The Threat of Embodied Carbon in the Building Sector.

What is Guiding the Solution?

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Abstract

Embodied carbon in the building sector is an emerging area for decarbonisation efforts due to its large contribution to carbon emissions and ability to support carbon neutrality targets. This thesis aims to understand the roots of current embodied decarbonisation strategy recommendations, by exploring how embodied carbon reduction strategies are in line with the philosophy of ecomodernism. A thematic content analysis was conducted on embodied carbon strategy documents from global organisations. The findings suggest that embodied carbon reduction strategies highly align with ecomodernism principles through their use of technology, efficiency, economic growth, and state support. However, while aligning with this theory strategies neglect to consider their unintended consequences that can cause global inequalities and ineffective growth. The philosophy of ecomodernism suggests that current research neglects the main action triggers of financial and state support. For a livable future, the theory suggests efforts must wholistically implement the recommended strategies according to ecomodernism.

Keywords: Embodied Carbon, Building Sector, Ecomodernism, Decarbonisation, Climate Change, Building Materials

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1 Introduction

1.1 The Issue of Climate Change & Paris Agreement Response

Since the early 20th century carbon emissions from human activity have increasingly warmed the planet, causing great concern for the state of our climate in the end of the 21st century (IPCC, 2023). In response, global action has been widespread and collaborative (IPCC, 2023) to face what some may argue to be the greatest threat to humanity in the 21st century. A monumental step forward in addressing climate change concerns occurred at the 21st Conference of the Parties (COP21) with the signing of the Paris Agreement (GlobalABC et al., 2020). In this treaty, numerous countries agreed on a common goal to keep rising global temperatures below an ideal target of 1.5 degrees Celsius compared to pre-industrial levels by the end of the century (GlobalABC et al., 2020). This responsibility would now trigger nations and industries to adopt decarbonisation strategies to become carbon neutral by 2050 and have a chance at meeting their global 1.5 target (GlobalABC et al., 2020).

1.2 The Built Environment Carbon Emission Shares and Decarbonisation Opportunities

The building sector is an emerging dominant area for decarbonisation actions due to its large contribution to carbon emissions (GlobalABC et al., 2020) with ~37% of the global annual total (UNEP, 2022), as well as its opportunity as a key actor for meeting 2050 carbon neutrality targets (GlobalABC et al., 2020). The opportunities for climate mitigation in the building sector are recognised as substantial, achievable, and essential (UNEP, 2022), making large reductions in the building sector accounted for in most Intergovernmental Panel on Climate Change (IPCC) 2050 scenarios that meet global warming mitigation targets (GlobalABC et al., 2020; UNEP, 2022). To achieve the 2050 net-zero targets of the Paris Agreement, building sector emissions must reduce by over 98% compared to 2020 levels (UNEP, 2022). This makes the building industry a critical sector for decarbonisation (Ürge-Vorsatz et al., 2020). To achieve these targets, many countries and businesses are acting to reduce operational carbon (emissions from building operations) but are neglecting action on lowering embodied carbon (carbon emissions from the material production and construction of the building) (Hu & Esram, 2021; Huang et al., 2018; Khan et al., 2022; UNEP, 2022; Ürge-Vorsatz et al., 2020). While both these emission sources must be addressed to achieve the set targets, this thesis will focus on embodied carbon. The concept of embodied carbon will be further outlined in chapter two.

1.3 Challenges of Decarbonising the Building Sector

One of the challenges to decarbonising the building sector is due to building industries being localised and fragmented because of no primary leadership having control over a shared direction (GlobalABC et al., 2020). Therefore, resources from global organisations such as the United Nations Environmental Program (UNEP), World Green Building Council (WGBC), and the International Energy Agency (IEA) have developed visions and recommended strategies to guide collective decarbonisation of the industry. An emerging topic of importance they address is the necessity to act on embodied carbon reductions.

1.4 Current Research on the Building Sector's Embodied Carbon Emissions

Current research regarding embodied carbon within the building industry is primarily focused on targets and solutions. When conducting a literature review to understand embodied carbon in the building sector, key topics emerging from the reviewed articles addressed the following. The first primary topic addressed in almost all reviewed articles included techniques for reducing embodied carbon (e.g., developing innovative low-carbon or alternative materials, adjusting design strategies, utilising recycling and technological tools, adopting new construction methods, and optimising material use) (Huang et al., 2018; Khan et al., 2022; Minunno et al., 2021; Pomponi & Moncaster, 2016; Sizirici et al., 2021, 2021; Ürge-Vorsatz et al., 2020). Additionally, key building lifecycle stages and materials with high emissions are commonly addressed and quantified (Anderson & Moncaster, 2022; Fisch-Romito, 2021; Hu & Esram, 2021; Huang et al., 2018; Khan et al., 2022; Miller et al., 2021; Minunno et al., 2021; Sizirici et al., 2021, 2021; Ürge-Vorsatz et al., 2020). Other topics of importance include the building sectors contributions to global carbon emissions (Hu & Esram, 2021; Huang et al., 2018), the urgent need to address these operational and embodied carbon emissions (Miller et al., 2021; Ürge-Vorsatz et al., 2020), and the role the building sector should play in decarbonisation efforts (Ürge-Vorsatz et al., 2020). More specific topics include the opportunities to capture and store carbon in biobased materials, or Carbon Capture and Utilisation or Storage (CCUS) technologies (Arehart et al., 2022; Huang et al., 2018; Miller et al., 2021; Minunno et al., 2021; Ürge-Vorsatz et al., 2020), policy actions (Ürge-Vorsatz et al., 2020), emission drivers of the sector (Arehart et al., 2022; Miller et al., 2021), and tools for knowledge development (Anderson & Moncaster, 2022; Hu & Esram, 2021).

1.5 Thesis Aim and Structure

Based on the literature review, it appears most research regarding embodied carbon in the building sector is focused on targets or solutions, and neglects to consider the roots of these strategies to understand their deeper ideas, intentions, and potential threats. In particular, these identified strategies and perceptions of embodied carbon present possible roots from the philosophy of ecomodernism, which offers a new critical lens to further analyse and understand the industries actions. This thesis aims to address the identified research gap by asking, 1) how are embodied carbon reduction strategies in the building sector in line with the philosophy of ecomodernism and 2) what consequences does the building sector and the world face if they are guided by the central themes of ecomodernism? This can be used to further analyse what the current strategies emphasise and how impactful they can be.

This thesis begins by giving context to the embodied carbon narrative within the building sector by reviewing its contributions to emissions, emergence of importance, and role in global climate objectives. The contributions to sustainability science from this thesis will also be addressed. Subsequently, the ecomodernism philosophy is outlined to understand its propositions to protect nature while maintaining human wellbeing. This is followed by an explanation of the methods and documents used to conduct a thematic content analysis to answer the research questions. The results are summarised and analysed according to the methodological codes. Finally, a discussion and conclusion will draw upon the research to answer the research questions and provide recommendations for future research.

2 What is Embodied Carbon and Why Is It Important?

2.1 Building Sector Carbon Emission Contributions

Carbon emissions from the building sector are currently estimated to be about 37% of the total energy and process related carbon emissions globally (UNEP, 2022). This is broken down further into operational and embodied carbon. 27% of global emissions are associated with operational carbon from operating lighting, electrical services, heating, and cooling building systems (IEA, 2022a). From the remaining 10%, 6% is from major emitters such as cement, steel, and aluminum (IEA, 2022a) and 2-4% is from glass and brick (UNEP, 2022), which is categorised as embodied carbon (UNEP, 2022).

2.2 What Is Embodied Carbon and Why Is It Important?

Embodied carbon is defined as the amount of carbon emissions put into producing and using a product (UNEP, 2022). For the building sector specifically, it is the carbon emissions associated with the whole lifecycle of building construction and materials (Khan et al., 2022). Its calculations can consider all lifecycle emissions including raw material extraction, manufacturing of the product, transportation, construction, maintenance, and disposal at end of life (Hu & Esram, 2021; Khan et al., 2022; UNEP, 2022; Ürge-Vorsatz et al., 2020). It is important to note that embodied carbon can be calculated using different methods and include select stages of the item's lifecycle, as documented in a lifecycle assessment report (Hu & Esram, 2021). Therefore, when comparing embodied carbon in materials it is essential to ensure they account for the same stages.

