Barriers for Integrating Zero Carbon into the Design Studio in the USA

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The authors co-teach a design studio in which building performance is highlighted as a primary educational objective. For years, we helped students to use evidence-based feedback to improve the structural, energy, and cost performance of their designs. The design-assisting tools used by the students include verified computer programs for structural design, energy simulation, and cost estimating. Most recently, in response to climate change, we examined introducing carbon analysis as an additional design-assisting tool in order to expand the definition of building performance to include the environmental impact of embodied carbon. Initial results were revealing. Findings showed that while energy performance evaluation is often (in both academia and professional practice) limited to the evaluation of operational energy, embodied energy is likely to be the determining factor in the near future. As buildings become more energy efficient and/or increasingly reliant on renewable energy sources, the higher the contribution of its embodied energy is to its overall energy consumption. When buildings reach zero energy in operation, 100% of energy consumption will be due to embodied energy. Furthermore, consideration of a building's embodied energy is the architects' most controllable factor. Therefore, educators must stress to students the importance of embodied energy even though educators may face a number of challenges that may hinder their ability to fully integrate carbon analysis into the design studio.

1 INTRODUCTION

The authors of this paper co-teach their school's comprehensive design studio in which building performance is highlighted as a primary educational goal. In this studio, every student works on one project for the entire 15-week semester, which allows them to address technical issues while taking the project up to the construction documents phase. Besides the typical educational goals that address the functional, aesthetic, social, and contextual aspects of design, students are also required to seek evidence-based feedback to improve the performance of their design, i.e., the structural, energy, and financial performance of their design. The design-assisting tools used by the students to assess performance include verified computer programs for structural design, energy simulation, and cost estimating. Students' experience in the studio emulates what they would do when they enter professional practice after graduation. For almost two decades, the studio has maintained a track record of success, which was once rewarded by the NCARB Grand Prize back in 2004 for the 'creative integration of practice and education in the academy'. Intentionally, the studio is being continuously developed to both mirror and anticipate concurrent discourse in professional practice which now includes accounting for building's carbon contribution.

2 CLIMATE ACTION

In response to climate change, the same team of faculty most recently examined introducing carbon footprint as an extra measure of performance that addresses the combined environmental impact of both operational and embodied energy. For carbon analysis, students used Athena, the Impact Estimator for Buildings as a design-assisting tool to quantify carbon footprint of the building. Initial results were revealing. Findings showed that while energy performance evaluation (in both academia and professional practice) is typically limited to the evaluation of operational energy, embodied energy will likely be the determining factor in the near future. The more energy efficient buildings become increasingly reliant on renewable energy sources, the higher the contribution of their embodied energy is to their overall carbon footprint. When buildings reach zero energy in operation, 100% of their carbon footprint will be due to embodied energy. Furthermore, in terms of some design decisions such as selection of systems and materials, consideration of the building's embodied energy is the architects' most controllable factor. Therefore, educators must stress to architecture and architecture engineering students the importance of embodied energy to carbon performance even though educators may face a number of barriers that may hinder their ability to fully integrate carbon analysis into the design studio. This paper strives to define what can reasonably be done in order to meaningfully integrate carbon analysis into design in response to the pressing need for climate action.

3 METHODOLOGY

In quest of defining meaningful integration of carbon analysis into studio, the authors here pursue a comparative analysis of the available knowledge base and analytical tools for the quantification of operational energy and embodied energy. Currently, quantification of operational energy is well-defined, of acceptable accuracy, and possible with the use of user-friendly tools; and students are facile with the use of energy simulation programs to compare between design alternatives and to compare the performance of their buildings to a meaningful baseline and/or benchmark. In the next section (section 4), the authors provide an introduction to and an overview of how operational energy is currently addressed in the studio. Subsequent sections will take a critical look at the prospect of addressing embodied energy as well.

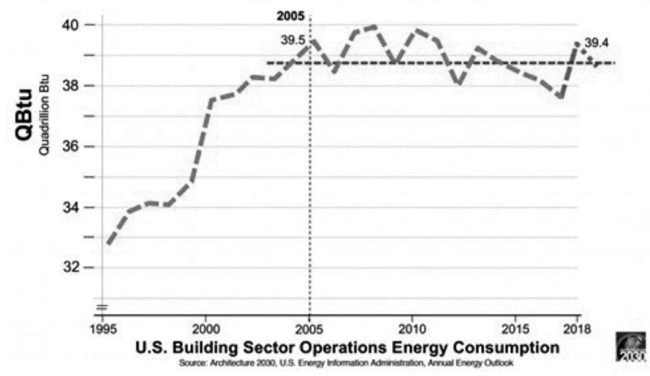

Figure 1. No increase in operational energy consumption since 2005 despite ongoing construction of new buildings. Source: Architecture 2030, accessed January 2020.

