A Sustainable Design Method Acting as an Innovation Tool

Jeremy Faludi

Abstract Product companies generally see sustainability as a burden limiting their design process, similar to cost or safety limits. A method for sustainable design was created, attempting to turn sustainability from a burden into an innovation tool with inherent business value. The method combines creative whole-systems thinking with quantitative sustainability metrics. It facilitates innovation by the creation of visual whole-system maps that encourage more thorough and more radical brainstorming. It facilitates sustainability by using quantitative measurements, such as life-cycle assessment or point-based certification systems, to set priorities and choose final designs. The method has been anecdotally tested in classes at four universities, and many of the companies partnering with these classes have said the students provided both sustainability and feature /functionality benefits. This paper also compares the method to Lindahl's nine recommendations for being useful to engineering designers. Thus there is at least anecdotal evidence that the design method may turn sustainability from a burden into an innovation tool. Future studies should compare the method against industry-leading innovation and green design methods.

Keywords Sustainable design · Innovation · Design method · Design process · Systems thinking · Life-cycle assessment · Design fixation

1 Introduction

Sustainability is one of the critical problems of our time, affecting all people on Earth in some way, as well as affecting economies and ecologies. Green architecture is an increasingly established industry, with three billion square feet of LEED-certified buildings alone [1], but green product design is decades behind, with few sustainable alternatives to most consumer products. Behrisch et al. bemoaned the lack of studies

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on how often green design techniques are even used in industry [2] or advertised as capabilities [3]. Sustainable design has been studied extensively, but most studies have found that companies perceive it to be a burden on designers and engineers, due to the extra time and money it requires [4–6]. Many eco-designers have been touting sustainability as an innovation tool for years—a conference named “Sustainable Innovation” is in its 19th year [7]. However, academic studies showing its advantages for innovation are scarce to nonexistent. Collado-Ruiz’s quantitative study shows the opposite—that eco-design methods limit design creativity [8].

This does not have to be the final word, however. Different design methods can be assumed to drive different outcomes, or else they would not be used. Some methods are actually not design but just sustainability assessment, such as life-cycle assessment (“LCA”), or assessment and strategizing, such as Waage’s “road map” [9]. Other methods focus almost entirely on idea generation, such as Biomimicry [10]. Most methods combine ideation, strategizing, and assessment together, e.g., The Natural Step [11], the UNEP/TU Delft Design for Sustainability manual [12], Factor Ten [13], and various certification systems like Cradle to Cradle [14] or EPEAT [15].

Some green design strategies have unquestionably caused innovation in the market (in the sense of radical design change): for example, turning a product into a service. Product-service-systems have been great financial successes for Xerox, Electrolux, Castrol, and many others [16], showing that economically valuable innovation can come from sustainable design. Product-service-systems are not appropriate for every product category, but perhaps a design method prioritizing both sustainability and innovation could suggest valuable solutions for any product category.

2 Background

Why is it important for a sustainable design method to also be an innovation tool? Most companies only use sustainable design when it is required by government regulation, reduces legal liability, or saves money, rather than prioritizing sustainability in itself [17]. Of these, only “saving money” sees sustainability as an investment rather than a burden, but all three motivations have direct economic value for companies [18]. Innovation is a direct economic value, which is also seen as an investment by companies [19, 20]. Therefore, sustainable design as innovation should be pursued for three reasons: First, because innovation is valued by companies, and can thus promote sustainable design in cases where it does not obviously save money, reduce legal liability, or solve regulatory compliance. Second, because sustainable design usually requires companies to think very differently about their products—a natural driver for innovation. Third, because innovative companies are market leaders, and leaders shifting towards sustainability could pull whole industries along with them.

Lindahl [21] studied engineering designers to find their requirements for sustainable design tools, and listed nine recommendations: #1. Easy-to-understand benefits. #2. Easy to understand process. #3. Adjustable to different contexts. #4.

Low setup time. #5. No need for simultaneous cooperation. #6. Low need for data. #7. Visualization of results. #8. IT-based (use dedicated software). #9. Give direction, not a result.

The Whole-Systems and Life-Cycle (“WSLC”) method was created for the Autodesk Sustainability Workshop [22], a free online set of training resources for students, professionals, or professors. While quantitative assessments of learning outcomes have not been studied, anecdotal evidence suggests it may be an effective learning platform [23–26]. In the Sustainability Workshop, the WSLC design method is a keystone. It frames later videos and readings on specialized sustainable design strategies such as material choices, design for disassembly, reducing material use, and energy efficiency.

