Integrating Embodied Carbon Knowledge for Design Decisions

Preprint

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National Renewable Energy Laboratory

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Integrating Embodied Carbon Knowledge for Design Decisions

ABSTRACT

Measuring energy consumption of buildings is well established, and techniques to evaluate the carbon associated with operating buildings are improving. Embodied carbon of buildings is more complex as it considers the release of carbon throughout the building material supply chain and building material end of life fate. Decisions made early during the design and construction of the building can influence and potentially reduce the embodied carbon of buildings. The design and construction communities are uniquely positioned to make decisions that reduce embodied carbon. The objective of this project is to understand barriers to low carbon design and delivery and to point the design and construction communities to useful resources that will result in decisions that reduce embodied carbon. The outcomes of this work include educational resources that familiarize designers and contractors with embodied carbon and life cycle assessments (LCA), case studies that focus on design changes from LCA results, an overview of LCA tools, and examples of readily available, cost-effective design and construction steps to lower embodied carbon. We present an evaluation of existing resources, organized in a decision tree guidance, and identify gaps for further resource development. Through this evaluation process we investigated ways to streamline the process of identifying barriers to implementing solutions quickly.

Background

Buildings are the largest consumers of energy and one of the largest sources of greenhouse gas emissions (EIA 2021; UNEP, IEA 2021). Emissions associated with operating buildings can be reduced through the deployment of energy efficiency measures, and great strides have been made in reducing operational emissions through these measures. However, there are emissions associated with the sourcing, processing, manufacturing, transporting, assembling, maintaining, and disposing of materials. These emissions are considered embodied emissions (also expressed as equivalent embodied carbon) and can make up 11% of global CO_2 emissions (UNEP, IEA 2021). Embodied carbon is more complex to evaluate than operational carbon because it considers the release of greenhouse gases throughout the supply chain, and transparency of emissions released from sourcing, processing, and manufacturing throughout the supply chain is lacking. Data are disparate, and methodologies are inconsistent. In addition, the ability to complete a thorough analysis requires expertise that may not be available at every organization.

Embodied carbon represents the carbon footprint of building materials, and most is released at the front end of a building's life cycle, therefore indicating the opportunity for impactful embodied carbon decisions to be made at the design and initial construction phase (Carbon Leadership Forum 2020). Expeditious growth in the building sector compounds the need for considering embodied carbon in architectural, engineering, and construction decisions. Current projections expect that global building floor area will double by 2060 (UNEP, IEA 2021). Thus, there is increased interest in the industry to reduce embodied energy and carbon of the built environment.

As a result, several professional organizations have created carbon reduction goals that are inspiring their members to find ways to contribute to these reduction goals. Architecture

2030 aims to "achieve a dramatic reduction in the energy consumption and CO_2 emissions of the built environment by 2030 and a complete phase-out of fossil fuel CO_2 emissions by 2040" (Architecture 2030). Structural Engineers 2050 Commitment Program is "designed to ensure substantive embodied carbon reductions in the design and construction of structural systems by the collective structural engineering profession." SE2050 Challenge states "all structural engineers shall understand, reduce, and ultimately eliminate embodied carbon in their projects by 2050" (Structural Engineering Institute). MEP2040 Challenge states "all systems engineers shall advocate for and achieve net zero carbon in their projects: operational carbon by 2030 and embodied carbon by 2040" (Carbon Leadership Forum 2021). While there is significant interest in the design and construction communities to play a large role in the decarbonization of the building sector, practitioners are still faced with difficulties to achieve such results.

This paper documents the challenges and barriers to considering embodied carbon that were shared by numerous leading architecture, engineering, construction, and contracting organizations and outlines our efforts to produce effective guidance that provides the right information for decision making. More specifically, we consider how to communicate the value of embodied carbon for broader implementation to achieve these aggressive goals set by professional societies and demonstrate the culmination of our efforts in the deployable "Embodied Carbon Resource Navigator."

Approach

The Better Buildings Design and Construction Allies program engages architects, engineers, and contractors to dive into current market practices and identify opportunities to engage the market in adopting advanced energy-efficient building design showing clear pathways for energy savings and decarbonizing the built environment (Better Buildings 2022). To date the Design and Construction Allies (the Allies) group includes 54 participants, representing 25 organizations from the engineering, architecture, construction, and contracting sectors. To recruit members for the Allies group, the National Renewable Energy Laboratory (NREL) team meets with interested organizations to discuss the initiative and determine whether they can commit to the terms in the non-binding program agreement.

NREL and the U.S. Department of Energy (DOE) work with the Allies towards a common end goal of scaling decarbonization solutions. To achieve this end goal, the Allies first brainstormed barriers that they face in decarbonizing buildings. Allies then ranked the barriers in terms of what was most important and what could be addressed by NREL, DOE, and the Allies together. Working groups made of participants from the Allies were created to address prioritized barriers. NREL then investigated different resources to address those barriers. The working groups discussed and evaluated the resources and the format of the resource organization put forward by NREL. These feedback sessions were guided with questionnaires and open discussion. NREL synthesized and used the feedback from these working group sessions to create new iterations of resource organization. The decision tree concept was first proposed, and iterations in this working group based on the decision tree concept included a website and a clickable PDF. Once a near final iteration was agreed upon, the Allies then implemented the solution within their organizations and provided additional feedback for a final, scalable solution. This process is outlined in Figure 1.