4 OPERATIONAL ENERGY IN PROFESSIONAL PRACTICE & ACADEMIA

Currently, awareness of the benefits of energy efficiency is at its highest level in the profession in the USA. This state of awareness culminates several decades of progress in the right direction. According to the data published by the US Energy Information Administration, due to the improved efficiency in the building sector, no increase in the operational energy has occurred since 2005 despite the ongoing construction of new buildings (Figure 1). The following two sections (4.1 and 4.2) highlight the progress made and the currently available resources that can be used in academia to educate future designers on the subject.

4.1 PROGRESS OVER TIME, THE LAST 60 YEARS

Although the issue was raised in the USA back in the 1960s by books such as Design with Climate by Olgyay (1963) and Man, Climate & Architecture by Givoni (1969), Energy-Conscious Design caught the attention of architects and engineers in the early 1970s. Soon after, several pioneering architects published heavily on the subject in books such as Solar Energy and Building by Szokolay (1975) and The Passive Solar Energy Book by Mazria (1979). Fast-forward, now an increasing number of design firms use verified energy simulation programs in-house to predict the energy use index (EUI) of their buildings, (AIA 2017). Besides its several publications to promote energy efficiency, most recently, the American Institute of Architects published the Architect's Guide to Building Performance (AIA 2019), which is an evidence of the growing commitment of the profession to designing high-performance buildings. The guide provides architects with the knowledge and resources they need to perform energy modeling in order to be able to assess energy performance. Besides its several standards that address human thermal comfort and energy efficiency, in 2018, the American Society of Heating, Refrigerating, and Air Conditioning Engineers published ASHRAE Standard 209-2018 titled Energy Simulation Aided Design for Buildings except Low-Rise Residential Buildings (ASHRAE 2018). As for benchmarking, the US Environmental Protection Agency provides free online access to its Target Finder Calculator, which helps architects to set their performance goals (EPA 2019). Architecture 2030 provides an alternate calculator for benchmarking (Architecture 2030, 2019a). The following section provides clarification of how the currently available resources are utilized to educate students on high performance in terms of reducing operational energy.

4.2 CURRENTLY AVAILABLE RESOURCES

As stated earlier, every student in the studio is required to use evidence-based feedback to improve the energy performance of his/her design. This requirement is highly technical and tests the students' ability to apply the knowledge they previously acquired in the prerequisite technical courses. To inform the later comparison to resources available for embodied energy analysis, the points below expand on how the students utilize the currently available resources to assure the accuracy and validity of their analysis, and their prediction and assessment of the building's energy use index (EUI).

- Enforced energy code: Students refer to the most current International Energy Conservation Code (IECC) which mandates specific energy efficiency requirements in terms of envelope design, i.e., maximum glass ratio, minimum R value or maximum U factor for opaque envelope components, maximum U factor and SHGC for fenestration, and a minimum glass VT. Note: R is thermal resistance, U is thermal transmittance, SHGC is the glass solar heat gain coefficient, and VT is the glass visible transmittance. For more information, refer to Chapter 4 in IECC (ICC 2016).

- ASHRAE standards: For human thermal comfort, students refer to ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy (ANSI Approved), and for fresh air requirements, students refer to ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality (ANSI Approved).

- Material specifications: For thermal properties of building materials, students refer to ASHRAE Handbook of Fundamentals; and for performance data of glass, they refer to the manufacturer data as verified by the National Fenestration Rating Council (NFRC).

- Weather files: Students obtain the weather files of the location of their project free of charge from the US Department of Energy portal for Energy Plus, DOE (2019a).

- Energy simulation computer programs: students currently use the latest version of eQuest, which is among the programs verified by the US Department of Energy (DOE). For the complete list of verified programs, refer to DOE (2019b).