3 The Whole Systems + Life-Cycle Design Method

The WSLC method combines creative whole-systems thinking with quantitative sustainability metrics in a four-step process: First, designers /engineers /business managers start with the existing product or service, and visually map its whole system. This includes all major physical sub-systems, life-cycle stages, inputs and outputs, customer use, and the connections between these nodes. Second, this system is quantitatively analyzed, using LCA or point-based certification systems (e.g., Cradle to Cradle or EPEAT) to find the worst environmental impact(s). The worst impact becomes the top-priority goal for sustainable redesign. The design team then ranks the top-priority sustainability goal(s) along with the project’s top business goal (s) such as cost and functionality, and writes quantitative metrics of success for all goals. Third, the team brainstorms on their top-priority sustainability goal, using the visual system map to facilitate the brainstorm. This helps designers be more thorough by ensuring there are alternatives to every component or step in the system map, and helps designers generate more radical ideas by encouraging them to skip steps/eliminate components in the system. Finally, quantitative environmental impact estimates (LCA or certification scores) are used to judge the brainstorm results. These estimates are very imperfect, but are still better than untrained guesswork—engineers, designers, and managers are not environmental scientists, so quantitative estimates will be better than their intuition of where eco-impacts lie. The WSLC design method’s two divergent, creative stages balance its two convergent, analytical stages to turn sustainability from a limitation into a jumping-off point for exploration. A video describing the method can be seen at http://sustainabilityworkshop.autodesk.com/products/whole-systems-and-lifecycle-thinking . Some illustrations from educator materials are included here as examples.

For Step 1, Fig. 1 shows a possible whole system map for a refrigerator. In the center is the product with all its major parts: doors, insulation, cooling coils, compressor, etc. The life-cycle of the refrigerator is shown from bottom left to bottom right, going from raw materials to landfill. Since refrigerators exist to prevent food from spoiling, the food’s life-cycle is shown from top left to top right.

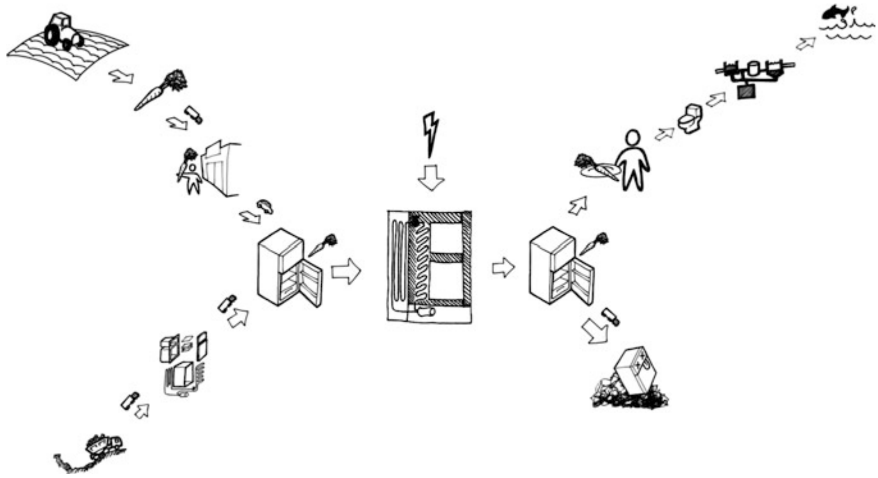

Fig. 1 WSLC Step 1: an example whole-system map for a refrigerator

Next to the cutaway drawing of the product in the center, the adjacent nodes in the map show how it is used: the user opens and closes the refrigerator door to insert and remove food. The refrigerator's other significant input is electricity, shown at center top. There is not necessarily a "right" system map—it cannot capture the immense complexity of the entire world, it is merely a model to aid design teams in focusing on all the aspects of a design they can influence. Therefore the design team should tune the system map's completeness and level of detail to their purposes. More complete is generally better.