2.3 Emergence of Importance

Over the past decades, building and energy codes, policies, regulations, and strategies have focused on reducing operational carbon with signs of success (Hu & Esram, 2021; UNEP, 2022; Ürge-Vorsatz et al., 2020). Focus was placed on operational carbon because of its large contribution to global carbon emissions, alongside reduction feasibility because of contemporary building design and technology (Huang et al., 2018). In contrast, embodied carbon emissions are difficult to measure, making it a challenge for design teams who select hundreds to thousands of materials and components that require expertise to evaluate (Hu & Esram, 2021). As operational carbon targets are consistently being achieved through energy efficient buildings, the embodied carbon of new construction and maintenance of buildings begins to play a larger role in the sector's climate impact, thus becoming an emerging topic of concern for action (Hu & Esram, 2021; Huang et al., 2018; UNEP, 2022; Ürge-Vorsatz et al., 2020). For context, 30-70% of lifetime carbon emissions for a new building are expended before it is occupied (Cousins et al., 2018). Additionally, when considering energy efficient buildings, a commercial mid-rise building with a 30-year lifespan can have up to 65% of its total emissions associated with embodied carbon (Cousins et al., 2018). As concern for embodied carbon emissions rise, many key players such as large architecture, engineering, and construction firms have committed to carbon neutrality in projects, along with numerous global companies, material associations, and the WGBC (UNEP, 2022).

2.4 Projected Growth and Wellbeing Contributions

The construction sector is the largest consumer of global resources (Sizirici et al., 2021). As building floor area continues to grow by a projected 75% in the next 30 years globally (IEA, 2022b), our dependence on earth for building materials will continue to grow. By 2026 building materials are expected to double in associated greenhouse gas (GHG) emissions while dominating global resource consumption if current trajectories continue (UNEP, 2022). This building growth is driven by population growth and urbanisation that is expected to continue driving the demand for carbon intensive building sector resources (Miller et al., 2021). Particularly, with 70% of the population expected to live in cities by 2100 (Boersma, 2021) and a global population of 11 billion by 2100 (Miller et al., 2021). If there is no intervention, carbon emissions from the building sector will increase because of floor area growth, material demand, and their associated production emissions (Arehart et al., 2022) particularly from the highest emitters of steel and concrete that are used for structural purposes (Arehart et al., 2022; Fisch-Romito, 2021).

The building sector consumes large amounts of resources and emits carbon emissions to ultimately provide infrastructure and building services to society (Huang et al., 2018). The sector has also simultaneously become a fundamental part of societies' economic and social development (Huang et al., 2018). The services provided by this sector are essential to meet contemporary basic needs but, as a by-product utilises carbon intensive processes and materials (Fisch-Romito, 2021). This indicates inconsistencies in current approaches to mitigate climate change while maintaining high quality of life services for society (Fisch-Romito, 2021).

3 Contributions to Sustainability Science

Sustainability science is an emerging academic discipline designed to provide new ways of thinking and working towards sustainability. It is concerned with the complexity of human-environmental interactions (W. C. Clark & Dickson, 2003; Kates et al., 2001; König & Ravetz, 2017) as our technological, economic, political, and cultural spheres develop and continue to cause environmental problems (König & Ravetz, 2017). It aims to improve these human-environmental interactions by leveraging diverse interdisciplinary knowledge co-creation with the social sciences, natural sciences, technological innovations, governance, and other stakeholders. Alongside these actors, it uses systems thinking approaches to better understand the complexity in these relationships at numerous scales and levels to ultimately work collaboratively towards sustainability solutions (W. C. Clark & Dickson, 2003; Kates et al., 2001; König & Ravetz, 2017). Juxtaposing different disciplines and ways of knowing helps sustainability science identify knowledge gaps to further understand these complex problems and ultimately introduce new perspectives. This is brought further into visioning and recommended actions for stakeholders (König & Ravetz, 2017). By using different theoretical lenses and considering various worldviews to understand current knowledge and how it is changing, it allows sustainability science to understand different angles to complex problems for reflection and facilitation of transforming scientific research, practices, and technology (König & Ravetz, 2017). Ultimately, sustainability science is problem driven and solutions oriented to drive sustainable transformation (W. C. Clark & Dickson, 2003; Kates et al., 2001).

This thesis aims to contribute to sustainability science by exploring the building sector's human-environmental interactions. It uses new lenses to gain new perspectives on the relationship and associated actions with embodied carbon to ultimately view the complex problem from a new critical perspective. It aims to address research gaps by juxtaposing the building industry with natural and social sciences to inform future recommendations for sustainable oriented solutions. This thesis is driven by the problem of embodied carbon and curious about its proposed solutions.

4 Theoretical Framework: Ecomodernism

4.1 The Emergence of Ecomodernism

The ecomodernism philosophy first emerged in the early 2000's in response to the then dominant environmentalism philosophy as the latter was not fulfilling expectations (Boersma, 2021; Sagoff, 2018). It aspired to contribute an alternative view to the paradox that was emerging between human wellbeing gains and environmental losses (Boersma, 2021; Sagoff, 2018). While ecomodernists and environmentalists mutually advocate for the goal of sustainability and recognise efficiency gains alone are not sufficient for impactful change, their policy methods to achieve sustainability are contrasting (Isenhour, 2016). Environmentalists believe the collapse of human civilisation is inevitable and essential for sustainability, along with constraints of ecosystem services as the limit to human production (Sagoff, 2018). They focus on protecting nature through moral, ethical, and cultural values (Sagoff, 2018) to live more harmoniously with the planet (Boersma, 2021). In contrast, ecomodernism acknowledges humans as separate entities from nature and believes technology can decouple humans from nature to reduce environmental harm (Hällmark, 2023). These contrasting views illustrate two very different contemporary sustainable development discourses (Isenhour, 2016). Environmentalism lost much of its political power when researchers began to identify climate change was not exclusively an environmental problem (Sagoff, 2018). This triggered a widespread political strategy shift that followed scientific research and advocation for technological solutions (Sagoff, 2018).

4.2 Origins from the Enlightenment

The principal viewpoints behind ecomodernism can be derived from enlightenment thinking, an intellectual movement that brought society into modernity by seeing society predominantly dependant on the arts and sciences and independent from nature (Hällmark, 2023; Sagoff, 2018). The movement used human ingenuity, social progression, developmentalist ideology, and technological innovation to redefine "Western" culture into a new era (Isenhour, 2016). These perspectives were then developed to understand the relationships between economic systems, technology, and capitalism (Isenhour, 2016). This informed the view that technological energy capture was the truest measurement of human progress, viewing societies who can use technology to capture energy efficiently as the most modern and have the potential to free themselves from the constraints associated with natural energy and materials (Isenhour, 2016). Later in the 20^{th} century, development theories built on these ideologies, collectively agreeing that reductions in ecological harm are a function of improved economic development efficiency (Isenhour, 2016). The development of these concepts is also used to rationalise contemporary theories that argue for human activity intensification, economic growth, and technology to manage and separate human-nature relationships

(Isenhour, 2016). These concepts facilitate the essence of ecomodernism and bring justification to the philosophy because it is built off previously developed Western progressive thoughts consistent with capitalist ideologies (Isenhour, 2016).

4.3 Aim of Decoupling Human Wellbeing from the Planet's Ecosystem Services

To facilitate the ecomodernist philosophy it is important to understand how it strives to achieve its aims. Ecomodernism strongly argues in favour of decoupling human wellbeing from the planet's ecosystem services (Sagoff, 2018) because dependence on nature is seen to be a detrimental barrier to preserving it (Boersma, 2021; Hällmark, 2023). This perspective is derived from the hypothesis that outlines the degradation of ecosystem services does not have to impact human wellbeing because humans are knowledgeable enough to find ways to decouple (Sagoff, 2018). Subsequently, the less humans rely on these services and land areas, the more space nature has to thrive (Boersma, 2021). The aim of decoupling is designed to simultaneously decrease natural resource consumption while economic output increases, to support wellbeing growth with decreased environmental impact (Isenhour, 2016; Sagoff, 2018). For example, ecomodernism argues in favour of reducing carbon emissions while allowing the economy to continue growing for relative decoupling (Isenhour, 2016).

4.4 Use of Science, Innovation and Technology

Decoupling is achieved through the use of science, innovation, and the main tool of technology to use resources efficiently and ultimately spare nature (Sagoff, 2018). Technology offers numerous methods to meet humanities' quality of life needs, while simultaneously reducing the economic pressures and human reliance on nature (Sagoff, 2018). This is achieved by designing technology as substitutes for ecosystem service-based goods (Sagoff, 2018). This technology can then expand human agency to create a liveable future (Hällmark, 2023). However, humanity must advance technology whilst engaged with environmental concerns (Isenhour, 2016). Many social scientists would support the argument that although not linear, developments in technology are a strong factor in the improvement for quality of life in contemporary societies, despite developments being geographically inconsistent and unequal in some places (Isenhour, 2016). Ultimately, climate change mitigation and other environmental concerns are viewed as a technology challenge through the lens of ecomodernism (Isenhour, 2016).