- Benchmarking: Students are advised to compare their predicted EUI to a reference building that complies with the latest energy code and is located within the same climate zone. For this, students use the Zero Code Energy Calculator available online on the 2030 website, Architecture 2030 (2019a). Currently, this calculator generates performance results for a building in compliance with ASHRAE Standard 90.1-2016, which is the basis for IECC 2018 (most current). Students are, however, advised not to compare their predicted EUI to the median generated by Target Finder (Energy Star score of 50) since it retrieves its data from the CBECS database, which represents a mix of old and new existing buildings and not only new code-compliant buildings. CBECS is the Commercial Buildings Energy Consumption Survey conducted by the US Energy Information Administration (EIA). CBECS data collection only happens when funds are made available by the US government and not on a regular basis. 2018 CBECS is expected to be published in the summer of 2020. Most recent survey is 2012 CBECS which was the first in nine years (EIA 2019).

In conclusion, in their evaluation of operational energy, students use verified tools to process well-defined and accurate data and compare predicted EUI to a baseline building in compliance with the most recent energy code, which results in high educational value added to the design studio. Students are able to assess the performance of their successive design iterations and gain valuable skill and experience.

5 EMBODIED ENERGY, THE CHALLENGE

In 2019, in the authors' exploration into introducing carbon footprint (operational and embodied) as an additional performance measure in studio, it became evident that embodied energy, and not the operational energy, will likely be the determining factor in the near future. In contrast to the steady progress of the USA towards decarbonization of electricity generation, and progress within the profession towards both reducing operational energy and reaching Carbon Neutrality (operational carbon only) by 2030, embodied carbon is less likely to experience significant reduction in the near future. Even according to 2030 Challenge, the target year to achieve zero embodied carbon is 2050, with only 50% targeted by 2030 (Architecture 2030, 2019b). Given that fewer than 2% of architecture firms in the USA signed the 2030 Commitment (AIA 2017), it is both essential and timely to start training future architects and engineers on how to reduce embodied carbon. However, it is clear that at this point we are faced with many questions that need to be answered. These questions are summarized as follows:

- Which database should be used to quantify embodied carbon in building materials? And how accurate and comprehensive is it?

- How should the transportation portion of embodied carbon be quantified? Transportation of building materials is taken into consideration, but transportation of building occupants, possibly an even greater source of carbon, is not. Should we consider it? How can we quantify occupants' transportation carbon?

- Should we include embodied carbon due to the construction activities and site preparation? And how? Should we include transportation carbon of construction workers?

- Fair assessment of operational carbon should be based on source energy EUI and not site energy. Should we evaluate source energy based on the US national average carbon content or the fuel mix in every individual electrical grid?

- Besides quantification of CO_2 emissions, should we consider emissions of other greenhouse gases, such as CH_4, N_2O, SO_2 and NO_x? Should we consider the impact of greenhouse gases on the Ozone layer depletion?

- In order to define the boundaries of the problem, which factors should be considered internal and which can be treated as externalities? Refer to Figure 2 for the of life cycle stages involving energy and carbon of buildings (Dixit et al. 2012). In the figure, arrows represent transportation.

In order to begin to address these questions, we will draw parallel to the current consideration of operational energy in studio. We will also briefly look at how embodied energy has been addressed in the profession so far (section 5.1), and discuss the barriers to its integration into the design process (section 5.2).

5.1 RECENT HISTORY, THE LAST TWO DECADES

It can be claimed that the subject first gained attention of the profession with the publication of the book titled Remaking the Way We Make Things, Cradle to Cradle by McDonough and Braungart (2002). After several years of modest progress, recent years saw compelling calls for a holistic approach in addressing climate change, and not only operational carbon, in both the profession and academia, since civilization as we know it depends greatly upon the profession's response to climate change (Cramer 2019). Most recently, in June 2019, AIA approved the AIA Resolution for Urgent and Sustained Climate Action, in which it adopted three actions:

- Declare an urgent climate imperative for carbon reduction.
- Transform the day-to-day practice of architects to achieve a zero-carbon, equitable, resilient and healthy built environment.
- Leverage support of our peers, clients, policy makers, and the public at large.

In order to realize the newly-adopted AIA resolution, acceleration of the decarbonization of buildings require adopting and/or developing relevant knowledge, methods, and tools, such as: defining reasonable and meaningful boundaries of the problem, developing methods to calculate construction embodied carbon, developing a robust database of embodied carbon in building materials (manufacturing and transportation), accurate evaluation of source energy according to fuel mix specific to the location, etc. Compared to the sufficient resources available for the evaluation of operational carbon, the lack of complete information, methods, and design-assisting tools to evaluate embodied carbon is a barrier to meaningfully integrate holistic carbon analysis into the design studio. Section 5.2 will breakdown the problem to specific barriers and discuss these barriers one by one.