For Step 2, Fig. 2 shows the quantitative sustainability assessment using LCA. Step 2 starts with Step 1's whole system map and either calculates an LCA of the whole system, or of a subset of it chosen by the design team to only include things they feel they can influence. Step 1 also helps clarify the functional unit for Step 2's analysis. More expansive LCAs give a more complete picture, but require more

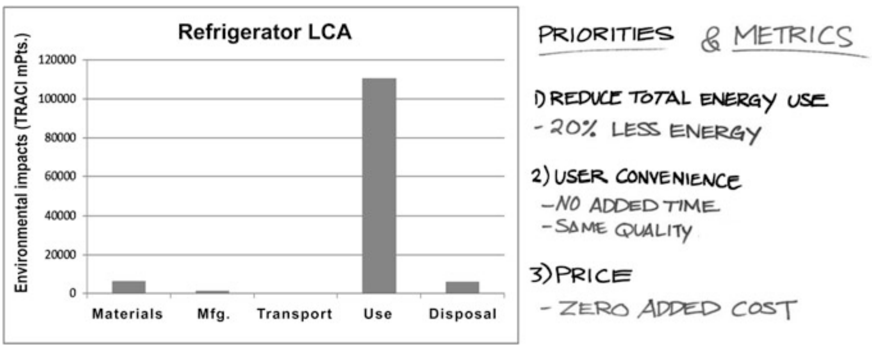

Fig. 2 WSLC Step 2: an example life-cycle assessment for a refrigerator, with the resulting sustainability priority and metric along with business priorities and metrics

time and expertise to perform. LCAs may be done by an engineer on the team, or by an outside department/consultant, using software such as SimaPro, GaBi, Sustainable Minds, or even paper-based systems if budget is limited. It may be a pre-existing assessment. The LCA should use a methodology that measures a broad variety of sustainability impacts and combines them into a single score; e.g., EcoIndicator [27] or ReCiPe [28]. This makes it easy to identify top sustainability priorities at a glance. Systems other than LCA can be used instead: for instance, scorecards such as EPEAT and Cradle to Cradle include both environmental and social impacts, and provide simple scores. Once the top sustainability priority is identified by one of these means, it is listed in the design specification, ranked alongside business priorities. These business priorities and metrics will generally be pre-existing, set by team managers or executives. Sustainability rarely ranks first, but it should be given a place in the list. Concrete metrics to measure success are decided upon here, for later accountability to the vision set forth in the design spec. Metrics for success depend on the team—an ambitious team might aim for 80 % reduction of energy use, while a modest team might choose 20 %. Metrics are not strictly needed but are helpful–they help teams decide when they are "done", versus when they need to keep generating more ideas.

For Step 3, Fig. 3 shows brainstorming off of the whole system map created in Step 1. (Note that Step 2's LCA may have narrowed the boundaries chosen by the

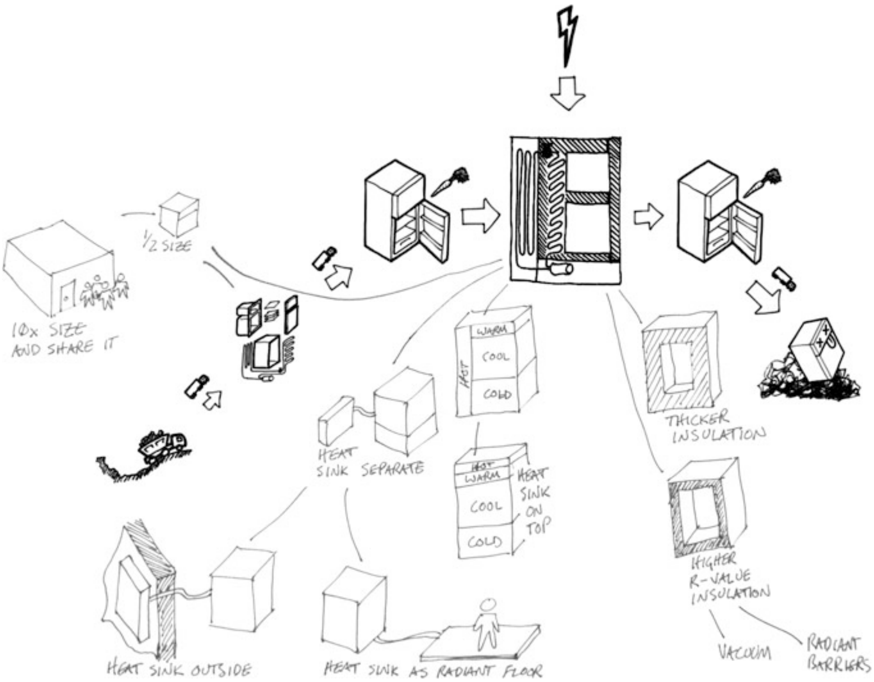

Fig. 3 WSLC Step 3: brainstorming off a whole-system map shows which parts of the system have new ideas and which do not, encouraging thoroughness in ideation