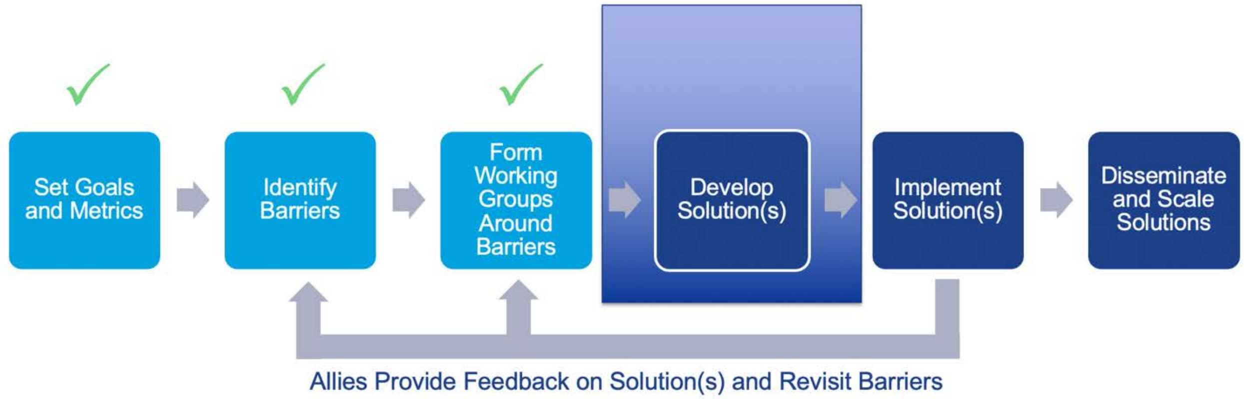

Figure 1. Schematic describing approach.

One of the barriers prioritized was a lack of understanding the complex relationship of the carbon lifecycle in building construction. In early discussions, the Allies shared two notable challenges experienced within their firms surrounding embodied carbon considerations in their projects. First, they were unanimously overwhelmed by the vast amount of available and published information on embodied carbon. This information ranges from simple definitions, terminology, and jargon, to advanced analytical approaches to assess and minimize region and project-dependent embodied emissions. The dearth of clear and consistent language and data impacts design decisions made by clients and firms that design and deliver buildings. Secondly, the Allies expressed that they do not always have the resources or staff that would be required to sort through the available information on embodied carbon for proper consideration in their projects in a timely and budget-sensitive manner. These two barriers substantiated the need for a working group to develop a "deployable literature review" that makes substantial progress to organize published information, educational resources, available tools, and examples through real-world case studies for the design and construction community to quickly leverage in their projects. This working group was tasked to dedicate this upfront effort for the benefit of the broader design and construction community.

Thus, the first goal for this working group within the Allies was to point the design and construction communities to the best available resources that will inform design and construction decisions to reduce embodied carbon. The "deployable literature review" resource would include the following elements: educational resources that familiarize designers and contractors with embodied carbon and life cycle assessments; case studies that focus on design changes from LCA findings; examples of readily available, cost-effective design/construction steps to lower embodied carbon; and an overview of LCA tools. The decision tree format and two different "deployable literature review" solutions (i.e., a website, and a clickable PDF) were prepared and evaluated by the Allies to overcome the lack of understanding of embodied carbon and how it impacts a building's carbon footprint. The final "deployable literature review" solution, the "Embodied Carbon Resource Navigator," will then be disseminated for further use outside of the Allies working group.

Methods

Educational Resources

There are many educational resources on the topic of reducing embodied carbon in the built environment. As mentioned earlier, these resources can range in detail, so we classified resources by several criteria. NREL evaluated how easy the resources are to use by noting the form of the resource, if there was a paywall associated with the resource, and how much time it may take to glean the relevant information from the resource. NREL also evaluated for whom the resource was intended, how useful the resource was, and how complex the information provided in the resource was. Resources were scored on a scale of 1 to 3 where a score of 1 meant the resource was easy to use, no paywall, meant for design audience and a score of 3 was very difficult to use, the material was not useful, and there was a paywall. Resources that had at least one category that scored well (1) were then considered to be included in the deployable literature review. Over 35 resources were evaluated, and 20 were included in the deployable literature review.

Educational Resources Organization

Given the breadth of embodied carbon resources available, the need for a hierarchical organization was a finding from the discussions with the Allies. Resources were organized in six different levels:

- resources that describe a basic introduction to carbon and why it is important for the building sector;
- resources that describe a more specific aspect of carbon impact, embodied carbon, and why it is important for the building sector (and building owners) to consider embodied carbon;
- resources that provide existing low embodied carbon alternatives to typical high embodied carbon materials;
- resources that introduce life cycle assessment as a tool to quantify and assess embodied carbon;
- resources for those who already have a basic knowledge of life cycle assessment and would like further guidance to calculate embodied carbon through this approach; and
- resources for additional guidance to become an expert in life cycle assessment.