4.5 Productive Use of Resources and Efficient Technology

Driven by science and innovation, technology is utilised as the main tool to achieve productivity when using ecosystem services, to ultimately use less and spare nature (Sagoff, 2018). This productivity is displayed through human-intense activities (Boersma, 2021), such as utilising technology to intensify agricultural production or energy-dense resources like nuclear electricity production (Sagoff, 2018). Additionally, efficiency, particularly in technology and economic development is related to reductions in environmental harm (Isenhour, 2016). For these strategies to be effective, the pace of productivity in technology must keep up with economic expansion (Sagoff, 2018).

4.6 Support Economic Growth to Afford Technological Advances

Economic growth is utilised in ecomodernism as a means to afford new knowledge and technological advances desired to protect nature (Isenhour, 2016; Sagoff, 2018). The perspective of being able to afford to protect the planet is associated with the ecomodernism outlook which views ecosystem services primarily for their economic potential and less for beauty and spiritual qualities (Sagoff, 2018). This is implemented through capital-intensive market-oriented technology products (Hällmark, 2023). While ecomodernism does want the economy to grow, market-oriented technology is intended to separate the economic growth from environmental impacts (Hällmark, 2023). This strategy draws on the ecological Kuznets curve hypothesis, which illustrates that after an intense period of resource development, society begins reducing environmental impact per capita (Isenhour, 2016). Some evidence also suggests that the carbon emissions required to produce a unit of gross domestic product (GDP) have declined steadily while the economy has developed (Isenhour, 2016). In addition, economic growth is understood to come in waves driven by technology, with historical patterns suggesting a new era of growth is coming but this time driven by efficiency and low-carbon strategies (Isenhour, 2016). The ecomodernism philosophy ultimately utilises the promise of expanded wealth as a means for progress and development (Isenhour, 2016), with capitalism being a necessary stage in history to commodify everything then de-commodify what is valued (Hällmark, 2023). The philosophy's connection between wealth and capabilities to invest in the planet establishes wealthier societies as able and willing to pay more for the technology needed to maintain contemporary living standards while reducing its environmental impact (Isenhour, 2016).

4.7 Utilising the State to Promote Ecomodernist-based Actions

In addition to relying on economic growth to fund technological innovation, ecomodernism also relies on the state to promote ecomodernism-based actions. This is because of the states' associated legitimacy, capacity, and financial abilities to drive the developments in science, technology and innovation that are required for ecomodernist-rooted solutions (Hällmark, 2023). Ecomodernism believes the state should provide the funding needed to advance technology, its procurement, and training to actualise the potential sustainability impacts it is capable of (Hällmark, 2023).

4.8 Why Ecomodernism?

Buildings are essential to meet humanities' contemporary needs by providing shelter and creating an industry to financially support livelihoods and other basic needs. However, environmentally damaging and carbon-intensive materials are required to build these services. Therefore, while building to create a high quality of life in the present, the future quality of life is jeopardised (Fisch-Romito, 2021). To lower embodied carbon in the building sector, current trends from background research for this thesis indicate strategies in technology, innovation, finances, and efficiency are being pursued. Additionally, lowering carbon emissions in the building sector have been identified as low-cost emission reduction pathways that simultaneously provide social (Huang et al., 2018; Ürge-Vorsatz et al., 2020) and economic development opportunities (Huang et al., 2018). Taken together, this indicates a potential corelation to the roots of ecomodernism which this thesis explores further.

5 Methodology

5.1 Research Design

Upon analysing current literature about embodied carbon using the search term *"embodied carbon" AND building OR construction OR material(s)* from a variety of databases, technology appeared as a dominant topic which presented possible connections to the philosophy of ecomodernism. This philosophy was then used as a lens in the context of sustainability science research to analyse data and provide conclusions to the research questions. As new connections between the theory and embodied carbon strategies were discovered, the research questions were developed in an iterative process to explore the most important realisations.

This process of starting with assumptions, then utilising theory as an interpretive lens to further analyse data through a procedure (Creswell & Poth, 2017) is highly reflective of qualitative research and thus used to inform the research design process. Qualitative research was also conducted to answer the research questions because this type of data provides a descriptive answer (T. Clark et al., 2021) by establishing themes and patterns (Creswell & Poth, 2017) which is relevant for the "how"- and "what"-based research question of this thesis. Finally, qualitative research provides the space to explore problems that cannot be easily measured and the contexts of complex issues (Creswell & Poth, 2017) such as embodied carbon reduction strategies.

5.2 Methods

The research methods for this thesis consisted of data collection from relevant report documents from leading organisations who influence the building sector's embodied carbon reduction strategies. Documents were identified as a suitable source for qualitative data because through analysis of the language and subsequent message conveyed, documents represent a reality of what the organisation desires to accomplish (T. Clark et al., 2021).

A thematic content analysis was conducted on the documents using coding techniques to identify underlying themes of ecomodernism, with examples from the text to answer the research questions (T. Clark et al., 2021). First, the documents were scanned to identify their meaning and potential relevance to concepts within the chosen lens of ecomodernism. Next, codes were developed by identifying repetitions, industry expressions, metaphors, similarities, and differences that represented the ecomodernism philosophy. The documents were then read and analysed deeper by writing code memos alongside text examples. The code examples were then broken down further into themes grounded in the actions of decarbonisation strategies. These themes and specific text examples were then interpreted to identify further significance and connection to the theory and answer the research questions (T. Clark et al., 2021).

5.3 Codes

The selected codes used for the document analysis were derived from theory chapters 4.4 to 4.7 and outlined below.

Table 1. Coding Technique Visualisation

Code	Utilise science, innovation, and technology to substitute for ecosystem services	Productivity, efficiency, intensity to utilise less resources but continue economic growth	Promote economic growth to afford technology	Utilise the state to promote and fund technology and productivity actions	Results not aligning to ecomodernism
Theme 1	Data	Material efficiency	Economic barriers	Levels of government	Certifications and rating systems
Theme 2	Innovation advancements for low-carbon materials	Use less and long-lasting materials	Investment	The role of policies and regulations	Build less and reduce demand
Theme 3	Efficient and renewable energy technology for material production	Circular lifecycle considerations and recycling	Financial based policies and tools	Policy examples	Produce locally
Theme 4	Technology support for waste reduction	Design for efficiency	Role of the financial sector		Other actors, stakeholders and collaboration
Theme 5	New technologies	Manufacturing	Local economy investments		

5.4 Analysed Documents

The first document selected is the *GlobalABC Roadmap for Buildings and Construction 2020-2050 Towards a Zero-Emission, Efficient, and Resilient Buildings and Construction Sector.* It is a publication developed by the IEA and the Global Alliance for Buildings and Construction (GlobalABC) hosted by the UNEP. GlobalABC is a premier global platform aiming to support building sector stakeholders and their vision for a zero-emission, efficient, and resilient industry (GlobalABC, 2023a). The roadmap was produced to support both regional and global decarbonisation pathways for the sector, with processes and frameworks in alignment with the Paris Agreement 2050 targets (GlobalABC, 2023b). It intends to provide a common pathway for decarbonisation in buildings and construction, a sector often difficult to change due to its highly fragmented composition (GlobalABC, 2023b).

The UNEP also produces an annual *Global Status Report for Buildings and Construction Towards a Zero-Emission, Efficient, and Resilient Buildings and Construction Sector.* This annual publication provides a global scale summary of the building and construction sectors' status in policy, financial, technological, and other solutions to achieve the Paris Agreement targets (GlobalABC, 2022).

The final document is from the WGBC, the head of a global network driving sustainable transformation in the built environment to achieve the Paris Agreement emission objectives (WGBC, 2019). The report *Bringing Embodied Carbon Upfront Coordinated Action for the Building and Construction Sector to Tackle Embodied Carbon* was developed from detailed literature reviews, expert interviews, visioning, and backcasting workshops to create recommended decarbonisation strategies that were reviewed by numerous industry experts and stakeholders (WGBC, 2019).

With publication years in 2020, 2022, and 2019 respectively, the documents provide the most up-to-date and relevant information for the industry. While the GlobalABC Roadmap document provided the most direct recommendations for action, the UNEP status report and WGBC embodied carbon report covered many of the same topics but in less detail. Between the different authors, many different perspectives are considered including the building industry, global relations, policy, economic, and energy sectors. Overall, these documents were selected because of the mutual aim to influence embodied carbon strategies at a global level.

