construction codes. The review aided in realizing the scope of the research investigated past or current contributions to knowledge and established further gaps or limitations that may have needed to be addressed.

The research was then conducted by implementing the chosen qualitative data methodology. Information and ideas were collected to be explored in-depth through document analysis of the chosen resources outlined. This analysis helped to identify the intentions of the research. Major findings and results of the research were presented, with a clear description of how the information contributes to new knowledge that could be used as a base for recommendations to address the issue.

3. Results

3.1. Embodied Policies in the Global Context

Four regions were examined in the document analysis based on geographical positioning. They are analyzed based on their embodied carbon and energy policies or relevant initiatives to mitigate construction embodied emissions.

As shown in Figure 2, the regions have been split up into; American, Oceanic, Nordic, and Western European nations. The countries explored include Canada, the United States of America (US), Australia, New Zealand, the Netherlands, the United Kingdom (UK), France, Denmark, Norway, and Finland. Table 2 exhibits the summary comparison of the policies identified and reviewed in this study.

The profiles of most of these countries regarding their construction codes and techniques can vary in many ways due to culture, design, landscape, functionality, weather, natural disasters, and other contributing factors. A vested interest amongst all these nations is their participation in the Paris Climate Accord [2,83], which imposes an expectation on their federal governments to commit to reducing carbon in all aspects of their industry. This is especially the case within the construction sector, which in many cases is one of the main culprits in the rise of energy use and resulting emissions into the atmosphere. The following sections present detailed analyses of the embodied policies of the identified countries.

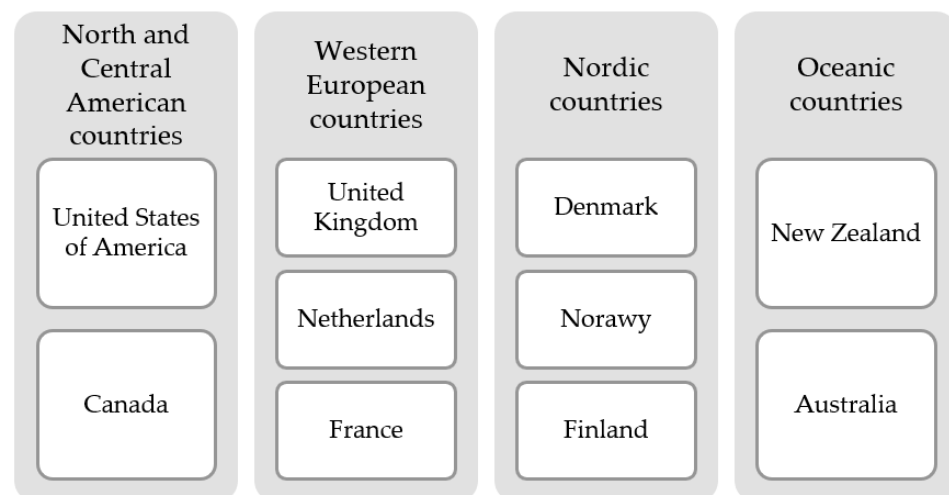


Figure 2. Countries in different regions that have embodied energy policies for construction industry practices.

Table 2. Comparison of policies on built environment embodied flow reductions reviewed in the study.