To navigate the user to the resources at the level the user needs to begin to inform design decisions, different formats of decision tree guidance were prepared and evaluated by the Allies.

Decision Tree and Different Decision Tree Formats

NREL aimed to capture a resource format that was based on both experience and needs of the user. It can be challenging to establish the right balance of a format that is not too simple but not too complex, and still meets a large spectrum of different users. NREL also needed to determine the appropriate endpoints in such a format and the references that would be most useful. Resources needed to be organized such that users could find the information that is relevant to them at the time they are needing information. One approach to this type of organizing is asking questions of the user and having the answers guide them to the right set of educational resources. This decision tree approach was proposed with the following guiding questions:

- Is my client interested in reducing their carbon footprint?
- Is my client interested in low embodied carbon options?
- Can I provide low embodied carbon options?
- Am I satisfied with my client interactions regarding low embodied carbon?

A series of different answers guides the user to one of a set of six different resource groupings. This decision tree (Figure 2) was not meant to be the final version of the navigation tool but a way to organize the thinking behind a final type of navigator. Feedback from the working group determined that the decision tree format was useful. Two actionable examples based on the decision tree format, a website and a static clickable PDF (Figures 3 and 4), were further investigated as public-facing options of a decision tree.

We discussed these formats with the Design Allies to help us determine the effectiveness of the presentation of information. The answers to the following questions were recorded:

- Is this an effective navigator?
- Does this help convince the client of the importance of embodied carbon?
- Will this help designers make informed decisions about embodied carbon?

Allies answered these questions on a scale of 1 (no) to 5 (yes). Additional qualitative questions included "What would make the navigator more effective?" and "What is missing that a user will need?" were discussed and responses were recording. The answers to these questions guided additional iterations and helped determine if iterations were improving towards the goal of the working group.