design team as being within their scope of influence—the map here does not include all the nodes of the original whole system map in Step 1.) Step 2's top sustainability priority is the "problem statement" that Step 3's brainstorm generates solutions for. Designers can avoid the classic brainstorming trap of fixating on certain solution types [29, 30], simply by brainstorming off of every node on the map. They immediately and constantly see what components of the product or steps in the system they have new ideas for, and which do not have new ideas. By requiring new ideas for every single node in the system map, brainstormers can break fixation to consider more varied solutions and ensure they are not missing opportunities for innovation in forgotten parts of the product's system. Visual messiness can be alleviated by having several copies of the system map (see Fig. 4 for a second page with more ideas). This is especially easy when teams are mapping and brainstorming with software. Most of the text in Figs. 3 and 4 is not readable here, but it is not necessary to understand the results of the brainstorm—the point is that brainstormers can see where they do and do not have new ideas in the system.

Figure 4 shows the second value of brainstorming off the system map: designers can see when they have eliminated a component or skipped a step in the system. The more steps they skip with an idea, the more radically innovative that idea is.

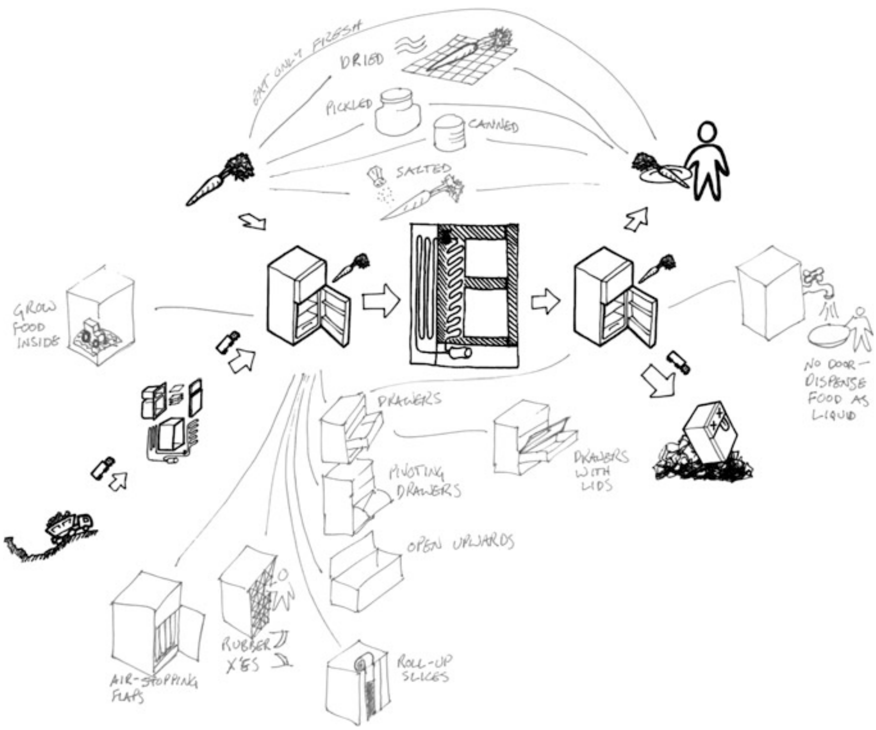

Fig. 4 WSLC Step 3 continued: brainstorming off a whole system map also shows when an idea eliminates components or skips steps in the system, encouraging more radical ideation

Teams can intentionally brainstorm to skip more steps for more radicalism. In this example, several ideas (salting food, pickling food, etc.) actually eliminate he refrigerator entirely. (Note the electricity part of the system was removed here to make the illustration compact.) These ideas may or may not be improvements, but that will not be judged here, it will be judged in Step 4.