Country	Human Development Index Tier (2022)	Sustainability Policy Implemented	Scope of Policy	Effectiveness	Authorizing Body
Canada	Very High (0.936 HDI)	Greening Government Strategy (2017)	Federal Government/Government Agency Operations (Construction Included)	Initial steps towards emission reductions were made; however, as of 2022, it has been found that the emission reductions were not as complete as they should have been when considering their targets.	Treasury Board of Canada Secretariat
The United States of America	Very High (0.921 HDI)	Buy Clean Initiative (2021)	Federal Government/Government Agency Construction Projects	A buy clean task force and embodied carbon workgroup have been launched to develop recommendations and policies, with new targeted commitments made in 2022 for the federal government to target embodied materials in its projects.	White House Federal Chief Sustainability Officer
Netherlands	Very High (0.941 HDI)	Bouwbesluit (2018)	New office buildings larger than 100 m squared and new residential buildings	No measures of effectiveness have been documented in research.	Ministry of the Interior and Kingdom Relations
France	Very High (0.903 HDI)	1. RE2020 (2022) 2. E+/C− (2016)	1. New residential or non-residential construction projects requiring a permit 2. Voluntary amongst French building material suppliers	1. No measures of effectiveness have been found due to limited timeframe. 2. Environmental labelling used as an experiment for further RE2020 research that aided the regulations currently in place.	1. Evolution of Housing, Development and Digital 2. French Federal Government
United Kingdom	Very High (0.929 HDI)	1. Net Zero Carbon Certification (2019) 2. RICS Embodied Energy Assessment (2018)	1. Builders attempting 'Net Zero Carbon' certification 2. RICS members submitting building reports	1. The UKGBC in 2021 stated that they believe this certification should be used as a verification method in building policy; however, it is currently still not mandatory for building permits, which has reduced its effectiveness. 2. The large member-base of the institute allows for more awareness of embodied energy and whole life carbon, but the resulting use of the calculations do not enforce change in builders' decisions.	1. UK Green Building Council 2. Royal Institute of Chartered Surveyors

Table 2. Cont.

Country	Human Development Index Tier (2022)	Sustainability Policy Implemented	Scope of Policy	Effectiveness	Authorizing Body
Denmark	Very High (0.948)	Sustainable Construction Strategy (2023)	All new construction from 2023 over 1000 square meters All new construction (any size) from 2025	No measures of effectiveness have been found due to timeframe.	Danish Government
Norway	Very High (0.961 HDI)	1. EPD-Norge (established 2002) 2. Norwegian Standard 3720 (2018)	1. Over 220 companies and 1500 construction materials 2. Norway Construction Industry	1. Has been able to increase its EPD database to effectively inform builders on material selection, as they cover over 220 companies. 2. Enforces greenhouse gas accounting effectively throughout the building industry. It is expected to be effective for creating future policy through its data.	1. Federation of Norwegian Construction Industries 2. Directorate for Building Quality
Finland	Very High (0.940 HDI)	Intended Low Carbon Construction Legislation (expected by 2025)	Finland Construction Industry	No measures of effectiveness have been found due to timeframe.	Finland Ministry of Environment
New Zealand	Very High (0.937 HDI)	New Zealand's First Emissions Reduction Plan (2022)	All New Zealand Industry (Construction Included)	No measures of effectiveness have been found due to timeframe.	New Zealand Government Minister of Climate
Australia	Very High (0.951 HDI)	National Construction Code Sustainability Standards (2019) Green Star Building Tool 'Upfront Carbon Reductions'	1. Australian Construction Industry 2. Builders attempting Green Star certification	1. Operational energy efficiency standards have been effectively applied. Embodied energy has not been implemented into the codes. 2. As it is a voluntary certification, it does not effectively enforce meaningful change in builders' decisions.	1. Australian Building Codes Board 2. Green Building Council Australia

HDI Tiers: Very High Human Development (0.80–1.0), High Human Development (0.70–0.79), Medium Human Development (0.55–0.70), Low Human Development (<0.55).

3.2. Canada

Compared to the rest of the world, "Canada's climate is warming twice as fast as the global average" [84,85]. The government of Canada has identified the reduction of greenhouse gas emissions as the primary element of their national policy to combat this climate issue [86]. They aim to do this by transitioning to net-zero carbons and climate-resilient operations as part of the "Real Property" strategy within the plan that will apply to all the Canadian government and their agencies' building plans. The country's target is to lower the embodied carbon of the structural materials used in significant construction projects by 30% by 2025 [86]. Their government aims to lead environmentally conscious buildings by employing more recycled and lower-carbon materials, increasing material

efficiency, and improving performance-based design standards to lessen the environmental effects involved in the material structure of a building [14,69]. As of the beginning of 2022, the amount of embodied carbon in structural materials of these significant building projects will also be disclosed, is based on lifecycle analysis and carbon intensity results [84,87].

Given that the Canadian government is the most significant owner of real estate in its own country, the green building sector can thrive as a result of the number of government assets that will be subject to these standards to lower the output of embodied energy in their construction sector [10,12].

