Embodied Carbon Reduction Strategies for the City of Charlottetown (Case Studies: Copenhagen and Vancouver)

Elnaz Eslami

Master of Island Studies, Sustainable Island Communities, Faculty of Arts, University of Prince Edward Island, Charlottetown, Canada

Introduction

Embodied carbon refers to the carbon dioxide emissions which are related to the production, transportation, and disposal of materials used in different sectors such as construction, manufacturing, and transportation. It represents the carbon footprint of materials throughout their life cycle including the extraction of raw materials, manufacturing processes, transportation, construction, use of materials, and end of life or recycling process (Akbarnezhad, A. & Xiao, J., 2017) (Wolf, C., Pomponi, F., Moncaster, A., 2017).

While operational carbon emissions which is the emissions that occur during the use of a building receive significant attention in research and industry, embodied carbon often accounts for a higher portion of the overall carbon footprint. It is estimated that embodied carbon is responsible for 11% of global carbon emissions in the globe. So, it is crucial to address embodied carbon in today's world, and reducing embodied carbon can help to create sustainable built environments and achieve sustainable development goals (Magwood, 2019).

This paper aims to explore the concept of embodied carbon and its significance in the context of climate change and sustainable development. The paper will provide an overview of embodied carbon and highlight its importance in the fields of climate change and climate action. Then, two case studies of Copenhagen and Vancouver will be investigated to examine their strategies for addressing embodied carbon. Drawing insights from these case studies which are at the forefront of sustainable development and are successful in implementing strategies in these fields can help us to conclude with the recommendations for the city of Charlottetown to enhance its approach toward this issue.

The City of Charlottetown is the capital city of Prince Edward Island in Canada and is a rapidly growing urban area. This city is known for its rich history, cultural heritage, and natural beauty. Like many cities in the world, this city is getting the impacts of climate change like extreme weather conditions, severe storms, and hurricanes. In 2022, the Fiona hurricane brought destructive winds, storm surge, and heavy rain to this city causing damages to Charlottetown assets and properties. This city has declared climate change as an emergency and started to consider plans and studies for this phenomenon since 2019. Climate Risk and Resilience Assessment (2019) and Community Energy Plan (2019) are two important plans conducted by the City Hall of

Charlottetown to provide strategies and support climate change goals. In 2023, The Climate Action Plan was started as an integration of climate change plans for this city, and embodied carbon reduction is introduced as a potential enhancement in the Climate Action Plan of the City of Charlottetown. So, the aim of this paper to introduce recommendations and strategies to address embodied carbon of city of Charlottetown can help the integration of Climate Action Plan. By analyzing the experiences of Copenhagen and Vancouver, two cities renowned for their embodied carbon efforts, this paper will provide valuable insights and recommendations for Charlottetown to enhance its approach towards embodied carbon reduction (Climate Action Plan, Phase 1: Discovery , 2023).

Embodied Carbon: Definition and Assessment Methods

As discussed before, embodied carbon refers to "the carbon emission associated with materials and construction processes throughout a building's life cycle" (Embodied Carbon: A Primer for Buildkings in Canada, 2021, p. 3). To measure and assess embodied carbon, various methods and tools have been developed. Two commonly used approaches are Life Cycle Assessment and Environmental Product Declarations. These measurement and assessment methods help stakeholders in the construction industry make informed decisions regarding material selection, construction practices, and design strategies to minimize embodied carbon and promote sustainable development.

- *Life Cycle Assessment (LCA)*: LCA is a comprehensive methodology that quantifies the embodied carbon of a product or system throughout its life cycle. It considers all stages, from raw material extraction to the end of life of materials, and provides a holistic assessment of carbon emissions.
- *Environmental Product Declarations (EPDs)*: EPDs provide standardized information about the environmental performance of products, including embodied carbon. They present data on carbon emissions, energy use, and other environmental indicators, enabling comparisons between different products in terms of their environmental impacts. Indeed, as it was hard to assess the Life Cycle Assessment of materials and systems, EPD is introduced to express the global warming potential of products (GWP factor), and this factor helps developers to quantify the embodied carbon emission of the system easier (Akbarnezhad, A. & Xiao, J., 2017) (Hammond, G. & Jones, C., 2011).