For Step 4, Fig. 5 shows the design team's favorite few ideas from Step 3 being evaluated with LCAs to find a "winner" or "winners." The team chooses the number of top ideas by balancing convenience (fewer ideas) against thoroughness (more ideas). A team engineer or external consultant performs these assessments by estimating the reduction or increase in product energy use, materials, change in materials, etc. for the different design ideas. The estimated bill of materials, transport, and usage have their impacts calculated the same LCA software as in Step 2, using the same scoring methodology and functional units. The assessments should provide a single score for each design idea and the original product, so they can easily compared as in this graph. Figure 5 shows a student team using both single-score and CO_2e measurements; it is simpler to only use single-score, but two measurements can help show uncertainty. Again, as in Step 2, sustainability measurement systems other than LCA can be used (e.g., Cradle to Cradle, EPEAT, etc.) as long as they have clear scores to show at a glance which ideas are the biggest winners.

Design ideas from Step 3 that do not significantly improve the score from the original product (such as "A", "C", and "E" above) should be thrown out in Step 4; likewise with design ideas that do not meet the business metrics from Step 2. This leaves only top-performing ideas for both the environment and the business. A faster but less rigorous alternative to this analysis is to simply measure ideas against Step 2's metrics. Remember that quantitative analyses of early-stage design ideas are merely guesses, and there will be large uncertainties. Differences of a few percent, or even perhaps 20–30 %, may be illusory. Ideally teams should only choose final design ideas that are very clearly large improvements. If none of the available ideas show large improvements, Step 3 may need to be repeated for more ideas.

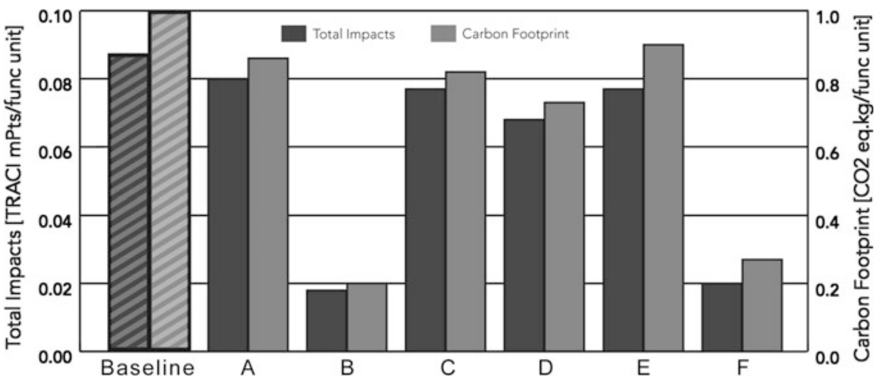

Fig. 5 WSLC Step 4: choosing between estimated LCAs of the top six design ideas ("A"–"F") by comparing them to the original product ("Baseline")

The WSLC design process can be done once or can be done iteratively, to address multiple issues or to drill down into specific parts of the product's system. A system map can be made once and used for many brainstorms, or many maps can be made at different scales. The method is intended to be flexible so teams can shape it to their needs.

4 Anecdotal Trials

The WSLC method has been used in classes at Minneapolis College of Art and Design, California College of the Arts, Emily Carr University of Art and Design, UC Berkeley, and elsewhere. In addition, universities such as University of Calgary in Canada, India Institute of Technology Kharagpur, University of Hongik in Korea, and many others have used the online video summary of the method in engineering and design classes. Hundreds of thousands of people from countries all around the world have viewed the video. The method has been applied to consumer electronics, clothing, outdoor gear, furniture, and kitchen appliances. In theory it can be used for any product category. Partner companies for anecdotal trials have included Motorola, Steelcase, Hamilton Beach, Cascade Designs, Oboz, Panasonic, Pacific Outdoor Gear, Anthro, Rayne Longboards, and others. Several of these companies have commented on its usefulness. Panasonic executives said they were "surprised and delighted how the students' ideas were not just improvements for sustainability, but were innovations for the functionality and aesthetics of the product as well." A Hamilton Beach executive said "Your process was as valuable as the actual concepts it produced."