3.3. *The United States of America*

The USA has made federal statements similar to the strategy released by Canada, as an executive order was released at the end of 2021 that announced that federal sustainability would be the beginning of a clean energy economy within the country. The aim is for the U.S. government to lead by example through its procurement practices, with the target being zero emissions from federal procurement by the year 2050, with a new 'Buy Clean' policy being implemented to encourage the use of building materials with low embodied emissions. For new construction and significant upgrading contracts, the presidential order also mandates that contractors reveal the embodied carbon of building materials. The emissions produced by mining, harvesting, processing, manufacturing, shipping, and installing materials are referred to within the directive as "embodied carbon" [10,29,88].

3.4. *The Netherlands*

A requirement for reporting whole-life carbon (WLC), lifecycle analysis (LCA), and material embodied energy accounting for structures larger than 100 square meters has been a part of the Netherlands' *bouwbesluit* (building act) since 2018 [89]. A carbon cap has been set for new buildings based on the required LCA, which involves eleven environmental impact categories that are reviewed in the analysis and account for embodied energy, amongst other things, to determine the 'shadow cost' per meter squared of building. This cost indicates the impact of emissions from the project and is known as the *Milieu Prestatie Gebouwen* (MPG) calculation method. The initial one euro per square meter allowance for builders will gradually be lessened until 2030, reducing the industry's capability to create further environmental impacts from emissions [10,12,38,90].

This carbon cap, which includes embodied energy and LCA, is the first of its kind implemented as a mandatory building act. This calculation method allows builders and compliance checkers to clearly understand how a building is expected to perform and is a method that a few countries have begun to replicate.

3.5. *France*

France's Ministry of Energy Transition has followed a similar path to the Netherlands with its new RE2020 standards. They have placed regulatory thresholds on whole-life carbon with a database to support LCA and accessible for builders in the country. Environmental Product Declarations (EPD's) through the E+/C- label have also been introduced to inform builders of the environmental impacts of the materials they use. This helps designers make more carbon-conscious decisions as it includes how much was required to make the product and can deter the use of high embodied energy production [10,91–93].

The 'Evolution of Housing, Development and Digital' was responsible for RE2020, and aimed to reduce climate impact, improve energy performance, and reduce energy consumption in new buildings. The limits were chosen after a period of information gathering through 'simulations' that the government undertook to determine the main criteria and thresholds for the regulation. RE2020 has set maximum reference values for embodied carbon at 640 kg CO₂ eq/m² for single-family buildings and 740 kg CO₂ eq/m² for multi-family buildings. These regulations aim to reduce the impact of new buildings on the climate by considering all the building's emissions over its life cycle. A database

containing the essential environmental data will be made available to the builders to perform lifecycle evaluations without additional costs [94].

3.6. The United Kingdom

The United Kingdom has yet to place mandatory regulations on embodied energy. However, there have been schemes that have looked to try to improve the situation [92].

The UK Green Building Council has placed standards for minimum embodied energy utilization in their criteria for builders to certify their projects as 'Net-Zero Carbon'. However, this optional certification does not impact a builder's ability to get a permit [95]. While the council is still researching potential verification methods, the standard has been set for upfront embodied carbon to meet or exceed a 1.5 °C target. However, the board has not yet consolidated the criterion for meeting the target. Currently, they are instructing builders to use third-party resources to prove that they are meeting this target. Whole-life carbon assessments are also required to be completed in the standards with total embodied carbon, and steps done to offset the carbon emissions need to be published to get the 'Net-Zero Carbon' label [96].

The Royal Institute of Chartered Surveyors (RICS) in the United Kingdom has also attempted to improve the embodied energy situation of the country. It has provided members with a prescribed approach to undertaking the calculation required for meeting standard EN15978, which is a requirement to assess and report on the life cycle carbon emissions in construction projects. They have done this with the hope of making embodied energy a more consistently considered principle of the industry. This assessment is only mandatory for RICS members, who comprise over 75,000 surveyors in the UK [97].