Literature Review of Embodied Carbon Reduction

The literature review of embodied carbon research reveals a growing focus on shifting attention from operational carbon to embodied carbon in the built environment. Researchers have recognized the significance of embodied carbon as a key contributor to overall carbon emissions and have emphasized the need to address it alongside operational carbon. The research in this field can be categorized into two perspectives: the architectural point of view and the urban scale perspective (Pomponi, F., Wolf, C., Moncaster, A., 2018).

The architectural point of view aims to introduce strategies at the building scale to mitigate embodied carbon. This perspective encompasses various aspects such as embodied carbon assessment methodologies, sustainable material choices, design for disassembly, and efficient construction techniques. Researchers in this field have focused on optimizing the design and construction process to reduce embodied carbon without reducing the functionality of buildings.

On the other hand, the urban scale perspective focuses on strategies and policies at the urban planning and development level to implement embodied carbon reduction. Urban planners and policymakers recognize the potential impact of urban design and development decisions on overall embodied carbon emissions. They explore initiatives such as zoning regulations, incentives for low-carbon construction materials, district-scale energy systems, and integrated urban planning approaches. In fact, this perspective tries to help the implementation architectural strategies in urban scale.

Having investigated the embodied carbon reduction strategies from the architectural point of view, it is essential to consider the international efforts addressing embodied carbon. Furthermore, as the aim of this paper is to recommend strategies for city of Charlottetown, lessons will be drawn and applied to the context of Charlottetown by analyzing the successful approach of two cities of Vancouver and Copenhagen which are at the forefront of sustainable development and embodied carbon reduction (Akbarnezhad, A. & Xiao, J., 2017) (Asdrubali, F., Grazieschi, G., Roncone, M., Thiebat, F., and Carbonaro, C., 2023) (Hakkinen, T., Kuittinen, M., Ruuska, A., and Jung, N., 2015) (Hammond, G. & Jones, C., 2011) (Huang, B., Xing, K. & Pullen, S. , 2017) (Peters, 2010) (Rydlewski, J., et al. , 2022) (Wolf, C., Pomponi, F., Moncaster, A., 2017) (Xing, K., Wiedmann, T., Newton, P., Huang, B. & Pullen, S. , 2019).

Embodied Carbon Reduction Strategies from Architectural Point of View

The embodied carbon reduction in architectural and construction point of view is influenced by factors such as material selection, construction techniques, transportation, and energy inputs. Different materials have varying carbon emissions based on their production processes, extraction methods, and transportation distances. Construction techniques and transportation of materials from their source to the construction site contributes to the amounts of carbon emissions as well. Moreover, the energy sources used during material manufacturing, whether fossil fuels or renewable energy, directly affect the emissions associated with material production. Considering these factors there are different strategies (from the architectural point of view) that can help the reduction of buildings' embodied carbon. These strategies includes:

- Using low-carbon materials in buildings
- Minimizing the amounts of materials
- Considering reuse and recycling of materials
- Using local sourcing of materials and components
- Choosing the best construction design strategies

(Akbarnezhad, A. & Xiao, J., 2017)

An Overview of International Efforts and Initiatives Focused on Embodied Carbon

International efforts to address embodied carbon have gained significant attention in recent years. Different organizations and initiatives are working towards reducing the carbon footprint related to construction and building materials. Below there are some of the efforts to support embodied carbon reduction.

- *United Nations Framework Convention on Climate Change (UNFCCC)*

The UNFCCC is an international treaty that aims to stabilize greenhouse gas concentrations in the atmosphere to prevent dangerous human interference with the climate system. While the UNFCCC primarily focuses on mitigating operational carbon emissions, it recognizes the importance of addressing embodied carbon in recent years. The UNFCCC provide a platform for discussions and collaboration on climate change, including the reduction of embodied carbon in various sectors (Bohringer, Ch., Carbone, J., Rutherford, Th., 2011) (UNFCCC, n.d.).

- *Intergovernmental Panel on Climate Change (IPCC)*

The IPCC is a scientific body established by the UN and the World Meteorological Organization (WMO). Its role is to provide policymakers with objective scientific assessments of climate change and its impacts. The IPCC's reports highlight the significance of addressing embodied carbon in mitigating climate change. They emphasize the need to consider the life cycle impacts of materials and products, promoting the adoption of low-carbon materials and sustainable construction practices (Mohareb, E., Kennedy, C. , 2012) (IPCC, n.d.).