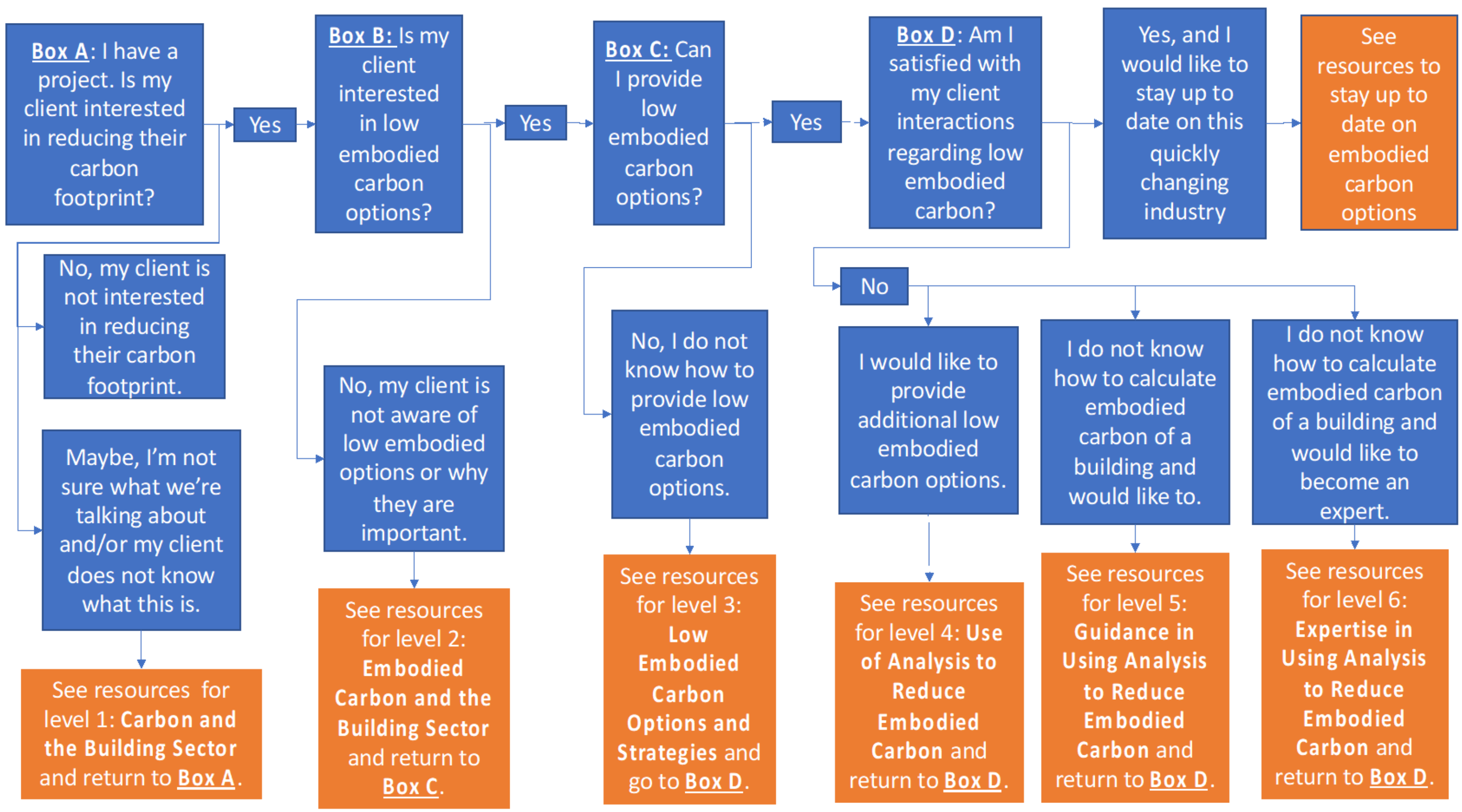

Figure 2. Example decision tree used to guide user to different resources.

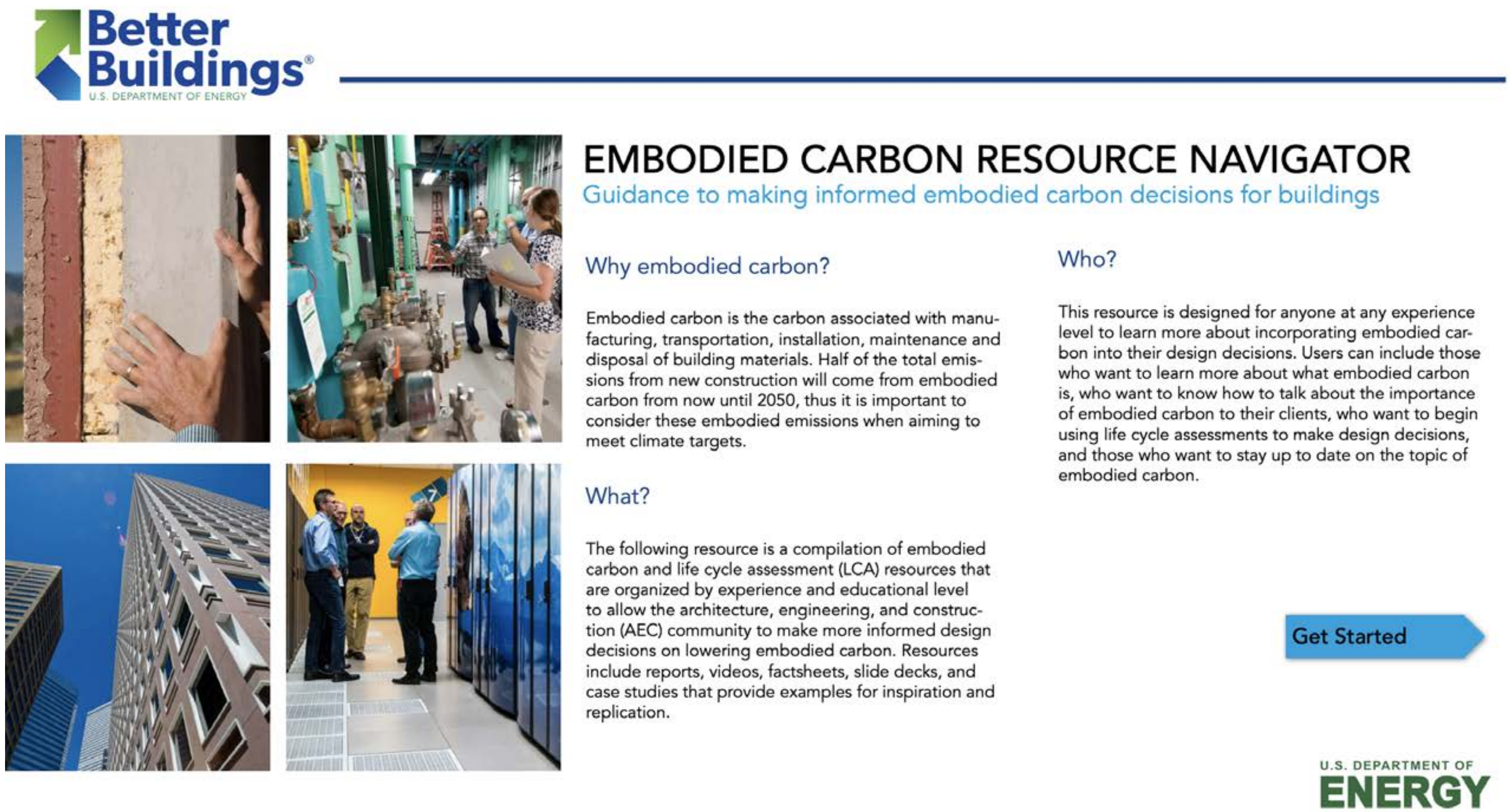

Figure 3. Cover page of proposed Embodied Carbon Resource Navigator.