It was reported in early 2022 that a bill was introduced to parliament based on reducing embodied energy, providing precise and targeted requirements for measuring, reporting, and reducing embodied carbon. While nothing had come from the bill, it was reintroduced to parliament in June 2022, and a second reading is expected later in the year. If the bill were to pass, it would incorporate whole-life carbon reporting as a mandatory regulation in the construction industry [98,99].

3.7. Denmark

In early 2021, the Danish government agreed to set limits for whole-life carbon emissions in the building regulations, which will take effect in 2023. This whole-life analysis makes builders accountable for operational and embodied energy produced by their activities.

As of 2023, all buildings over 1000 m² will complete a lifecycle analysis and are required to fall below the introduced whole-life carbon limits. Smaller buildings will also have to complete this analysis but are not required to adhere to the limits until 2025. The caps will begin at a value of between 5 and 12 kg of carbon dioxide equivalent per square meter per year. They will be reduced every second year until 2029. There is an expectation that the tools to calculate compliance will be integrated into BIM so compliance can be checked earlier in the design phase [9,10].

The introduction of the cap allowed Denmark to join France and Netherlands as the first countries to set carbon limits that incorporated embodied emissions within Europe.

3.8. Norway

Norway's building materials and construction policies include a standard called NS3720 that outlines a technique for calculating buildings' GHG emissions. As a result, life cycle GHG emission evaluations of Norwegian buildings have increased, and the life cycle assessment computation for builders has been synchronized. This data will be a significant resource for developing national benchmarking and target values for buildings, which will aid in improving their environmental performance over time [100]. The conclusions from the information provided by builders can be used to develop preliminary recommendations for benchmark GHG emission levels and criteria for future Norwegian building codes [92,101].

A Norwegian government body has also implemented environmental Product Declarations (EPD's) for over 220 companies covering 1500 products all over the country within a database named EPD-Norge. These EPD's provide information on construction material environmental performance using life cycle analyses that include embodied energy consumption used in manufacturing, which is a positive step towards awareness [92,102]. Norway's action towards embodied energy is similar to France's EPD program, along with setting carbon limits close to Denmark's current policy structure.

3.9. Finland

Finland aims to reach carbon neutrality by 2035 and is establishing a series of measures, including low-carbon construction laws. The Finnish government is introducing a carbon evaluation approach along with standards for various building types (such as residential and commercial), with a decision on single-family homes still pending [103].

They will be looking to follow Denmark, France, and the Netherlands in having maximum thresholds starting in 2025 based on buildings' whole-life carbon impact. This decision is based on the European standard EN15978, the same standard the RICS in the UK have based their standards on, as it is the requirement to assess and report on the life cycle carbon emissions in construction projects [92,103]. Finland's 'Ministry of the Environment' has had public consultations on their proposed assessment method, and it is suggested that builders will be able to find the method clear and comprehensive enough to comply with [100,104,105].

3.10. New Zealand

New Zealand's 'First Emissions Reduction Plan' [106,107] includes building and construction in its comprehensive national strategy, with one of its major focuses for the industry revolving around embodied energy and GHG emissions. The plan has calculated the expected effects of the policies they look to implement, which will be based on reducing embodied carbon of construction materials. It will provide an embodied energy platform, by increasing grants for EPD's, and supporting the forestry and wood processing industry to provide better manufacturing methods for energy reduction [108].

The first focus area is specifically trying to 'Reduce Embodied Carbon of Construction Materials.' There is an intention to accomplish this by advancing regulatory change, beginning with a consultation on incorporating whole-of-life embodied carbon requirements into the Building Code. They are also looking to explore barriers to whole life carbon reporting in existing regulations and broaden the sector's understanding of embodied carbon and its implications.

The waste and transport sectors have also been included in the ultimate action toward the focus area. Mandating waste minimization or recovery plans for construction licenses has been considered because recycling and reusing building materials can reduce the amount of embodied energy needed to manufacture. There will also be assistance for project management and prefabrication planning to decrease road transportation, with government contributions to freight and supply chain management being an approach that can reduce emissions from inefficient material transport.