5 Discussion

There are many green design methods; the most popular ones listed in an informal survey of practitioners were biomimicry, Cradle to Cradle, LCA, TU Delft's/UNEP's method [12], and "systems thinking." Comparing these, we find: TU Delft's method has tools to help teams prioritize sustainability, ideate, and evaluate results, much like WSLC. It has more tools related to business processes, but is more complicated (a nine-step process) and has less rigor in sustainability evaluation (uses team opinion rather than quantitative modeling). Its ideation tool is standard brainstorming, it does not have unique tools as biomimicry, WSLC, or systems thinking have. Biomimicry is an excellent ideation tool, and can also provide inspiration for measurement, but it does not have well-developed tools to measure sustainability like LCA or Cradle to Cradle, nor to ensure that they are prioritized in the design process, as WSLC or TU Delft's do. Cradle to Cradle the book is just a design philosophy; Cradle to Cradle the certification standard is a very well-developed tool to measure the sustainability of a product or service, and provides specific prescriptive suggestions, but it does not have ideation tools as biomimicry, WSLC, or systems thinking do. LCA is a measurement tool, useful for setting priorities and deciding between design options, but it does not provide ideation tools. “Systems thinking” is often poorly defined, but two concrete methods are Donella Meadows’s “12 leverage points” [31] and Rocky Mountain Institute’s Factor Ten Engineering Principles [13]. These are useful for driving radical ideation and can help set goals, but do not provide concrete metrics like LCA or Cradle to Cradle. The Whole Systems + Life-Cycle method was an attempt to join these for the best of both worlds. It also adds visual mapping of the system, to aid designers and engineers in boundary-setting and ideation.

While the WSLC method does appear promising, it has limitations. It requires the company to have at least one team member, or a consultant, who is conversant with a sustainability measurement system (LCA is preferred, but point-based certification systems such as EPEAT or Cradle to Cradle may also be used). It requires some training to learn how to create and use the system maps most effectively, and as with any design method, it does require time and effort to deploy.

The WSLC method always satisfies Lindahl’s recommendations for engineer-friendly sustainable design tools in points #1, 2, 3, and 7, and can be used in ways that fit #4, 5, 8, and 9 to a greater or lesser extent; it does not fit #6. Specifically:

1. Its benefits are easy to understand: it should simultaneously improve product sustainability and innovation by focusing teams on their highest sustainability priorities, then driving more thorough and radical brainstorming on those priorities.
2. Its process is easy to understand, a simple four steps describable in five minutes.
3. It is adjustable to different contexts by letting the team choose the depth and breadth of the system map, choose the complexity of the priorities list, and choose whether to use LCA or other scoring systems.
4. Its system-mapping has no setup time other than finding a whiteboard or large paper to draw on. LCA does take significant time to perform, but it can be done beforehand, or certification checklists take little time to estimate and are part of the design thinking process, priming team members for issues to consider.
5. It is designed for simultaneous cooperation, but this is not a hard requirement. System maps can be collaboratively drawn asynchronously, brainstorms can be asynchronous, and LCA is best done individually and asynchronously.
6. It does require data for the LCA, and for the product’s bill of materials in the system map. The method could be used without data, but its effectiveness will likely be reduced.
7. It is a fundamentally visual method, both in the system mapping and the graphing of LCA results (or other scores).
8. Its LCA portion is IT-based, using specific LCA software; however, its actual design ideation portions generally use whiteboard or paper. System mapping and brainstorming can (and often have been) performed using online collaboration software such as Google Docs, but these tools are not specific to it.

9. It is intended to give a result, not just a direction, but this result can be quite general. Scoring of final design ideas often shows that one category of ideas (e.g., product-as-service) performs much better than other categories (e.g., substituting a material with a greener material). Engineers and designers can use this as a direction rather than a fully-specified result.

6 Conclusion

The Whole-Systems and Life-Cycle method has been anecdotally shown to drive both sustainability and innovation. It clarifies sustainability priorities by using LCA or other measurements to find the product system's highest eco-impacts, and encourages accountability by choosing "winning" ideas based on their estimated improvement of these measurements. It encourages innovation by making the brainstorming process both more thorough and more radical through the use of system maps. While its effectiveness has not been deeply studied, evidence from student teams on industry projects suggests that it drives environmental improvements as well as creativity in product features and business. Companies have found the results valuable, and the method was found to meet between four and eight of Lindahl's nine recommendations for engineer-friendly design tools. This innovation may provide another important economic incentive for companies to practice sustainability, in addition to cost savings, lowered liability risk, and regulatory compliance.

Future studies should perform field trials of this method versus others, not only to compare which perform best, but also to find the valuable elements of each method. There may be other values that companies perceive in the methods, along with or even above innovation. Engineering and design educators are encouraged to try the method, as are industry engineering and design teams, to see if their results match those described here, as well as to suggest improvements. Together we can turn sustainability from a burden into an innovation tool that provides direct value to companies whether or not they prioritize sustainability itself.

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