- *World Green Building Council (WorldGBC)*

The WorldGBC is a global network of Green Building Councils (GBCs) that aims to transform the built environment towards sustainability. The WorldGBC's Advancing Net Zero initiative focuses on reducing both operational and embodied carbon in the construction and operation of buildings. It encourages GBCs to develop strategies and initiatives to promote the use of low-carbon materials, energy-efficient designs, and carbon-neutral building practices (Laski, J., Burrows, V., 2017) (WorldGBC, 2019).

- *International Energy Agency (IEA)*

The International Energy Agency or IEA is a Paris-based autonomous agency, established in 1974, that promotes energy security, economic growth, environmental sustainability, and policy recommendations about the energy sector. It works to advance energy technologies and policies that support clean and sustainable energy transitions. In addition, The IEA's Energy Technology Perspectives report highlights the importance of reducing embodied carbon in the construction sector as well (Yokoyama, K., et al., 2017).

Investigation of Two Successful Case Studies in terms of Embodied Carbon Strategies

Case Study I: Copenhagen, Denmark

Copenhagen, the capital city of Denmark, has demonstrated a strong commitment to sustainability and climate change throughout the world. This city has set ambitious targets to become carbon neutral by 2025 and strives to be a leading global example of sustainable urban development. Copenhagen's three board strategic areas which are important for its future as a green economy leader includes: low carbon, energy and resources, urban form, transport and accessibility, and innovation and business. The CPH 2025 Climate Plan, published in 2012, stated that “In 2025, Copenhagen will be the world’s first carbon-neutral capital and the city’s businesses and universities will be spearheading the development of green solutions generating employment and green growth” (Floater, G., et al. , 2014, p. 85)

Analysis of Embodied Carbon Reduction Strategies in Copenhagen

One of the important components of Copenhagen's approach toward embodied carbon reduction involves the adoption of innovative architectural and engineering. By encouraging the design and construction of energy-efficient buildings, incorporating passive design principles, renewable energy sources, and smart technologies, the city optimizes energy performance and reduces operational carbon emissions. This approach has indirect effects on embodied carbon reduction by minimizing the demand for energy-intensive materials and systems. In addition, this city adopts an integrated design approach that tries to address embodied carbon from the early stages of a project. So, by involving architects, engineers, and other professionals in decision-making, the city ensures that sustainability and embodied carbon strategies are included in designs, material selection, and construction. Moreover, the reduction of embodied carbon in the construction industry has become a key priority this city by promoting low-carbon construction materials, particularly those with a smaller carbon footprint compared to traditional materials like concrete and steel. These strategic approaches enables Copenhagen to mitigate the environmental impact of the construction sector and make significant steps towards sustainability.

Copenhagen places great emphasis on collaborative efforts and partnerships to address embodied carbon objectives. The city actively fosters collaboration among government agencies, architects, developers, researchers, and industry experts to facilitate the exchange of knowledge, share best practices, and develop innovative solutions. This approach can help the stakeholders and developers to reduce embodied carbon throughout construction. Furthermore, incorporating sustainable procurement practices into public tendering processes is another important facet of Copenhagen's strategy. The city prioritizes sustainability criteria, including embodied carbon considerations, when selecting contractors and suppliers for construction projects. By stimulating demand for environmentally friendly and low-carbon options, Copenhagen encourages the adoption of best practices and the use of sustainable materials in the construction industry.

This City implemented other strategies such as data monitoring and investment on embodied carbon research to achieve its goal of being carbon neutral in 2025. The city diligently tracks and assesses the environmental performance of buildings throughout their lifecycle, specifically monitoring embodied carbon and other relevant factors such as material choices, energy consumption, and carbon emissions. This data-driven approach allows for the identification of areas for improvement, the measurement of the effectiveness of implemented strategies, and the facilitation of continuous improvement in reducing embodied carbon. Furthermore, to drive innovation and accelerate progress in embodied carbon reduction, Copenhagen invests in research and innovation projects within the construction sector. The city provides funding opportunities and support for research institutions, universities, and industry partners to develop innovative solutions, technologies, and practices. By encouraging research and innovation, Copenhagen actively promotes the adoption of new methods and materials that contribute to lower embodied carbon, showing its commitment to sustainable construction practices and positioning itself as a global leader in the field (Climate Plan, A Green, Smart, and Carbon Neutral City, 2012) (Neuhoff, 2011) (Dams, T., Kjaer, T., Christensen, Th. , 2017) (Doren, D., Driessen, P., Giezen, M., 2020).