The overarching aims of the plan's building and construction sector are to have New Zealand's building-related emissions close to zero by 2050, with buildings also offering healthy places for occupants to work and live for current and future generations [106,107].

3.11. Australia

The focal point of this analysis is the response from Australia and its construction codes. Currently, in Australia, the building codes board that publishes the National Construction Code has neglected embodied energy from its standards, focusing only on the operational emissions of a building's life cycle. The Green Building Council has pushed for embodied energy requirements to be added to future versions of the codes with little indication from the ABCB that it is being seriously considered thus far [2,10].

Green Star's building tool is one voluntary measure that the Australian construction industry has had to adapt to as part of its rating process. There has to be a 10% reduction of upfront carbon emissions (in comparison to reference building) as a minimum expectation to receive a rating and claim certification by the GBCA. That percentage is also expected to grow over time [40].

The lack of mandatory regulation or meaningful government initiatives highlights Australia's need for a plan or strategy to address the growing share of embodied carbon emissions. It has become critical now as Australia has reaffirmed its commitment to net zero emissions by 2030 without enforcing any change for the high emission-producing construction industry and its energy efficiency codes.

3.12. Overall Findings

The Paris Agreement, World GBC standards, and the European Climate Law have been some of the climate actions influencing change amongst the regions researched within the document analysis. Building policies, plans, strategies, and tools have all been implemented globally as incentives for change in the construction industry, as many nations aim to achieve similar outcomes of having net zero carbon emissions.

The majority of the implemented embodied energy changes have been done using whole-life carbon analyses, life cycle analyses, carbon reporting, carbon caps, EPD's, and increased awareness of embodied energy for builders to consider.

Policies and strategies have been a recent trend amongst the leading nations fighting embodied energy. There has typically been a phased rollout of legislation that intends to increase energy performance and enforce firmer emission limits for builders to meet. Carbon caps have been decided and are either enforced or are to be enforced in four analyzed nations (Netherlands, France, Denmark, and Finland), typically using a metric of cost or carbon equivalent per meter squared for a building.

Federal governments in the U.S. and Canada have dedicated federal policy on their projects regarding embodied emissions and material selection, which can still be considered a positive action for these nations that have yet to place mandatory regulations on standard builds in their countries.

New Zealand has offered a different strategy to the European countries as they have committed to a plan incorporating LCA into their mandatory codes. They also aim to look at many surrounding factors, such as waste and transport sectors, along with educating the industry and supporting project managers so that there is more understanding of what embodied energy involves and how it can be reduced.

The analysis found that the UK and Australia needed to improve their approach to reducing embodied emissions to meet the same climate objectives that other nations in the investigation have been motivated. Voluntary tools and measures can be helpful for builders in these countries. Still, without any enforceable codes, they will continue to fall behind other contemporary initiatives and legislative actions in the surrounding regions.

4. Discussion

4.1. Embodied Policy and Built Environment Practices

The policy has been significant in guiding the industry towards more efficient practices, as the inclusion of embodied energy within these codes and standards has been expected to reduce greenhouse gas emissions and energy usage that comes throughout the often-overlooked stages of a construction project.

All the studied nations have implemented their strategies for carbon reduction in response to the Paris Agreements [10,109] and aim to be net-zero carbon by 2050, as many of them share similar aims and timeframes as their intended target.

As discussed, many nations have attempted to combat the rise in embodied emission share within their construction industries with policy and planning [110,111]. Yet, there is an expectation that their built environments will be impacted due to these process changes, new considerations, and innovation to meet new market demands resulting from the mandates.

The influence on the Netherlands' physical environment will be strongly emphasized, as the building act changes are one of the primary measures that have been implemented to make a 100% circular economy by 2050. A circular construction economy is a concept identified by the Dutch government's national environment database to improve their built environment by having the materials within the industry receive high recycling and reuse rates, along with reduced wastage and manufacturing of new materials for buildings. The goal of the Dutch government in their Coalition Agreement is for the economy (including construction) to be 50% circular by 2030, assuming that their principal resource use will be cut in half in the same timeframe. Along with carbon caps, the general goal of a circular economy can produce a future for the Netherlands in which material harvesting, manufacturing, and transportation can be decreased significantly, reducing embodied energy and emissions from these activities.