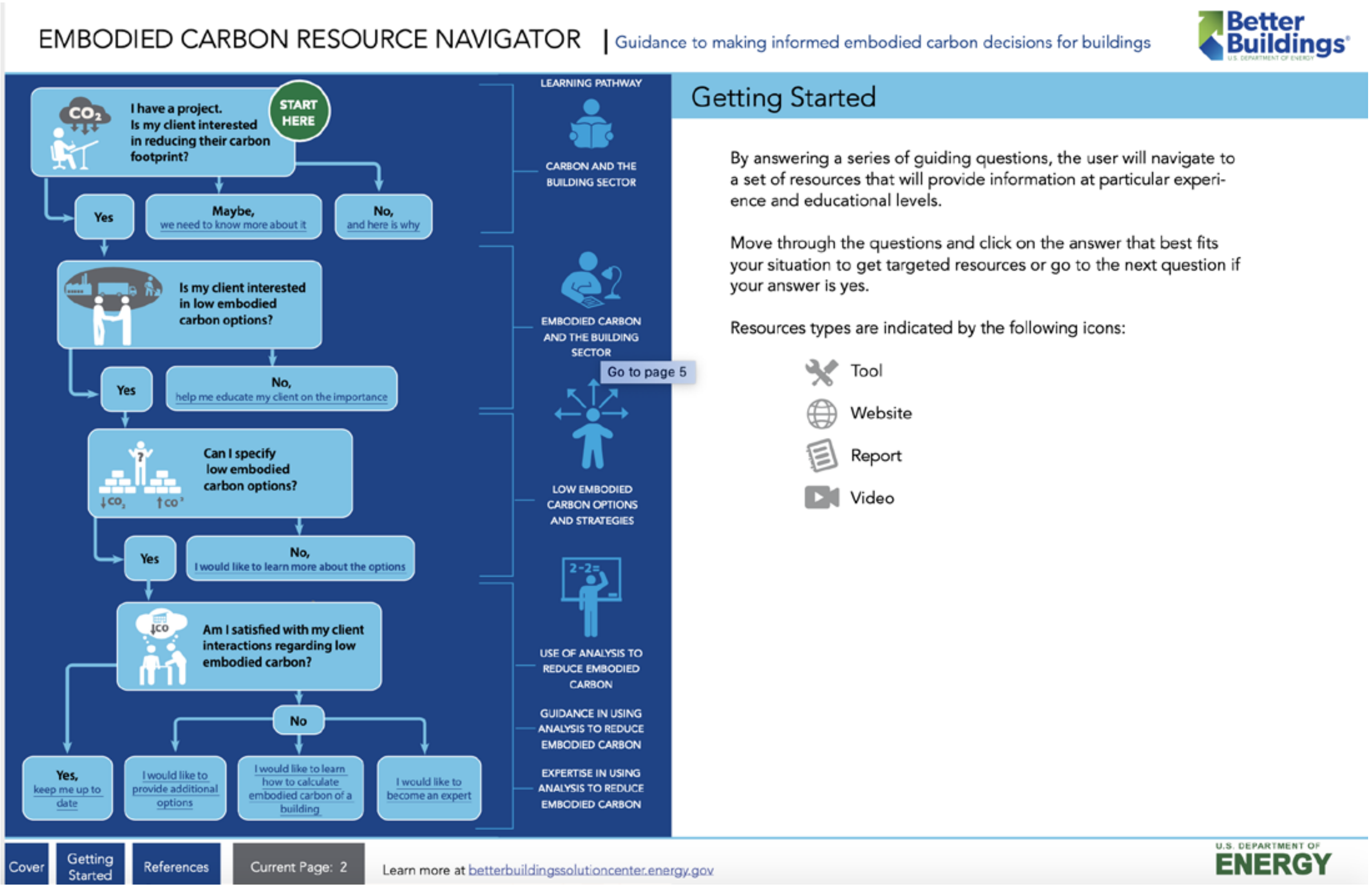

Figure 4. Decision tree directing the navigation to the resources needed.

Results

Educational Resources

Many resources scored well in terms of ease and usefulness. However, through the process of evaluation and through discussion with the Allies, we also determined the need for additional resources. Some of these necessary resources include videos, slide decks, and factsheets; actionable suggestions for the design and construction community; actionable case studies; and example specifications. It is important for these resources to not be specific to any rating system or proprietary information.

Decision tree

The decision tree format (Figure 2) was not intended to be a final version of the navigator but an organizational format for discussion. We asked the same questions of this organizational format as the navigator options for a baseline assessment.

When asked to choose an example project and navigate through the decision tree, most participants (but not all) landed at the very end of the decision tree, which was expected since the Allies who participated are generally familiar with embodied carbon and have clients who are interested in embodied carbon. While not explicitly on the decision tree, experts tend to use the right-hand side of the tree where those with less experience will tend towards the left. The objective is to move users more to the right of the decision tree as they gain experience. These participants are quite familiar with embodied carbon, and they are those who can largely drive education within the industry through their networks and professional associations (e.g. AIA). They are most familiar with the challenges in educating their peers on embodied carbon. However, we will gain additional information from testing this strategy with those who are not familiar with embodied carbon, and this test will be a next step for this work. Feedback was generally positive in that most people thought the decision tree format was an effective roadmap and that it could help designers make informed decisions about embodied carbon (Figure 5). More participants thought that the materials and layout of the information did not fully help convince the client of the importance of embodied carbon (Figure 5).