Case Study II: Vancouver, Canada

City of Vancouver which is located in British Columbia, Canada, is known for its strong commitment to sustainability and environmental issues. The city has set goals to achieve a 40% reduction in embodied carbon from construction by 2030, and become the greenest city in the world by achieving the goal of zero embodied carbon by 2050 (Climate Emergency Action Plan, 2020) (Teshnizi, 2019)

Analysis of Embodied Carbon Reduction Strategies in Vancouver

Vancouver's approach to address embodied carbon consists of four different actions, and each actions uses different policies and strategies to reduce embodied carbon. These four actions contains changing the rules, changing the market, changing the culture, and changing the context.

Changing the Rules: Policy and Regulation:

This section highlights rules and requirements to apply to private and public developments, and to reduce the carbon pollution from materials, construction practice and design. This action includes:

- Establish standardized 2018 baseline to measure reductions for developments and the city
- Require rezoning reduction targets through updates to the Green Buildings Policy for Rezonings
- Require Building By-law reduction targets and low-carbon code requirements, following the steps in the Green Buildings Policy for Rezonings.

- Target deep reduction in embodied emissions for City-owned buildings and infrastructure, as part of the City's Green Operations Plan.

Changing the Market: Remove Barriers and Provide Incentives

This section tries to remove barriers for implementation of embodied carbon reduction and create incentives to support developers in this fields. This action includes:

- Remove barriers in planning and building by-laws, policies, guidelines, and bulletins to low-carbon construction.
- Incentivize deep embodied carbon reductions in building design and construction.

Changing the Culture: Capacity Building and Industry Transformation

The section of changing culture pays attention to sharing knowledge and also supporting education and trainings to address embodied carbon reduction strategies and policies. In summary, this action consists of:

- Coordinate, support, advocate, and share knowledge with external organizations and other governments
- Support databases, tools, practice guides, training, and knowledge-sharing networks

Changing the Context: Complimentary Strategies and Actions

This section includes complimentary rules to help planners, architects, and other professionals toward implementation of embodied carbon reduction strategies, and it consists of strategies such as green operations, parking plan, green economy, zero waste, etc. (Climate Emergency Action Plan, 2020).

YEAR	ACTION
2020	• Embodied Carbon Strategy approved by City Council.
2021	• City staff begin work to update policies and regulations, provide incentives, build industry capacity, and integrate embodied carbon efforts with other City strategies.
2021	• Introduce our first reduction target(s) in updated rezoning policy, to begin reducing embodied emissions in new construction.
2021/22	• Rezoning updates come into effect for new rezoning applications.
2022–2025	• City staff seek approvals of various actions to support transition to low embodied carbon construction and begin implementation of approved changes.
2023	• Possible first changes to the Building By-law to include embodied carbon come into effect, such as material-specific requirements or changes for single-detached homes.
2025	• Review and update of Embodied Carbon Strategy for Council. • Adopt the targets and other requirements from the 2021/22 rezoning policy, and possibly those from incentive programs, into the code. • Increase reduction targets in the rezoning policy to be consistent with the 40% reduction target set by Council.
2025/26	• Updated embodied carbon reduction requirements come into effect for new rezoning applications and building permit applications.
2026–2030	• City staff seek approvals of further actions to support transition to low embodied carbon construction, and begin implementation of approved changes
2030	• Adopt the targets and other requirements from the 2025/26 rezoning policy into the code, consistent with the 40% reduction target set by Council. • Introduce new targets in the rezoning policy that go beyond 40%, taking a step toward net zero carbon construction.

Vancouver’s Road Map for Embodied Carbon (Climate Emergency Action Plan, 2020)

Comparison of Vancouver's and Copenhagen’s Embodied Carbon Strategies

While both Vancouver and Copenhagen share a commitment to sustainability and reducing embodied carbon, there are differences in their approaches. Vancouver's focus on green building policies and regulations, along with the use of LCA, demonstrates a strong emphasis on encouraging sustainable practices in the construction sector. Copenhagen, on the other hand, places significant importance on collaborative efforts and innovation. Comparing these approaches can offer valuable insights for other cities like City of Charlottetown to establish various strategies to address embodied carbon.

Conclusion and Recommendations

As the purpose of this paper is to establish strategies for the city of Charlottetown in terms of embodied carbon reduction, in this paper, after exploring the concepts of embodied carbon, its measurement methods, literature review, and international efforts to address embodied carbon, two case studies of Vancouver and Copenhagen were investigated to consider their strategies about embodied carbon. Both cities have demonstrated a strong commitment to sustainability, implementing policies, regulations, and innovative strategies to reduce embodied carbon emissions and promote low-carbon practices, and their strategies can provide with the valuable insights for the city of Charlottetown. Charlottetown, as a city aspiring to foster sustainable development, can draw upon the experiences of Vancouver and Copenhagen to inform its own approach. By understanding the concept of embodied carbon and its significance in the context of climate change and sustainable development, Charlottetown can take proactive measures to minimize the environmental impact of its built environment.