The built environment changes expected or hoped for by the French government include the need for buildings to have a reduced impact on climate change, improve energy performance, and guarantee they will have a better ability to combat heatwaves, which they expect will become more frequent due to rising temperatures. The thermal designs of these new buildings will be more of a focus, with building envelope and insulation measures also a big part of the new standards expected from construction. The embodied outputs are also likely to be reduced through material selection as envisioned by the International Energy Agency, as the sector's decarbonization seems destined to result in a more significant number of eco-friendly materials being used. The E+/C- labels will help create better decision-making for designers to create buildings that comply with the RE2020 and are certified.

Denmark's National Strategy outlines the expected changes to the built environment, as their five focus areas are to create more climate friendly construction, durable and high-quality buildings, resource efficient buildings, energy efficient/healthy buildings, and look to aid this with digitally supported construction. These focuses aim to balance the environment, social needs, and financial quality of buildings to improve the country's constructed landscape further.

The New Zealand strategy expects that there will be an estimated 0.9 to 1.7 metric tonnes of carbon dioxide equivalent (Mt CO₂-e) that can be reduced using their plan for the construction industry. The sector created 7.4 Mt CO₂-e in 2018 results, so a reduction of up to 22% would be a drastic change as part of an early plan, which they aim to further reduce to 3.9 Mt CO₂-e over time as they navigate policy implementation. The government wants to encourage more timber use in buildings by supporting smaller construction businesses. The government is also exploring ways to provide specialists to the companies so that they can be advised on creating more low-emission builds that use sustainable materials.

4.2. Australian Built Environment and Embodied Policies

Australia has well-established operational flow efficiency design standards currently being enforced in the construction industry. These have generated a market for green building designs and sustainable considerations that have benefitted Australia's built environment. Additionally, more consideration towards occupant health and emission reduction has occurred as there have been improvements in energy efficiency since the 1990s [19]. Despite this, the proportion of embodied flows associated with the harvesting raw material acquisition, manufacturing, transportation, and construction phases of building projects are increasing due to the lack of emphasis and attention.

However, some indications of policy changes to mitigate embodied flows of the built environment have been observed in recent years. The Green Star Buildings (GSB) rating tool introduced by the GBCA has incorporated embodied emissions as part of the minimum requirement for rating buildings. It further establishes that a building requiring a rating should have a reduction of 10% embodied emissions compared with a reference building, which is targeted to increase to 20% in 2030 [10]. It also allows buildings to offset emissions using carbon credits to rate as net-zero buildings. The developed GSB acting as a mandatory tool to reduce embodied flows in the Australian built environment is a positive signal of

industry-level change. In addition, there is a significant demand for change advocated by the industry stakeholders, requiring more stringent control and regulation of embodied flows in the near future [10,38]. Nonetheless, Australia is yet to take strong actions on establishing and enforcing effective policies and regulations and incentive schemes to direct the industry towards embodied flow reduction targets fast.

Clean energy finance corporation (CEFC) demonstrates that Australia has great potential to reduce embodied flows in the building sector [112]. It quantifies the decarbonization challenges and recognizes Australia's opportunities to mitigate embodied flows through optimizing material usage, utilizing low-carbon materials and construction technologies. Alternative material solutions, including geopolymer concrete, environmentally responsive concrete admixtures, and recycled materials, are proposed to substantially lower embodied flows [9,25,113]. Switching to renewable energy sources for material manufacturing and building construction is also one of the most effective methods of achieving embodied emissions reductions [112,114].

However, these potential solutions are not without their inherent risks and challenges [55]. Additional costs, supply chain issues, unawareness, and fear of change associated with green materials and technologies are perceived as the most significant challenges in adopting sustainable materials and technologies in the Australian built environment [93,115,116]. Although many research studies have established that embodied flow reduction does not lead to additional costs, low and medium-industry practitioners are yet reluctant to believe that truth [25,67,117,118]. Therefore, the regulatory bodies need to establish effective policies and frameworks and introduce incentive schemes to drive industry practitioners towards sustainable alternative solutions. If effective policies and strategies are not enforced soon, "Australia will fail to meet its 2030 Paris emissions reduction target" [2].