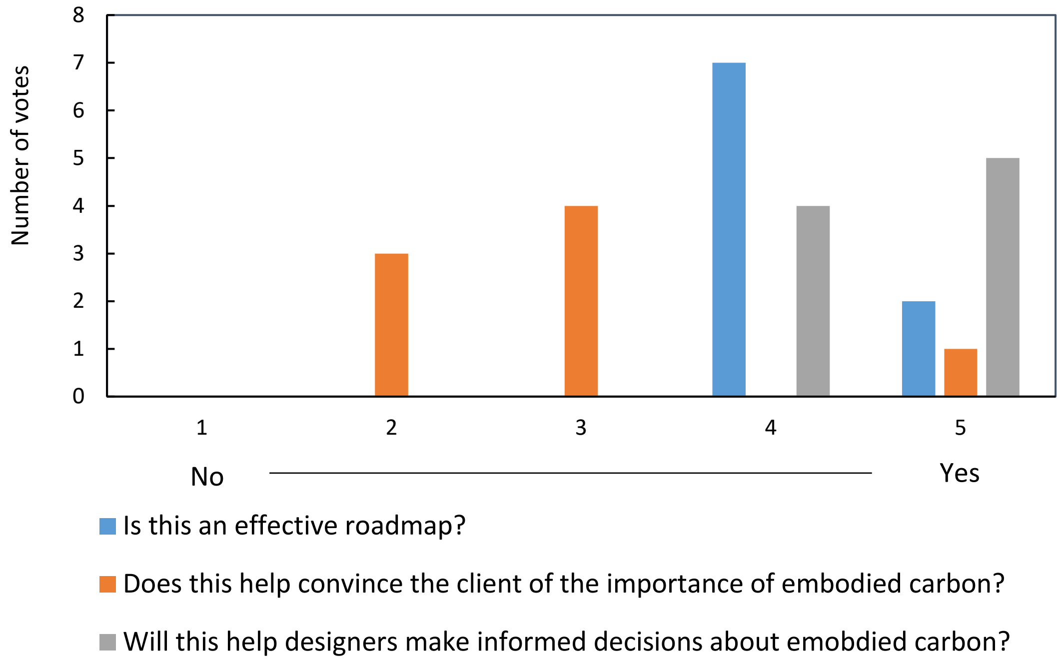

Figure 5. Results from the Allies answering questions on the usefulness of the decision tree. Total of 9 participants voted in the first question (blue); average score was 4.2. Total of 8 participants voted in the second question (orange); average score was 2.9. Total of 9 participants voted in the third question (grey); average score was 4.6.

Other qualitative feedback included the need for specific resources such as case studies or a database of other projects' data for comparison as a baseline or benchmarks, embodied carbon estimates for different building types, supply chain tools, and resources to help sub-contractors understand and identify what low-carbon options are available in their trade. Feedback for the organization included adding important information or summaries between the decision tree points and resources, making the decision tree design more amenable for people who may be less knowledgeable on the topic, adding an introduction video to explain how to use the decision tree, and suggesting a help line as a resource. Allies also mentioned that if there are a lot of resources to go through or if the resources themselves are onerous that people may not end up using the resource, indicating that short summaries of the relevant information would be useful.

Website

The guiding questions and example resources in the decision tree discussed above were formatted into a mock website to gauge interest and effectiveness. As a format that most people are familiar with, a website with links to resources could provide a structure to guide the user to the resources needed. Similar questions were asked of the Allies to determine the effectiveness.