5.2 BARRIERS TO THE EVALUATION OF EMBODIED CARBON

In comparison to the systematic overview of how operational energy is currently addressed in the studio (section 4.2), this section comments on the availability or the lack of necessary resources for the consideration of embodied energy in the design studio.

a. Undefined boundaries: Boundaries of the analysis that should be integrated into the design process have not been defined yet. Current research tends to define the

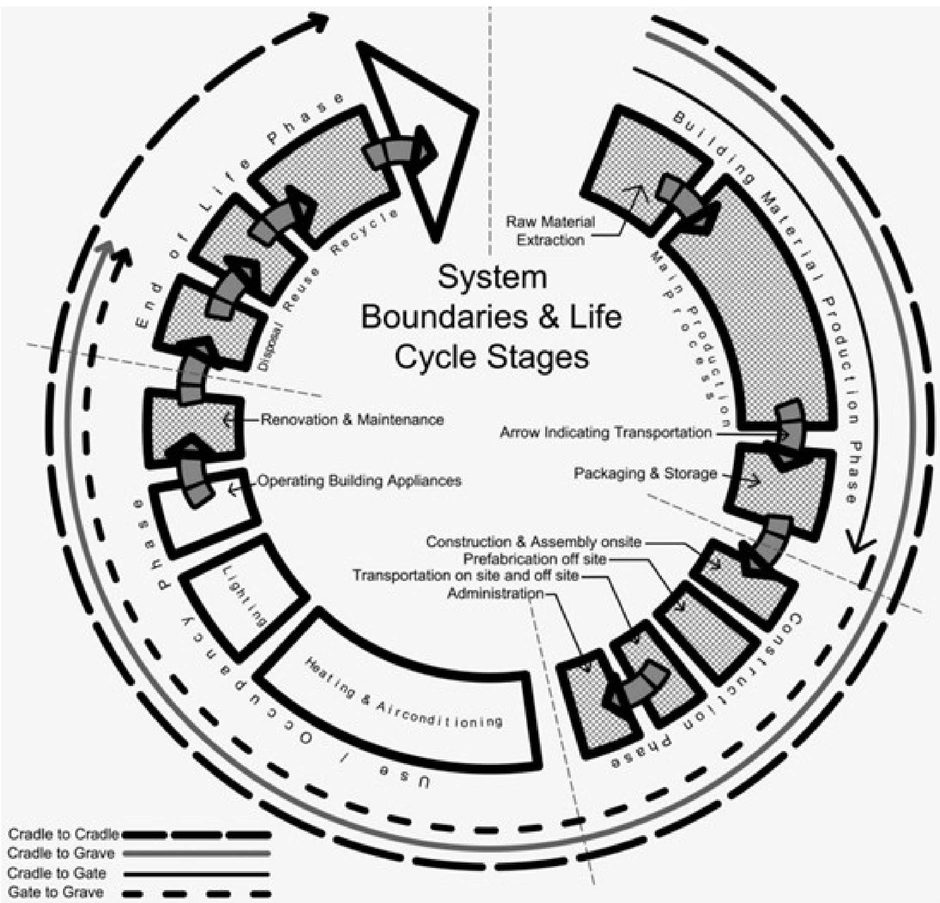

Figure 2. Life cycle stages involving energy and carbon of buildings. Source: Dixit et al. 2012

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boundaries of carbon analysis as an integral part of life cycle analysis as a whole, involving all of cradle-to-cradle stages (Figure 2). However, significant portions of these stages are out of the control of architects and architectural engineers. Further research is needed to define a logical stopping point to the rippling effect of building design on carbon generation. It would be even better if research can break down the effects per design phase, i.e., schematic design, design development, and construction documents.

b. Lack of codes and standards: Arguably, because awareness of embodied carbon matured almost four decades later than operational energy, it is yet to form a well-structured network of societal backing. Embodied carbon can understandably be considered outside of the scope of ASHRAE. No other big effective professional organization is taking the lead on the issue. ICC (International Code Council) seems to overlook the issue, and no other consensus-based regulators look at the issue.

c. Lack of incentive programs: The US Environmental Protection Agency does not run a voluntary incentive program similar to Energy Star that may encourage the public and the profession to take action.

d. Limited data: Embodied energy data is very scarce compared to data available to calculate operational energy. Not all manufacturers provide data on the carbon footprint of their products (building materials and equipment). Construction companies do not keep track of energy consumed during construction or site preparation. However, it is worth-mentioning here that the AIA encourages architects to use more of the materials with Environmental Product Declaration (EPD), which gives points to their projects submitted to the AIA's COTE annual Top Ten competition (AIA, 2018).