5. Conclusions and Recommendations for Policy Improvement

Policy improvement in Australia would have to be aligned with current political agreements. The current Sustainability Development Report has Australia's climate action categorized as having "major challenges" and becoming stagnant [119]. The latest commitment from Australia to the United Nations, as of June 2022, has been for a 43% reduction in emissions by 2030. This target is higher than the one that was initially 28% reductions in the same timeline [2,9]. This increase has been enacted by the new labor government and was signed off. However, this rise in expectations has not come with many details surrounding the construction industry. The carbon neutrality target in the Paris Agreement is still an expectancy for Australia to achieve by 2050.

The updated commitment to the UN by Australia should follow the improvement of Australian policies by having the construction industry be an area of focus, as building produced significant emissions that could aid in making overall reductions included in the 43% target. Using this target as an underlying objective for performance improvement means that a holistic approach to emission reduction is a way that can be done using the government as a driver for change. The structure set by the New Zealand government can be a template for how Australia could implement a similar scheme, which approaches these reductions in five key actions: (1) industry education, (2) government support, (3) improvement of emission stakeholders, (4) encouragement of sustainable material selection, and (5) addition of building regulations based on embodied energy.

As embodied efficiency is still a gap in knowledge within the Australian construction industry, education is necessary to increase awareness of these emissions, where they come from and how they affect the environment's natural state. Education can come through many different avenues, such as adding it into the curriculums for higher education and industry courses so that prospective industry professionals and trades know these outputs. Accessible information platforms such as websites can be provided for building companies and people already in the workforce to inform themselves on embodied efficiency. This focus can help reduce anxiety and resistance to change, as more informed companies and workers will understand why the change is necessary and how it can be done.

Government support for smaller businesses can improve their energy planning and performance when trying to meet new targets. Increasing builders' ability with fewer resources and incentives to improve energy efficiency will allow the industry to perform better. The smaller companies are more vulnerable and typically have less capability of dealing with changes to requirements, especially when finding ways to reduce energy usage. Government advisory on how these businesses can improve logistics, make better decisions, and improve efficiency can help gain their support and improve the lower floor of the industry.

Surrounding stakeholders are as important to reducing embodied outputs as the construction industry. Government focus on improving harvesting and manufacturing industry procedures and efficiency can significantly affect the outputs used to gather and form materials. Finding reductions in these processes and providing information to builders on which materials have a lower carbon footprint can allow for better decision-making and motivate these industries to meet the inevitable market demand. Transport industry logistics and improved planning for project managers to optimize their resource procurement may also be achievable through government advising for project managers. In addition to project managers, having load requirements for material transport vehicles can help to reduce unnecessary trips and capitalize on wasted space that may occur during expeditions. Improving the amount of wasted transport and space can reduce fossil fuel consumption and contribute to lessened emissions.

Creating a demand for sustainable materials through marketing, policies, and information (such as EPD's) can be valuable in furthering the cultural shift away from high-carbon products. This helps improve manufacturing, harvesting techniques, and building projects as the industry moves towards 'green buildings'. Design of these materials to be disassembled for reuse or recycling can reduce overall waste and emissions that come with the demolition, transport, and disintegration of waste.

Most importantly, a mandatory policy must be added to the National Construction Code. The most common way this can be done is using whole-life carbon reporting and life cycle analysis. As shown by Netherlands, France, and Denmark, using carbon caps that can limit whole-life carbon is a possible scenario that Australia can consider. Each of these countries, New Zealand, Finland, and Norway, has taken the time to gather data and find a threshold suitable for their industry. They are suitable for their industry and have been implemented gradually. Australia can mirror these nations' policy improvements to target all emissions in the industry. Offering an accessible database or LCA tool would be necessary to make the policy a realistic target, as creating additional costs would likely face severe backlash. Enforcing this change can be supplemented by the previously stated focus areas. It would have the potential to drastically change the current situation on embodied emissions and energy in Australia, as it would reduce its share of emissions and help Australia in its commitments to the United Nations.

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