5.5 Limitations

Despite best efforts, these research methods do have some limitations. Firstly, the documents utilised are not an exhaustive list of every influential source of information for embodied carbon reduction strategies. However, due to the authors' global presence and significant influence on global building sector actions, a strong representation of the narratives influencing decarbonisation of the building sector are provided.

6 Results and Analysis

This results section provides a summary of the embodied carbon reduction strategies addressed in the analysed documents. The strategies and examples are organised according to the codes outlined in the methodology section with additional sub themes. Each section is concluded with an analysis to support the first research question (how are embodied carbon reduction strategies in the building sector in line with the philosophy of ecomodernism?).

6.1 Utilise Science, Innovation, and Technology to Substitute for Ecosystem Services

6.1.1 Data

Numerical data is identified as an important technological tool to improve knowledge of embodied carbon for materials and buildings. It is the first step to understanding baselines and improvements for net-zero carbon strategies by providing the evidence needed to inform decarbonisation strategies and provide quantifiable benefits to close key information gaps (GlobalABC et al., 2020). Embodied carbon data for building materials should continue being collected, managed, developed, and visualised (GlobalABC et al., 2020; UNEP, 2022) into standardised reporting tools such as environmental product declarations (EPDs) or benchmarks to support the evaluation of embodied carbon and inform targets for material production, nature-based solutions, decarbonisation technology strategies (GlobalABC et al., 2020), and material lifecycle assessments (GlobalABC et al., 2020; WGBC, 2019). The EPD's standardised format provides a useful tool for stakeholders to compare products regarding embodied carbon and environmental impacts to make data-informed material selections (GlobalABC et al., 2020; UNEP, 2022; WGBC, 2019) that reduce raw material usage and prioritise low-carbon materials (WGBC, 2019). The format can also inform certifications for a product based on the data provided (WGBC, 2019). Current barriers to effectively using embodied carbon data include the variability in measurement methods, data quality, and product category rules (UNEP, 2022).

Available numerical data should be compiled into an embodied carbon database for all stakeholders to draw from for carbon calculations, product comparisons, and lifecycle analysis to enhance informed carbon reduction decisions on materials and design (GlobalABC et al., 2020; WGBC, 2019). Currently, there are only a few openly available databases for material carbon emissions, making data accessibility a challenge (UNEP, 2022). Continued innovation from businesses, researches, and organisations have and will continue to be needed to support the development of accessible data tools for calculating embodied carbon in the building industry (WGBC, 2019).

To improve the application of embodied carbon data from these databases, digital tools should be developed. For example, carbon accounting assessment technology can be used to show whole lifecycle carbon impacts for traditional designs in comparison to new innovative designs and materials (UNEP, 2022). The data comparison in these programs can highlight and visualise new innovative efficiencies, materials, and structural designs for both on-site construction and off-site production methods (UNEP, 2022). These digital tools are recommended to be developed by experts who are able to contribute to the body of knowledge on material complexities by considering emissions, ecosystem impacts, and energy flows (UNEP, 2022). Examples of current tools being used and developed include the EC3 Carbon Calculator, Athena Impact Estimator for Buildings, and Open LCA (UNEP, 2022). These tools are currently in early development stages and can only provide rough frameworks (UNEP, 2022).

6.1.2 Innovation Advancements for Low Carbon Materials

Key elements to reduce embodied carbon as discussed in the documents are to use alternative low carbon materials (GlobalABC et al., 2020; UNEP, 2022), biobased materials, and decarbonise existing ones (UNEP, 2022). Conventional high-carbon materials such as steel, concrete, aluminium, plastic, and glass are essential to create carbon reductions for these materials (UNEP, 2022). In addition to the highly advocated for low-carbon materials, biobased materials are also identified as an innovation opportunity because the raw material can sequester carbon during growth, then store it in a building until end of life; however, this material must be produced by responsibly managed sources to foster effective impacts (UNEP, 2022; WGBC, 2019). These material transitions are strongly related to innovation advancements in all documents. The GlobalABC Roadmap identifies a crucial need to support research, development, and innovation to enable these low-carbon material solutions (GlobalABC et al., 2020). The UNEP describes that more investment, incentives, research, and development is needed to scale new innovations for hybrid and low-carbon materials that are being developed to replace high carbon materials such as concrete (UNEP, 2022). Additionally, this low-carbon material strategy alongside nature-based solutions is addressed in the UNEP's embodied carbon reduction strategy (UNEP, 2022). A barrier to these innovations is that they are not cost competitive yet and traditional bias can present challenges (UNEP, 2022). Innovation is also explicitly addressed in the WGBC report where it is identified as a tool for change to create new business models and technologies that can respond to policy or financial incentives, to ultimately reduce embodied carbon in the building industry (WGBC, 2019).

6.1.3 Efficient and Renewable Energy Technology for Material Production

Manufacturers of building materials are encouraged to switch energy sources to cleaner or renewable energy mixes to electrify and decarbonise production emissions (GlobalABC et al., 2020; WGBC, 2019). As renewable energy can be challenging to use with the technology of some industrial processes, particularly ones that use heat, manufacturers are encouraged to innovate ways to use heat waste (GlobalABC et al., 2020). It is also advised to use zero-carbon production technologies (WGBC, 2019). These transitions are showing promise in the cement and steel production processes where advanced technology could create a new industry (GlobalABC et al., 2020). Additionally, materials should be transported using low-carbon energy sources to further reduce embodied carbon (WGBC, 2019). Information should be shared amongst industry members, particularly on these practices and technologies that reduce energy demand and improve energy efficiency (UNEP, 2022).

6.1.4 Technology Support for Waste Reduction

Circular design is often promoted for material and building design to reduce embodied carbon. To do so, research and development for the equipment and technology needed to recover and process waste must continue to be developed (UNEP, 2022). With these technologies, and designing for disassembly and enhanced longevity, materials can be reused more effectively (UNEP, 2022). Digitalised construction processes that create prefabricated and modular construction designs are another technology that has proven to reduce material waste (UNEP, 2022). While material reuse is growing in demand, it should be avoided as the primary strategy to reduce material embodied carbon because growing demand is exceeding the available materials to reuse (UNEP, 2022).

6.1.5 New Technologies

The WGBC identifies academics and researchers as crucial stakeholders that can accelerate the development of these new technologies, tools, benchmarks, and methods to reduce embodied carbon or improve existing ones (WGBC, 2019). Examples of low-, to zero-carbon technology strategies for embodied carbon reductions currently include carbon capture and storage, electrolysis, hydrogen ironmaking, and 3D printing (WGBC, 2019). Additionally, technology to produce materials with bio-based inputs is a developing sector (WGBC, 2019). A notable perspective is the necessity to facilitate a common vision with transparency, inclusion, and co-operation amongst various stakeholders in order to implement these emerging innovative technologies into practice (GlobalABC et al., 2020). Additionally, many of the recommended policies are designed to support the implementation of technology for zero-emission buildings, making it a key tool for decarbonisation strategies (GlobalABC et al., 2020).

6.1.6 Analysis

Based on the results, it becomes evident that all documents heavily emphasise science, innovation, and technology as key tools to reduce embodied carbon in the building sector. As stated in the analysed documents, the intention of these recommended strategies are to reduce human-enabled embodied carbon emissions, which have significant negative environmental impacts. This is to support the required low-carbon material production and building strategies needed to provide humans with the infrastructure for a high quality of life, while having lower environmental impacts. While the results do not explicitly mention using technology as a substitute for ecosystem services to decouple humans from the earth to spare nature, the carbon-focused technologies can be seen as a replacement for the natural carbon cycle which cannot keep up with the pace of production. As humanity develops technology to reduce and reuse embodied carbon, it will soon rely on its own agency to maintain the necessary embodied carbon cycle for a liveable future. Humans are now knowledgeable enough to use technology as a means to decouple the built environment from the carbon cycle to support their wellbeing while sparing nature for a liveable future.

6.2 Productivity, Efficiency, and Intensity to Utilise Less Resources but Continue Economic Growth

6.2.1 Material Efficiency

Material efficiency is a dominant strategy discussed in all documents to reduce embodied carbon because of its significant estimated impact. The potential for emission reductions for building materials is associated with the increased raw material usage to support a growing economy that burdens the environment by building more. Therefore, efficient (maximum productivity with minimum waste) utilisation of resources is necessary to ultimately use less and thus reduce emissions (UNEP, 2022). These material efficiency strategies can be realised with improved data as previously discussed to improve material comparisons (UNEP, 2022). The following are identified strategies to facilitate material efficiency for embodied carbon reductions.