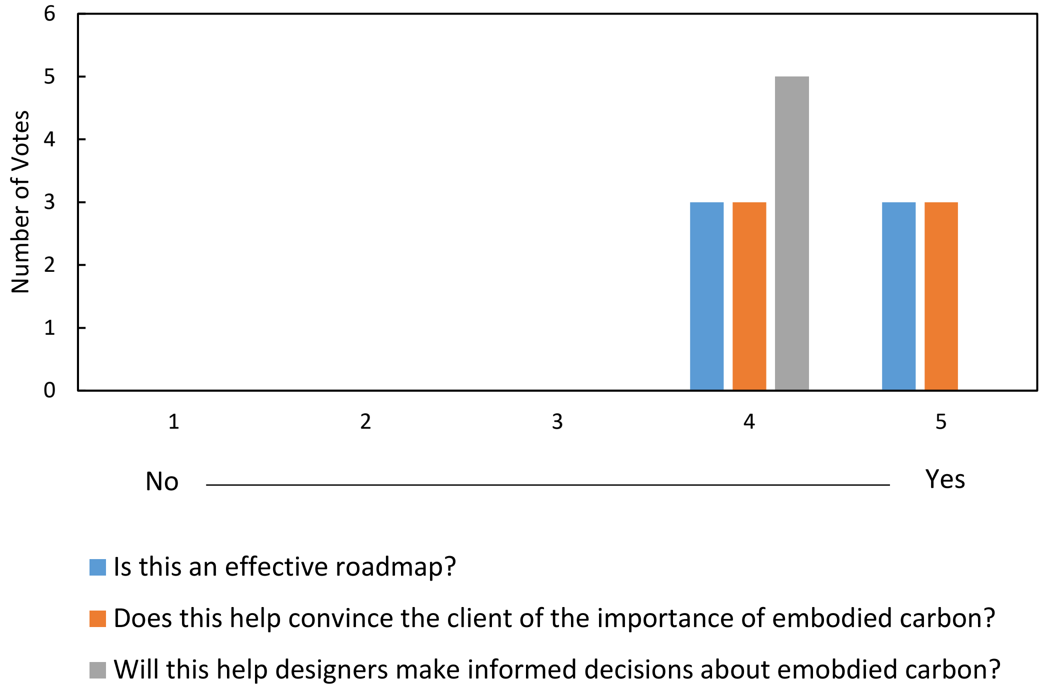

Figure 6. Results from the Allies answering questions on the usefulness of the website. Total of 6 participants voted in the first question (blue); average score was 4.5. Total of 6 participants voted in the second question (orange); average score was 4.5. Total of 5 participants voted in the third question (grey); average score was 4.

Feedback was generally positive for a website version of the decision tree (Figure 6). While the website format seemed amenable for the group polled, websites can be a challenging format to maintain and host. Throughout the testing process, we learned that hosting a website in this case would be especially difficult. We then investigated an option where the format could have similar attributes of a website that make it attractive but be less cumbersome to maintain or own.

Clickable PDF

As an alternative to a website, the decision tree discussed above was formatted into a static, but clickable, PDF format where the user could scroll to the page of interest or click on icons that would provide a shortcut to the resources needed. The format lends itself to being printed or used in a presentation for client reviews for architecture, engineering, construction, and contracting firms. It can also easily be embedded into a website as a downloadable file or recoded into a website. Similar questions were asked of the Allies for feedback on effectiveness on two iterations of the document; results are shown in Figures 7 and 8. In all three questions, Allies' feedback indicated that the second iteration of the clickable PDF (Figure 8) is more useful and effective than the first iteration (Figure 7).

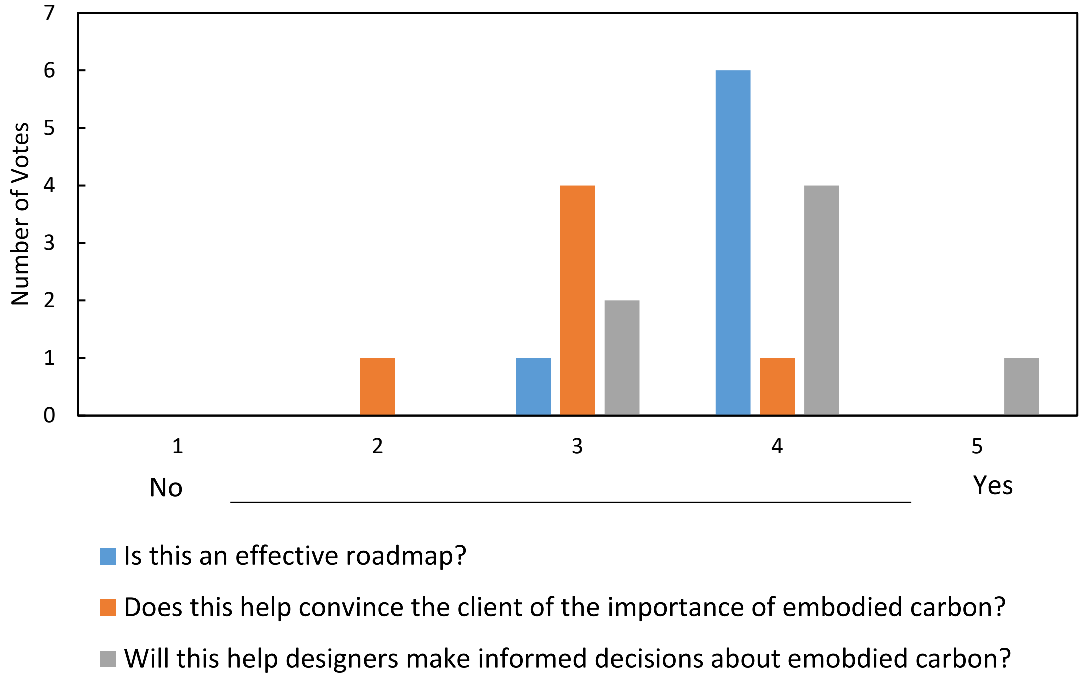

Figure 7. Results from the Allies answering questions on the usefulness of the first version of the clickable PDF. Total of 6 participants voted in the first question (blue); average score was 3.9. Total of 6 participants voted in the second question (orange); average score was 3. Total of 7 participants voted in the third question (grey); average score was 3.9.