The recommendations and strategies for the City of Charlottetown in this paper are based on the successful practices observed in Vancouver and Copenhagen. By following these strategies, the City of Charlottetown can pave the way for a more sustainable future, and the actions taken today will have a lasting impact on the city's carbon footprint. Charlottetown can serve as a model for other cities, demonstrating that sustainable development can go hand in hand.

Key Recommended Embodied Carbon Reduction Strategies for the City of Charlottetown

1. *Set Ambitious Embodied Carbon Goals*: Like Vancouver and Copenhagen, the City of Charlottetown should establish clear and ambitious Embodied Carbon goals. These goals should include targets for reducing embodied carbon emissions, promoting sustainable construction practices, and achieving energy efficiency in the built environment.
   Based on Charlottetown Community Energy Plan, the Charlottetown's targets for operational carbon is to reduce GHGs in operations to 40% by 2030, and strive to be 100% carbon neutral by 2050. So, these targets can be considered for the embodied carbon target of City of Charlottetown as achieving to 100% carbon neutral is not possible without embodied carbon reduction strategies and goals (The Community Energy Plan for A Naturally Bright Future, 2018).
2. *Develop and Implement Green Building Policies*: Charlottetown can learn from Vancouver's and Copenhagen's green building policies and regulations. The city should consider implementing policies that encourage the use of low-carbon materials and energy-efficient designs in construction projects. These policies can include incentives for developers and builders to adopt sustainable practices and certifications that prioritize energy efficiency and embodied carbon reduction.
3. *Incorporate Life Cycle Assessment (LCA) in Decision-making*: Following Vancouver's example, Charlottetown can integrate LCA into decision-making processes for construction projects. LCA provides a comprehensive assessment of the environmental impacts associated with building materials and processes. By considering the entire life cycle, from production to disposal, LCA can inform choices that minimize embodied carbon and promote sustainable materials selection.
4. *Improve Collaboration and Knowledge-sharing*: Copenhagen's collaborative approach to sustainability can be applied in Charlottetown. The city should encourage collaboration among stakeholders, including government agencies, industry professionals, research institutions, and sustainability organizations. This collaboration can facilitate the exchange of best practices, research findings, and innovative ideas, accelerating the adoption of low-carbon construction practices and driving sustainable development.
5. *Support Innovation in Construction Methods*: Following Copenhagen's lead, Charlottetown can encourage innovation in construction methods. This can include exploring alternative materials, such as timber-based construction, which have lower embodied carbon compared to traditional materials. The city can incentivize the adoption of innovative and sustainable construction techniques, promoting the use of renewable resources and reducing the environmental impact of the built environment.
6. *Engage the Community*: Both Vancouver and Copenhagen prioritize community engagement in their sustainability efforts. Charlottetown should actively involve its

residents, businesses, and community organizations in sustainability initiatives. This can be done through public consultations, awareness campaigns, and educational programs that promote sustainable practices, energy conservation, and the benefits of reducing embodied carbon. Engaging the community can foster a collective commitment to sustainability.

Based on the Community Sustainability Plan of City of Charlottetown in 2010 and its review in 2017, leadership, collaboration to share knowledge, innovation, and action are some strategies to support sustainability plan of this city. So, this approach can be applied in embodied carbon strategies as well (Integrated Community Sustainability Plan, 2017)

7. *Monitor and Evaluate Progress*: Charlottetown should establish a monitoring and evaluation system to track progress in reducing embodied carbon and achieving sustainability goals. This can involve regularly measuring and reporting carbon emissions, tracking the adoption of sustainable practices in construction projects, and assessing the overall environmental performance of the built environment.
8. *Research and Development Funding*: The city should support research, studies, and development strategies by financial subsidies and funding to institutions, universities, and industry partners. Encouraging research and innovation can help to display the adoption of new methods and strategies related to embodied carbon by the city.

By implementing these strategies, the City of Charlottetown can make significant steps in reducing embodied carbon and promoting sustainable development. Drawing insights from the case studies of Vancouver and Copenhagen, Charlottetown can create a roadmap towards a low-carbon and environmentally responsible built environment, contributing to the global effort to mitigate climate change and ensure a sustainable future.