6.2.2 Use Less and Long-Lasting Materials

New building construction should use resources efficiently by reducing the amount of materials used (GlobalABC et al., 2020; UNEP, 2022), especially those that are carbon-intensive like steel, concrete, and plastic which are expected to be used more with projected growth in the built environment (UNEP, 2022). New buildings should also use materials that are long-lasting (GlobalABC et al., 2020) and designed for longevity to hold carbon longer (UNEP, 2022; WGBC, 2019). This supports the recommendation to optimise materials for favourable use in a buildings design to ultimately use less (GlobalABC et al., 2020). The UNEP also recognises that longevity is more than just a physical durability. Buildings and materials should be durable to social, cultural, and economic factors that create value for buildings to expand the accepted useful life (UNEP, 2022).

6.2.3 Circular Lifecycle Considerations and Recycling

It is recommended to consider whole-lifecycle carbon and promote circular economy principles with a cradle-to-cradle lifecycle approach for buildings and materials to reduce embodied carbon (GlobalABC et al., 2020). Lifecycle assessments should be used to quantify environmental impacts from material extraction, to manufacturing, and end-of-life. This should influence material decisions and building designs with the support of embodied carbon information databases (GlobalABC et al., 2020). A lifecycle approach often considers avoiding, shifting, and improving to build less and ultimately use less (UNEP, 2022). These lifecycle and systems thinking approaches are also effective tools to select materials that have multiple benefits to ultimately use carbon efficiently (UNEP, 2022).

It is highly recommended to repurpose and recycle materials and buildings to avoid waste (GlobalABC et al., 2020; WGBC, 2019) and use materials efficiently (UNEP, 2022). Particularly those with high-carbon footprints such as concrete (UNEP, 2022) or biobased materials that store carbon like timber (WGBC, 2019). Circular economy strategies, where waste is designed out or recovered and reused, are strategies that can significantly extend building and material lifespans to reduce emissions (UNEP, 2022). Additionally, product adaptability, take-back programs, and designing for reuse or deconstruction are also effective circular economy principles used to maximise product lifespans (WGBC, 2019). Circular design can be supported with material mapping data, which can make buildings into a material bank for reuse (WGBC, 2019).

Recycling and reusing in the proposed circular economy strategies contribute to embodied carbon reductions at a products beginning and end-of-life, by providing materials without extraction or waste emissions (WGBC, 2019). This is facilitated by initially designing materials and products for reuse or recycling, with the subsequent technological services to support this as crucial components to reducing whole lifecycle embodied carbon emissions (GlobalABC et al., 2020). A barrier to using recycled material is that supply is not currently able to meet demand, especially for high-carbon materials like steel (UNEP, 2022).

6.2.4 Design for Efficiency

Design was another consistent method identified to apply efficiency in embodied carbon reduction strategies, as well as to support many of the other topics discussed in the results. For example, evaluating design choices for embodied carbon considering whole lifecycle thinking (WGBC, 2019). When designing new buildings, material performance factors such as thermal transmittance, solar factor, heat gain coefficient, and surface reflection are often dominant factors for selecting façade materials. By adding embodied carbon data to the design efficiency consideration list, it adds carbon as a priority to inform material decisions during the design process (GlobalABC et al., 2020). Additionally, questioning the need for traditional materials and considering alternatives that meet the same goal could reduce emissions for a particular design (WGBC, 2019). A major efficiency through design strategy identified is to optimise a building's design (e.g., optimise structural design by reducing oversized components), selecting efficient building techniques, and the intensive use of existing materials to reduce the usage of new materials and reusing existing materials (GlobalABC et al., 2020). This strategy can be assisted by the technology solutions previously discussed along with new construction techniques (GlobalABC et al., 2020). For existing buildings, focus on design decisions for longevity and reuse is crucial (UNEP, 2022). Another core principle is to consider the buildings future lifecycle by designing for maintenance, repair, renovation, and flexibility. Designing buildings and its materials for disassembly and deconstruction will also support the reuse and recycling process that were previously mentioned (WGBC, 2019). Designing for reuse and renovation avoids the need for demolition and new construction which carries high embodied carbon impacts (WGBC, 2019).

6.2.5 Manufacturing

Efficient manufacturing techniques are also an essential method to reduce embodied carbon (GlobalABC et al., 2020). A key factor that must be accelerated and maximised in material manufacturing to reduce embodied carbon is energy efficiency (GlobalABC et al., 2020; WGBC, 2019) and the transition to low-carbon energy sources (WGBC, 2019). This is highly aligned with the previous codes findings for technology innovation to support these efficient transitions. Industries should set and monitor efficiency targets while sharing these targets, best practices, and methods to promote improved manufacturing technologies (GlobalABC et al., 2020). Manufacturing technologies should be updated and maximised for efficiency (UNEP, 2022) by using the technologies previously discussed such as alternative renewable energy sources, changing or reducing raw material feedstocks, more efficient production methods, or using carbon capture to reuse waste efficiently (GlobalABC et al., 2020; WGBC, 2019).

6.2.6 Analysis

Based on the results identified for this code, it becomes evident that embodied carbon reduction strategies for the building sector rely on the productive and efficient use of materials and technology. These are used to lower embodied carbon in buildings by using less to lower emissions. Notably, many of these efficiency impacts are achieved with the support of the technology strategies previously outlined. The achieved efficiency is intended to use less by being productive to ultimately spare nature. The productive actions all involve human innovations or decisions that could potentially become more intense as strategies improve, particularly in material manufacturing, building design optimisation and construction techniques. Which, when fully productive, could further reduce environmental harms from the building industry as the theory suggests.

6.3 Promote Economic Growth to Afford Technology

All three documents identified economic growth, investment, and financial strategies as essential to facilitate the necessary changes needed in technology and strategy to reduce embodied carbon in the building sector. In particular, GlobalABC specifically outlines financial actions and tools for all its decarbonisation sector strategies (GlobalABC et al., 2020) and the WGBC expands on the IPCC reports recommendations to use economic transitions to limit global warming (WGBC, 2019). The following sections break down the economic strategies recommended to reduce embodied carbon.

6.3.1 Economic Barriers

Finances are a common hindrance for actions designed to achieve the Paris Agreement targets (UNEP, 2022). For example, a major barrier preventing manufacturers from investing in new low-carbon technology and processes to reduce embodied carbon is the cost (WGBC, 2019). Research and development, particularly those in early stages, typically need support grants to scale up the technology to market (WGBC, 2019). Manufactures perusing circular business models also face a barrier of accessing the required finances because they are deemed “high risk” to lenders and investors who only consider traditional evaluation criteria (WGBC, 2019). These capital investments are particularly needed to decarbonise heavy industries like steel and cement (WGBC, 2019). Awareness for those financial incentives and services that are available should be improved through information sharing and standardisation which is often lacking (GlobalABC et al., 2020).

6.3.2 Investment

The financial sector must support embodied carbon reductions in materials by investing in the research, innovation, development, usage, and commercialisation of products and services (UNEP,

2022) to ultimately scale up the essential benefits of zero emission, efficient, and resilient buildings (GlobalABC et al., 2020). Increasing funding for research and development to foster innovation of new sustainable products, services, and technologies can also enable them to become cost-effective options for the market (GlobalABC et al., 2020). Investment is particularly needed in fast growing countries to build up their capacity for low-carbon and energy efficient resources, and supply chains to sustainably construct the projected building growth (UNEP, 2022). Investing now in these methods is a way to reduce embodied carbon emissions for not only today but also throughout the future (UNEP, 2022). Therefore, organisations are also advised to consider long- and medium-term investment strategies for embodied carbon (GlobalABC et al., 2020).

The UNEP currently advocates for funding in the following areas to accelerate development, usage, and commercialisation for chemical carbon reduction and biobased strategies in concrete production, carbon capture sequestration in material manufacturing, CO2 mineralization techniques for products, designing for disassembly or reuse, and finally computer-assisted manufacturing techniques (UNEP, 2022). These highly align with the reports specific recommendation to invest in technological solutions (UNEP, 2022). GlobalABC also recommends investing in renewable energy for manufacturing (GlobalABC et al., 2020). While investors and developers are integrating embodied carbon reduction requirements into projects, using fossil-free construction, developing embodied carbon data disclosures with EPDs, and running research and development for carbon-free or capture techniques; these actors may need more financial support to fully transition to net-zero embodied carbon (WGBC, 2019).