e. Benchmarking not possible: The US Department of Energy does not include embodied energy in its surveys of the existing building stock, which results in no extensive data being available for benchmarking. However, it is worth-mentioning here that the AIA encourages architects to compare the global warming potential, measured in pounds of CO2 equivalent per square foot (lbs CO2e/sf) of their buildings to a range of low to high derived from the database developed by the MIT Building Technology Program, using the online tool deQo (database of embodied Quantity outputs) (MIT, 2017). This tool provides benchmarking per country (and not state), building type, construction type, LEED rating, gross built area, etc., but sampling cannot be narrowed by more than two filters, which may produce results not narrow enough for a specific building type in a specific state in the USA. The tool was developed by then a doctoral student who is now in Europe working for the Ecole Polytechnique Federale de Lausanne.

f. Analysis tools: Only very few analysis tools are available to estimate carbon footprint of buildings. There is no evidence that these tools are verified by the government or a third party. No information on whether the US government is providing funding for a certain calculator of embodied energy or not. Historically, significant improvement of energy simulation programs (operational energy) was the result of government funding for the Doe2 simulation engine and then Energy Plus.

In conclusion: several barriers exist that hinder the ability of educators to fully integrate embodied energy into the design studio. However, urgency of climate action dictates a start in the right direction. Section 6.1 is a discussion of how to define boundaries of carbon analysis that is appropriate for architecture education at this point. Section 6.2 presents our recommendations on how to introduce embodied carbon to students and what can reasonably be expected of them.

6 RECOMMENDATIONS

6.1 SETTING THE PROBLEM BOUNDARIES

Arguably, as a starting point and in order to create a well-defined problem, all externalities and undetermined factors should be excluded from the analysis. Based on such assumption, the following points determine boundaries of the problem.

- Cradle to gate embodied energy (refer to Figure 2) should be included since, at least, some manufacturers provide the Environmental Product Declaration (EPD) of their products, and this makes embodied carbon quantifiable by tools such as Athena, the Impact Estimator for Buildings. In the future, codes and/or standards may be enforced by the government or encouraged by incentive programs calling all manufacturers to provide EPD of their products.

- Although important, construction embodied energy/carbon should be excluded until keeping record of energy, water, and material consumption becomes a common practice in the construction industry. Future research should target this hindering gap of information in order to define best practices and probably to suggest enforceable codes and/or standards.

- Analysis is to include operational energy during the occupancy phase of the building, excluding the undetermined future renovation and maintenance. Unless related to site selection, employees' transportation should be excluded since it is out of the control of architects and does not affect any design decisions during any of the design phases.

- End of life phase should be included since it is quantifiable by tools such as Athena, the Impact Estimator for Buildings. However, future research is needed to quantify the impact of design in terms of using reusable and/or recyclable building materials and/or assemblies. Limitations may exist in case of lack of information. Calculation of embodied energy associated with the end of life phase will stay of high level of uncertainty mainly because it is based on assumptions that may or may not prove to be true in the future.

6.2 SIMPLIFIED CARBON ANALYSIS IS POSSIBLE

In academia and professional practice, the ultimate target is to move towards zero carbon, both operational and embodied. However, in conclusion of the literature review and the survey of currently-available knowledge and tools, it becomes clear that due to the current lack of some necessary resources, it is impossible to address all cradle-to-cradle phases of buildings in the design studio. On the other hand, it is essential and still possible to integrate carbon footprint of both operational and embodied energy into the design process as a holistic measure of environmental impact during the design development phase since this is when design becomes detailed enough to accurately calculate operational energy and when materials are selected, which enables the calculations of embodied energy. Despite the current limitations, a simplified analysis is sufficient to generate meaningful results that help students make informed design decisions in order to reduce the carbon footprint of their buildings. Students should, however, be informed of factors affecting all cradle-to-cradle phases and accept the fact that certain aspects, such as in the construction phase, are out of reach at this point.

Through exposure in a comprehensive design studio, architecture and architectural engineering students will be able to more fully understand the process of integrating carbon footprint and embodied energy considerations into the design decision process. This is an important aspect of design to which they will be exposed and expected to consider upon graduation and entrance into their profession. Further, as this topic continues to evolve and grow in importance in the near future, it is up to higher education to introduce and educate students on the issues involved in the process of integrating zero carbon design criteria into their designs. By including carbon footprint and embodied energy considerations in the design studio, students will be better prepared to take on the challenge of designing for zero carbon buildings.

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