References:

Akbarnezhad, A. & Xiao, J. (2017). Estimation and Minimization of Embodied Carbon of Buildings: A Review. *Buildings*.

Asdrubali, F., Grazieschi, G., Roncone, M., Thiebat, F., and Carbonaro, C. (2023). Sustainability of Building Materials: Embodied Energy and Embodied Carbon of Masonry. *Energies*.

Bohringer, Ch., Carbone, J., Rutherford, Th. (2011). Embodied Carbon Tariffa. *NBER Working Paper Series*.

(2023). *Climate Action Plan, Phase 1: Discovery* . City of Charlottetown.

(2020). *Climate Emergency Action Plan.* City of Vancouver.

(2012). *Climate Plan, A Green, Smart, and Carbon Neutral City.* City of Copenhagen.

Dams, T., Kjaer, T., Christensen, Th. . (2017). Implementaion of Local Climate Action Plans: Copenhagen - Towards a Carbon-neutral Capital. *Journal of Cleaner Production*.

Doren, D., Driessen, P., Giezen, M. (2020). Learning within local government to promote the scaling-up of low-carbon initiatives: A case study in the City of Copenhagen. *Energy Policy*.

(2021). *Embodied Carbon: A Primer for Buildkings in Canada.* Vancouver: Canada Green Buiding Council.

Floater, G., et al. . (2014). *Copengagen, Green Economy Leader Report.* London: LSECities.

Hakkinen, T., Kuittinen, M., Ruuska, A., and Jung, N. (2015). Reducing Embodied Carbon During The Design Process of Buildings. *Journal of Building Engineering* .

Hammond, G. & Jones, C. (2011). *Embodied Carbon, The Inventory of Carbon and Energy (ICE).* BSRIA.

Huang, B., Xing, K. & Pullen, S. . (2017). Carbon Assessment for Urbna Precincts: Integrated Model and Case Studies. *Energy and Buildings*, 111-125.

(2017). *Integrated Community Sustainability Plan.* City of Charlottetown.

IPCC. (n.d.). Retrieved from https://www.ipcc.ch/reports/

Laski, J., Burrows, V. (2017). *From Thousands to Billions, Coordinated Action Towards 100% Net Zero Carbon Buildings By 2050.* London, Toronto: World Green Building Council.

Magwood, C. (2019). Opportunities for Carbon Dioxide Removal and Storage in Building Materials. *Trent University* .

Mohareb, E., Kennedy, C. . (2012). Gross Direct and Embodied Carbon Sinks for urban inventories. *Journal of Industrial Ecology*.

Neuhoff, K. (2011). *Climate Policy after Copengagen, The Role of Carbon Pricing.* United States of America : Cambridge University Press.

Peters, G. (2010). Carbon Footprints and Embodied Carbon at Multiple Scales. *Environmental Sustainability*.

Pomponi, F., Wolf, C., Moncaster, A. (2018). *Embodied Carbon in Buildings: Measurement, Management, and Mitigation.* Springer Cham.

Rydlewski, J., et al. . (2022). Identification of Embodied Environmental Attributes of Construction in Metropolitan and Growth Region of Melbourne, Australia to Support Urban Planning. *Sustainability*.

Teshnizi, Z. (2019). *Policy Research on Reducing the Embodied Emission of New Buildings in Vancouver.* Zera Solutions.

(2018). *The Community Energy Plan for A Naturally Bright Future.* City of Charlottetown.

UNFCCC. (n.d.). *Race to Zero*. Retrieved from https://climatechampions.unfccc.int/system/builtenvironment/

Wolf, C., Pomponi, F., Moncaster, A. (2017). Measuring Embodied Carbon Dioxide Equivalent of Buildings: A review and Critique of Current Industry Practice. *Energy and Building* .

WorldGBC. (2019). *Bringing Embodied Carbon upfront.* London, Toronto: WorldGBC.

Xing, K., Wiedmann, T., Newton, P., Huang, B. & Pullen, S. . (2019). *Decarbonising the Built Environment, Development of Low-Carbon Urban Forms- Comcepts, Tools, and Scenario Analysis.* Palgrave Macmillan.

Yokoyama, K., et al. (2017). International Energy Agency Evaluation of Embodied Energy and CO2eq for Building Construction. *Building Environment and Energy Conservation*.