Embodied carbon data can provide evidence for consumers, lenders, and investors on where to direct funds for emission reduction targets. For this to be successful, training on embodied carbon must be normalised (UNEP, 2022). Additionally, green building certifications driven by data can increase awareness and knowledge to guide investment and financing by providing a measurement of quality for embodied carbon reductions (UNEP, 2022). This data and high-market demand will be a key driver for financial incentive providers to reward low embodied carbon practices (WGBC, 2019).

6.3.3 Financial Based Policies and Tools

Policy frameworks for mobilising and directing financial investments into decarbonising the building sector are essential to actualise low-emission building actions (GlobalABC et al., 2020). Additionally, financial support is critical to turn ideas driven by policy into a reality (GlobalABC et al., 2020). In particular, national and local actors are advised to develop financial policies and frameworks designed to increase investment for energy efficiency, material embodied carbon reductions, low-carbon technology, and effective retail channels; while removing fossil fuel subsidies and giving policy makers and financial institutions influential capacities (GlobalABC et al., 2020). Financial and policy incentives should also incentivise longevity in building design, low-carbon adaptation, and refurbishment to extend the useful life of embodied carbon (UNEP, 2022). Since 2015, some progress has been made in investments and policy actions to reduce embodied carbon, but more is needed (UNEP, 2022).

The following are examples of identified financial tools that can be used to stimulate investment for decarbonising the building sector. From the private sector there are recommendations for dedicated lines of credit from banks for sustainable buildings and development projects (GlobalABC et al., 2020), along with green bonds to compile sustainable project funding (GlobalABC et al., 2020). For the private and public sector, recommendations include requiring embodied carbon assessments on new major buildings, financial incentives for low-carbon projects with preferential loans to support low-carbon material markets (GlobalABC et al., 2020), and low-risk or guaranteed loans with risk default covered by governments, banks, or aid organisations to allow project funding with lower costs and terms (GlobalABC et al., 2020; WGBC, 2019). For the public sector, recommendations include preferential tax facilitated by government funding to reduce taxes on sustainable products and services or tax incentives, grants, subsidies and rebates from governments to support purchases of sustainable products or services by overcoming upfront cost barriers, and infrastructure funds for projects that prioritise sustainable designs (GlobalABC et al., 2020). For businesses, recommendations include procurement purchase and lease strategies that provide the opportunity to rent items, for example energy-efficient products, to ultimately reduce capital-intensive investments and overcome high upfront cost barriers (GlobalABC et al., 2020). These policies can ultimately enable low embodied carbon, efficient design and purchasing decisions (GlobalABC et al., 2020).

Carbon pricing, with cooperation from other countries and regions, can also play a key role in facilitating the decarbonisation of material production, increasing recycling, or reuse to reduce embodied carbon (GlobalABC et al., 2020; WGBC, 2019); along with the development and usage of low embodied carbon materials (GlobalABC et al., 2020). This is particularly relevant for high emitting materials like cement and steel (GlobalABC et al., 2020). Another market lever that can be used to finance and achieve lifecycle net-zero emissions in the built environment is to integrate the cost of those lifecycle emissions into the products and services (UNEP, 2022).

6.3.4 Role of the Financial Sector

The financial sector is a key actor to help achieve decarbonisation goals by developing services that are designed to facilitate low embodied carbon projects in the building sector (WGBC, 2019). They can help by facilitating the capital investments that are needed for resource efficient and circular business models in the manufacturing industry that target embodied carbon reductions (WGBC, 2019). This investment will only happen if there is demand coming from key enablers such as designers, clients, and real-estate investors. Therefore, the financial sector must support both ends of supply and demand through investments that enable full decarbonisation (WGBC, 2019). This can stimulate market demand for low embodied carbon products, which is essential to accelerating the required investments needed to facilitate competitive market solutions for various net-zero embodied carbon strategies (WGBC, 2019).

6.3.5 Local Economy Investments

The financial savings from retrofits and renovations instead of building new can provide money to further invest in sustainable choices. Renovations also provide local service jobs that can contribute to sustainable actions (GlobalABC et al., 2020). Producing materials locally is another way to boost local economies with jobs (GlobalABC et al., 2020), while reducing carbon emissions from material transport. Capitalising on local construction techniques or materials can also stimulate local economies with jobs to foster economic growth, reduce negative ecosystem effects, and support local culture in some cases (UNEP, 2022).

6.3.6 Analysis

Based on the results identified in this code, it becomes evident that embodied carbon reduction strategies for the building sector, particularly in technology, are highly reliant on investment and its associated economic growth to support its implementation. Continuous economic growth is necessary to provide the newfound financial capital essential for society to afford the embodied carbon knowledge and technological advances desired to protect nature. In other words, our ability to implement these embodied carbon reduction strategies is highly dependent on our ability to afford them. Therefore, to create economic growth, society is more likely to see the potential of natural resources through an economic lens rather than its natural spiritual qualities to gain the necessary capital. Furthermore, market-oriented technology strategies can also support economic growth in the industry while simultaneously supporting the key strategies for decoupling from nature. Ultimately, the recommended strategies align with ecomodernism by relying on expanded wealth to support the technological and efficiency strategies for embodied decarbonisation.

6.4 Utilise the State to Promote and Fund Technology and Productivity Actions

6.4.1 Levels of Government

National, subnational, and municipal governments can bring industries towards net-zero embodied carbon because of their associated power (GlobalABC et al., 2020; WGBC, 2019), making them key actors in facilitating actions towards embodied decarbonisation in the building sector (UNEP, 2022). The national level, which has the most power (WGBC, 2019), acts as a regulator and facilitator for stakeholder partnerships (GlobalABC et al., 2020). They have significant influence on changes in value chain collaboration, sparking market demand, and integrating circular economy principles into buildings (GlobalABC et al., 2020). They can also design and implement policies for low embodied carbon actions (GlobalABC et al., 2020), which is critical to developing building sector regulations (UNEP, 2022). At the subnational level, governments can also design and implement policies, while implementing the necessary changes as owners of public buildings (GlobalABC et al., 2020). Finally at the municipal level, cities can use urban planning strategies with whole lifecycle considerations for buildings, incentivisation schemes for new construction, and local policy action to reduce embodied carbon emissions (WGBC, 2019). Ultimately, governments must leverage their power at every level by developing comprehensive strategic roadmaps to facilitate action towards net-zero embodied carbon (GlobalABC et al., 2020).

6.4.2 The Role of Policies and Regulations

The documents indicate that net-zero embodied carbon in the building sector is possible but requires investment in ambitious policies and regulations (GlobalABC et al., 2020; UNEP, 2022; WGBC, 2019) to accelerate the identified key embodied decarbonisation strategies such as material efficiency and low-carbon materials (GlobalABC et al., 2020). Policies are also important to set good precedents for industry members to contribute to change (UNEP, 2022). This is because regulation is seen as a tool for change that can mandate embodied carbon reductions and create incentives to drive innovation (WGBC, 2019). Additionally, when progressive and feasible policies are made mandatory and not just voluntary, they can drive the necessary private sector action (WGBC, 2019). As 2050 approaches carbon offset demand will rise which can interfere with actual decarbonisation strategies, making regulation for embodied decarbonisation essential (UNEP, 2022).

In particular, the documents emphasise a few areas policies should focus on. Policies must be relevant and applicable to effectively decarbonise building materials (UNEP, 2022); by considering a buildings whole lifecycle from design, development and operation, to end-of-life (GlobalABC et al., 2020).

Furthermore, policies must address the regulatory and financial barriers to decarbonisation, improving skills for designing new buildings, reusing old buildings, and associated technologies (UNEP, 2022). They should also address materials specifically and the associated planning required (GlobalABC et al., 2020; UNEP, 2022; WGBC, 2019), along with innovation and technology (UNEP, 2022). Disclosure derived from benchmarking and data are essential tools to understand and facilitate decisions in policy making. The disclosure of environmental impacts of buildings and materials should also be required to enforce regulations and improve efficiency (GlobalABC et al., 2020).

For government policies to be effective, they must be supported by other actors. For example, the material and construction industries must commit to developing and implementing zero-carbon techniques and strategies to reduce carbon emissions in their value chain and support government policies (UNEP, 2022). Therefore, while political leaders are essential actors to implement and prioritise decarbonisation actions for the built environment and associated material production, organisational leaders are also important (UNEP, 2022). Reporting requirements can support policy transitions by allowing businesses to prepare for incoming policies and encourage skill development before it is mandatory in the market (WGBC, 2019). Additionally, policies from governments must be implemented with civil society participation (UNEP, 2022). When governments include civil society in the process of policy design, they can access feasibility and relevance for their actions among many perspectives. Involving civil society can also build relationships, drive acceptance, and improve participation (GlobalABC et al., 2020).