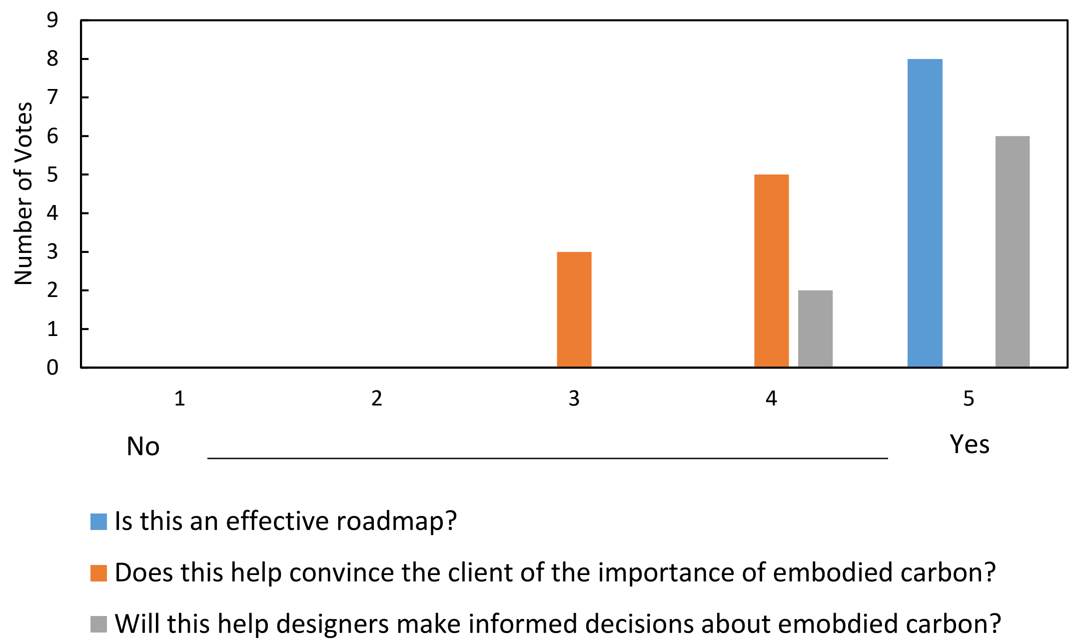

Figure 8. Results from the Allies answering questions on the usefulness of the second version of the clickable PDF. Total of 8 participants voted on the first question (blue); average score was 5. Total of 8 participants voted on the second question (orange); average score was 3.6. Total of 8 participants voted on the third question (grey); average score was 4.75.

In addition to the quantitative results, Allies provided useful qualitative feedback. Several practitioners asserted that once someone has a useable guide and knows that they can find the answers they are looking for, they will rely upon that guide in the future. Additionally, including diagrams and figures in the clickable PDF will be useful to show the client.

Throughout this iterative process, we were able to develop a resource in a new topic area designed to educate the design and construction community and their clients. Through both the quantitative and qualitative results, we were better able to determine what information should be included, which information is important to focus on, what level of detail is needed for the end points of the decision tree, and what is important to include for additional resources, such as case studies.

Case study value

Case studies were discussed within the Allies working group as an important resource for the design and construction communities, as they can be an important tool to help convince clients that embodied carbon reductions are possible at low cost or no additional cost premiums. Presenting this information in a clear way is crucial, and we discussed with the Design Allies about effective case study formats and what value they can bring.

The Allies working group indicated that case studies can be inspiring to both designers and clients. Designers can use case studies internally for review of their own work and comparison to their own examples. Case studies can also add credibility for the designer when discussing the potential for low embodied carbon construction projects with their clients. These examples of real low embodied carbon projects indicate that low embodied carbon options can be feasible and attainable, while also providing realistic expectations by showcasing the difficulty and possibility of addressing embodied carbon. Once you can get the client to this point, "[designers] can have a more productive discussion on how to make the approach work [for] their project," as shared by one working group participant.

The valuable nature of case studies has led to potential case studies being drafted for use in the Embodied Carbon Resource Navigator. To date, case study attributes have been discussed and those attributes indicated as important by the Design Allies will be used for gathering relevant information for case studies in the next stage of this product. Case study attributes discussed include: project details (type of building, square footage, climate zone), scope of project (goal and approach to project), metrics (cost effectiveness, carbon reduction, base case used for comparison), challenges experienced, and major takeaways and lessons learned.

Conclusion

This effort has included providing an organizational structure of educational resources to help the design and construction communities more easily make informed decisions on lowering embodied carbon in the built environment. With the urgency of making lower embodied carbon decisions, it is important to get information to people faster, to streamline between problem and barrier identification and solution. With the help of early adopter practitioners, we were able to investigate different approaches to providing resources and evaluate how helpful those resources are against the overarching goal.

Throughout this process we learned much about what works and what does not work. When brainstorming ideas, providing a blank canvas and asking broad questions about what the community needs does not always work. We found the most success when providing product examples for working groups to react to along with questions to aid discussion. If someone does not understand how to navigate to the resource that can solve their problem, the navigator is useless. Thus, providing guiding questions in the decision tree format of the clickable PDF addressed this issue and was found to be most useful.

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