Policy measures are essential to remove barriers, prepare industries and ensure zero-carbon products can be successful in the market (WGBC, 2019). Governments are key stakeholders to implement these because of their ability to implement standards (GlobalABC et al., 2020; UNEP, 2022; WGBC, 2019) and develop partnerships (UNEP, 2022) to help meet their influential international commitments (UNEP, 2022) and national emission targets (GlobalABC et al., 2020; UNEP, 2022; WGBC, 2019).

6.4.3 Policy Examples

The following are areas governments are recommended to direct their policies towards.

Circular Economy & Lifecycle Thinking

Governments should implement policies that support, promote, and facilitate circular economy and lifecycle assessments (GlobalABC et al., 2020; UNEP, 2022). This is particularly applicable to the previously discussed strategies of renewable materials that sequester carbon (UNEP, 2022), materials with reduced carbon footprints (GlobalABC et al., 2020; UNEP, 2022), and material reuse strategies (GlobalABC et al., 2020).

Building Codes & Regulations

Updating building codes to consider embodied carbon is an essential policy tool to enforce its reductions (GlobalABC et al., 2020; UNEP, 2022). National and subnational governments, whom have control of building codes, should update their codes to achieve zero-carbon across whole building lifecycles (UNEP, 2022). Many building codes currently do not consider embodied carbon, only operational carbon, which is critical to change to reach targets and achieve whole lifecycle thinking in regulations (GlobalABC et al., 2020; UNEP, 2022). Minimum environmental standards for materials should be implemented into building codes to promote low-carbon options and drive their market (GlobalABC et al., 2020). Additionally, all governments should enforce regulations for the disclosure of embodied carbon in buildings (GlobalABC et al., 2020; WGBC, 2019) of a selected size for permitting and building codes (WGBC, 2019). This requirement can also promote other embodied carbon reduction strategies such as renovation and reuse (WGBC, 2019). Finally, these code updates should be guided by the previously disused data techniques (UNEP, 2022).

Financial Support & Market Stimulation

As previously mentioned, financial support is essential to actualise embodied carbon reduction strategies and governments can play a large role in facilitating it. Governments have the ability to create political solutions that support low-carbon investments and financial incentives to stimulate and enable the low-carbon markets (UNEP, 2022; WGBC, 2019); or provide financial relief to zero-carbon building investments for developers (GlobalABC et al., 2020; UNEP, 2022). In particular, governments should be supporting, promoting, and facilitating investment in efficient (GlobalABC et al., 2020) or low-carbon technology, energy efficiency, and low-carbon materials (UNEP, 2022). All of which are key themes previously identified. Government financial incentives such as loan guarantees, which aligns with previous themes, should be used to drive markets and enable the private investment of sustainable low-carbon materials and construction techniques. For this, incentives should support both manufactures and consumers so public and private entities can make purchases (GlobalABC et al., 2020). Carbon pricing is also a tool that can be used by governments (UNEP, 2022).

As government procurement contributes significantly to local GDP, it can generate sustainable growth (UNEP, 2022) when it considers embodied carbon and environmental requirements for more sustainable materials (GlobalABC et al., 2020). For this, procurement policies must prioritise low-carbon materials with additional budgets for lifecycle assessments to improve data derived knowledge for their material choices (UNEP, 2022). With the increased purchase of sustainable products, unsustainable products will start to phase out (UNEP, 2022).

Governments should also invest in research and development (R&D) to shift markets and accelerate innovation towards low-carbon options (GlobalABC et al., 2020; WGBC, 2019). Additionally, increased funding for R&D can improve local production while making it economically competitive (GlobalABC et al., 2020). Ultimately, government policy and regulatory measures can leverage industry demand and create acceleration which is a key tool for change (WGBC, 2019). This can also create new markets (UNEP, 2022).

Support Supply and Demand Sides

Many of the current embodied carbon policies for the built environment target the supply side. These include energy efficiency standards, energy consumption taxes, waste taxes, and carbon trading schemes. More policies such as innovation funding and reuse or recycling incentives for supply side actors are also needed to drive the necessary investment in technology and manufacturing processes that were previously discussed (WGBC, 2019). For the demand side policies such as building codes, which currently focus on operational carbon, must be developed to implement political priorities on embodied carbon (WGBC, 2019). This approach meets the recommendations for policies to support efficient building techniques and technology that can lower embodied carbon (GlobalABC et al., 2020).

Capacity Building and Training

Information and training at a variety of educational levels (e.g., university and certification programs) should be used to increase awareness and improve decision-making to enable low-carbon choices (GlobalABC et al., 2020), which the government has the ability to influence (UNEP, 2022). Training for government stakeholders regarding embodied carbon benefits, data, policy strategies, and assessment tools can improve the implementation of the policy strategies discussed above and stimulate collaboration with other actors for improved policy coherence (GlobalABC et al., 2020). Beyond the government, training professionals such as architects, engineers, and contractors on how to design for low-embodied carbon, use technology, data, and the circular design tools discussed previously, as well as how to comply with government policies, can significantly support the implementation of these strategies (GlobalABC et al., 2020). Training for manufacturers on how to decrease embodied carbon in materials, improve manufacturing efficiencies, use local and circular design principles, and how to comply with labelling policies like EPDs or disclosure is also important to deploy low-carbon solutions

(GlobalABC et al., 2020). Training for investors and developers on how to identify, assess, and invest in zero-carbon options is essential to create an understanding of the benefits of zero-carbon, efficient, and resilient buildings (GlobalABC et al., 2020). Finally, training the public through certifications, mandatory disclosure, educational resources, and government programs can increase awareness, decision making, and sustainable choices (GlobalABC et al., 2020).

6.4.4 Analysis

Based on the results, it becomes evident that the documents address the government as a key actor to promote and actualise embodied carbon reduction strategies. The state has become the largest actor to trigger technological action to decouple human wellbeing from the environment due to its associated legitimacy, capacity, and financial abilities to drive the necessary technology and efficiency strategies. Here, responsibility is placed on the state to actualise embodied decarbonisation to decouple human wellbeing from the environment. The question remains whether the state has these capabilities in actuality.

6.5 Results Not Aligning to Ecomodernism

While majority of the recommendations to act on embodied carbon are aligned with the main themes of ecomodernism, there are a few recommendations that are perceived to not directly fit into the identified themes of ecomodernism.

6.5.1 Certifications and Rating Systems

Green building and material certifications are recommended to incorporate net-zero emission strategies to provide evidence for low-carbon choices (GlobalABC et al., 2020; UNEP, 2022). This can help designers, investors, product manufacturers, governments, and NGOs adopt and recognise standards to achieve decarbonisation (UNEP, 2022). Additionally, carbon rating systems should reward avoiding building new structures, selection of low-carbon or biobased materials, and improved production of conventional materials (UNEP, 2022).

6.5.2 Build Less & Reduce Demand

Although not a dominant narrative, it is recommended to reduce embodied carbon by building less (UNEP, 2022). It is also recommended to use design and construction techniques that use less material (GlobalABC et al., 2020; UNEP, 2022).

6.5.3 Produce Locally

Local material production can significantly reduce embodied carbon from reduced transportation emissions, even more so if low embodied carbon materials are manufactured (GlobalABC et al., 2020; UNEP, 2022). It is also recommended to develop locally appropriate building strategies (GlobalABC et al., 2020) or nature-based construction techniques such as rammed earth or sun-dried bricks in Africa (UNEP, 2022).

6.5.4 Other Actors, Stakeholders and Collaboration

There are many additional actors included beyond the government who are essential to facilitate embodied carbon reduction strategies (GlobalABC et al., 2020) because of their ability to control different levers of change (WGBC, 2019). For example, property developers, manufacturers, designers, financial institutions, civil society, NGOs, and green building councils all have the ability to contribute in different ways to the strategies for embodied decarbonisation previously mentioned (GlobalABC et al., 2020; WGBC, 2019).

Achieving embodied carbon reductions at the necessary pace and scale requires engagement and collaboration between all these actors (GlobalABC et al., 2020; WGBC, 2019) to facilitate the required shared vision, transparency, and co-operation for effective policies and the integration of technology (GlobalABC et al., 2020). In particular, actors on the demand side must work in collaboration with the supply side to form positive feedback loops for market demand stimulation to increase net-zero carbon actions (WGBC, 2019). Public and private sector collaboration is essential to develop momentum for change by creating policy frameworks to give confidence to businesses to invest in net-zero embodied carbon. Additionally, multi-stakeholder engagement also offers various perspectives and can create a stronger buy-in from communities to maintain momentum when leadership changes (GlobalABC et al., 2020).

6.5.5 Analysis

These recommended strategies do have potential connections to themes discussed in other sections that directly align with ecomodernism. For example, certification and rating systems can be associated with the recommendation to use data; building less and reducing demand could align with efficiency strategies to use less; local production can support financial strategies and information sharing; or training can be associated with the influence of the government. However, these were not included under those themes as justification for the strategies' connection to ecomodernism. This is because the way these strategies were described, it is perceived their intentions do not fully align with the aim of ecomodernism, despite the surface actions being similar. Regardless of there being some strategies that do not strongly correlate with the goals of ecomodernism, they are not the prominent recommended strategies. Therefore, they should be considered in embodied carbon reduction strategies but do not define the overall intentions of them.

7 Discussion and Conclusion

7.1 How are Embodied Carbon Reduction Strategies in the Building Sector in Line with the Philosophy of Ecomodernism?

Based on the identified results and subsequent analysis, it becomes evident that the analysed embodied carbon reduction strategies in the building sector are in line with the philosophy of ecomodernism. This is because each code, which represents a key strategy to achieve the aims of ecomodernism, has significant supporting evidence from the analysed documents. When put together, it can be understood as follows.

The technology strategies to reduce and reuse embodied carbon emissions are projecting a path for humanity to create its own embodied carbon cycle, to replace the natural ecosystem service which cannot keep up with emissions in the pace of production. This example of human agency is ultimately decoupling the infrastructure essential to humanities' wellbeing from nature to spare it from damaging emissions. The human-driven technology strategies are also supporting efficient operations to use embodied carbon resources productively to ultimately use less to spare nature. However, economic growth is necessary to provide the financial capital for society to afford these technological advances desired to protect nature. Finally, all these recommended strategies to reduce embodied carbon rely on the government because of its associated power, making the state a crucial actor to trigger technological action to decouple human wellbeing from the environment.

7.2 What Consequences Does the Building Sector and World Face if They are Guided by the Central Themes of Ecomodernism?

While it appears the building sector is highly aligned with the philosophy of ecomodernism to create change for embodied carbon reductions, there are limits to the philosophy that should be addressed to understand what consequences these strategies may face if they are guided by ecomodernism.

Firstly, there is evidence against successful decoupling, suggesting that it should not be used as an escape route for continuous growth (Isenhour, 2016). With increased efficiency, economies are emitting less carbon per economic unit (relative decoupling). However, economies are growing faster than their efficiency gains, resulting in a net-carbon emission growth. For absolute decoupling to be achieved, efficiency must outpace growth. To do so, technology improvements need to increase 10x faster than the current rate to avoid dangerous GHG emission levels. Additionally, efficiency strategies will not solve resource scarcity or stabilise the climate. In reality, resource consumption is accelerating, making emissions increasingly difficult to de-link from human wellbeing (Isenhour, 2016).

Secondly, there are many unintended rebound effects (Isenhour, 2016). For example, at various scales efficiency gains are reinvested into production and consumption. This is exemplified through monetary savings being used to purchase more of the item or directing it towards other purchases, thus increasing consumption. Despite there being evidence of rebound effects, particularly with energy efficiency, it is often not addressed in ecomodernism (Isenhour, 2016).

Third, efficiency improvements can often trigger environmental degradation off-site through burden shifting (Isenhour, 2016). Burden shifting occurs when the domestic environmental costs associated with extraction and production decrease because the economy shifts to information and technology-based services, typically in affluent nations. However, the nations still need materials and energy for their economies. These become imported goods with environmental costs outside the nation, typically in developing nations that are eager to grow economically but politically unable to enforce environmental protection. Producer nations are thus responsible for product emissions, with majority of the associated revenue not staying in the nation. This causes further inequalities by enabling unequal trade and relations to achieve growth. This aligns with research that indicates decoupling can cause environmental damages to not be eliminated, but rather displaced in the unequal global market. These displaced emissions allow for affluence in some countries and mitigation and investment responsibility in others. This metabolic rift of unequal exchanges is likely to be a large concern in the future both environmentally and socially if technology is continued to be viewed as separate to burden shifting (Isenhour, 2016).

Finally, the idea that technology can separate humans from nature can be traced back to the industrial revolution where technology was a means to rely less on the land while fulfilling affluent lifestyles (Isenhour, 2016). These views of separation are more Western thought dominant and not universal (Isenhour, 2016).

Based on these critiques of the ecomodernism philosophy, it is important to see where ecomodernism-focused embodied decarbonisation strategies may also be lacking. Firstly, while efficiency is a significant strategy recommendation for the building sector to reduce embodied carbon emissions, the recommendations neglect to consider how to ensure that the pace of efficiency does not outpace economic growth to guarantee decoupling is being achieved. Secondly, while the documents advise for investment into low-carbon developments, they do not address how rebound effects should be handled to reduce overconsumption. Additionally, the recommendations particularly in policies and the advocation for government agency, do not address strategies to reduce the burden shifting that is likely to be a result of the proposed technology strategies and their associated social and environmental inequalities. Finally, because the proposed strategies are highly aligned to separating humans from nature, they may not be fully applicable or accepted outside Western thought. Ultimately, the strong modernisation belief of the Enlightenment-derived theory, which advocates for new ideas and technology as the solution, is not reflective enough of world dynamics. Therefore, to make these embodied carbon reduction strategies of the building sector more comprehensive and effective, they must address these limits of the ecomodernism philosophy of which they align to. Further research should be conducted to address these knowledge gaps and implement them into future embodied carbon reduction strategies.

7.3 What Do the Strategies Emphasise and How Impactful Can They Be?

Despite the efforts beginning to implement building sector embodied carbon reduction strategies as discussed in this thesis, the sector is not on track to meet decarbonisation targets (GlobalABC et al., 2020; IEA, 2022a; UNEP, 2022) which is an essential step to avoid catastrophic climate change (UNEP, 2022). Upon reflection on the current building sector embodied carbon emission research discussed in section 1.4, it becomes clear that much of the current work is addressing the use of science, innovation, technology, and efficiency (code 6.1 and 6.2) to address embodied carbon targets and solutions. This is seen in examples such as developments for innovative low-carbon or alternative materials, adjusting design strategies to optimise material use, technological tools to facilitate recycling, quantifying embodied carbon for educated material selections, and technology to capture and store carbon in buildings.

If focus is only put on the main strategies of technology and efficiency (code 6.1 and 6.2) to reduce environmental impacts, then the philosophy of ecomodernism would suggest that the main triggers of the state and financial support (code 6.3 and 6.4), who can facilitate and scale the required impactful change from technology are neglected. Therefore, if society wants to pursue an ecomodernist paradigm to combat climate change by meeting decarbonisation targets, more research should be directed towards actualising governance and financial policy tools to reduce embodied carbon. This would have cascading support for all four key areas of ecomodernism, which rely on each other to achieve the aim of reducing environmental harm through decoupling. It would also address one of the previously mentioned challenges to decarbonising the building sector, which is an identified lack of primary leadership having control over a shared direction. Ultimately, current actions need to step back from the tools directly closest to facilitating numerical carbon targets, which the Paris Agreement could be a blinder for, and see the larger interdisciplinary picture of how impact is facilitated to get back on track.

This can be supported by the academic discipline of Sustainability Science and its ability to work collaboratively towards sustainability solutions with a focus on how technological, economic, political, and cultural spheres cause environmental problems. Additionally, by leveraging diverse interdisciplinary knowledge co-creation and systems thinking approaches to better understand complex relationships at numerous scales and levels, its key areas highly align to the topics and connections needed to actualise ecomodernist-rooted solutions for successful embodied carbon reductions. With improved efforts to wholistically implement the recommended embodied decarbonisation strategies, impactful change could be achieved for a livable future.

7.4 Conclusion

By understanding building sector embodied carbon reduction strategies from an ecomodernism theoretical lens, one can gain an understanding of their deeper ideas, intentions, and potential threats from a critical perspective. Then, when analysing recommended strategies or existing research, this deeper understanding can shine a light on how the components work together to create change or address weaknesses. Furthermore, the findings of this thesis can be used to inform future sustainability science research to support leaders in creating a shared direction for embodied decarbonisation strategies.

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