Strengthening Sustainability Rating Credit for Off-Site Construction

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ABSTRACT
Off-site construction has inherent advantages over conventional construction in terms of sustainability that extend well beyond lower construction site waste, yet the common building sustainability rating systems in the U.S. and Canada provide little or no credits to reflect prefabrication's sustainability-promoting characteristics. As project owners in the U.S. and Canada increasingly demand that their projects receive certification by one of the common building sustainability rating systems, off-site construction's inherent advantages over conventional construction in terms of cost and time may be reduced by off-site construction's lack of advantages in terms of sustainability rating credits. After identifying sustainability rating credits that favor off-site production and other credits that disfavor off-site production, the paper concludes by identifying actions off-site construction producers should consider to increase sustainability rating credits for their products.

KEYWORDS
Sustainability Rating Systems, Pre-fabrication, LEED, Green Globes, Living Building Challenge

INTRODUCTION
As documented in past papers from this conference, off-site construction is inherently superior to conventional, all-on-site construction for achieving two critical goals on all construction projects: Cost and schedule. But over the past decade or two, another project goal has become just as critical to some owners: achieving a sustainability rating for the completed facility. Indeed, there are over 32,500 LEED certified commercial projects and 1.85 million additional LEED certified square feet per day (USGBC 2016a).

The purposes of this paper are to examine how the current text within common sustainability rating systems in the U.S. favor or disfavor off-site construction, and to identify ways that sustainability rating systems could be modified to better acknowledge the inherent advantages of off-site construction for various aspects of sustainability. The paper does not present the results of case studies or data collected from past projects. Rather, the paper is based on a literature search, the author's detailed review of three sustainability rating systems, the author's previous research on construction innovation, especially in the area of prefabrication, and the author's professional experiences as a developer, general contractor and engineer.

INTRODUCTION TO SUSTAINABILITY RATINGS
The goals of sustainability rating systems are to provide an objective, measurable tool for determining the extent to which a new building or facility should be considered sustainable development. New buildings and other infrastructure are the most salient outcomes of economic development and are associated with significant consumption of natural resources and significant generation of harmful waste products. For example, buildings account for approximately 40% of

total energy use in the U.S. (U.S. Energy Information Service 2016) and generate nearly the same percentage in carbon dioxide emissions (Center for Climate and Energy Solutions 2016).

Sustainability rating systems apply to entire projects, which can be either new construction (the focus of this paper) or renovation of existing buildings. Sustainability rating systems do not provide certification for individual products, such as Energy Star for appliances or Water Sense for plumbing fixtures (Whole Building Design Guide 2016). But sustainability rating systems often require compliance with one or more individual product rating systems.

Sustainability rating systems are not required building codes. Whether a project's design and construction team is responsible for providing a completed building that becomes certified by one of the sustainability rating system organizations is entirely up to the project owner. Neither are sustainability rating systems considered true construction standards, such as "ASTM E2432 Standard Guide for the General Principles of Sustainability Relative to Building." Such standards may be referenced and even required by local building codes and typically substantially overlap with sustainability rating systems.

The three sustainability rating systems most used in the U.S. include Leadership in Energy and Environmental Design (LEED) promulgated by the U.S. Green Building Council (2016b), Green Globes (which was first developed in Canada) promulgated by the Green Building Initiative (2015), and the Living Building Challenge promulgated by the International Living Building Institute (2014a). The Whole Building Design Guide webpage (https://www.wbdg.org/resources/gbs.php) provides a helpful summary of the origins and format for each of these ratings systems, as well as for a half-dozen rating systems that are well known outside of the U.S.

The Living Building Challenge is by far the most stringent of the three rating systems due to its incredibly challenging requirements for the building to be net zero (meaning the site must overall generate as much as it consumes) for both energy and water, the prohibition again combustion, the requirement for 100% recycling or diversion of construction waste, and a "red" list of materials that cannot be found in the building because they are the "worst-in-class materials/chemicals with the greatest impact on human and ecosystem health" (International Living Future Institute 2014a). Several of the prohibited items are commonly found on commercial construction sites, such as PVC and volatile organic compounds (VOCs) in wet-applied products.

WHY OFF-SITE CONSTRUCTION IS INHERENTLY SUSTAINABLE

As documented in the literature, off-site construction is inherently more sustainable than stick-built construction. Many articles (Tam et al 2007, Luo et al 2008, McGraw-Hill 2011, Quale et al 2012, Yunus and Yang 2012) have focused on the reduced construction site waste associated with off-site construction. Reduced volume of waste heading to landfills not only reduces the rate at which new landfills need to be developed, but also reduces the energy consumed and pollutants generated while transporting construction waste to landfills.

Another way of looking at reduced waste is to recognize that less materials are needed to be produced and shipped to the site in order to create the completed facility if off-site production is used (Modular Building Institute 2009). Less materials shipped to the site means less loss due to weather damage and theft. Less materials shipped to site often means less area needed for material storage, which means the site is less impacted and requires fewer resources to restore. Less materials needed means fewer natural materials needed to be extracted from the earth, processed into the final composition and shape, and shipped to the jobsite, thereby reducing the energy used and pollutants and greenhouse gases generated during each of those steps (Gangolells et al 2009, Quale et al 2012).

The improved labor productivity associated with off-site construction (Luo et al 2008, Modular Building Institute 2009, National Research Council 2009, McGraw-Hill 2011, Yunnus and Yang 2012) has not only economic benefits but also environmental benefits in that fewer total labor hours means that fewer workers are driving to their workplace and/or workers are driving fewer times to a workplace to complete the tasks associated with a project with off-site construction. Fewer total miles, of course, means less fossil fuels burned and fewer pollutants and greenhouse gases produced.

The more uniform quality that results from controlled environments and often automated equipment (Tam et al 2007, Luo et al 2008, Modular Building Institute 2009, National Research Council 2009, McGraw-Hill 2011, Yunnus and Yang 2012) means that less waste occurs in the factory and less waste is generated on site because less defective units are shipped to the site but discarded on site if the defect is noted by the installer. Fewer defective items also reduces the chance that a defect will be missed or ignored by the installer, installed, and later require rework. The higher quality associated with off-site production therefore reduces the energy and pollution embodied in the wasted materials and associated with the rework effort. Higher quality from off-site production can also lead to reduced energy usage and greenhouse gases over the life cycle of the building. For example, invisible defects in a stick-built building envelope can lead to substantial energy losses over the 30-80 year life of the building. Invisible defects in plumbing and HVAC systems can lead to additional losses in pressure, thereby requiring more energy over the building life-cycle.

Reduced total construction duration associated with off-site production (Tam et al 2007, Luo et al 2008, Modular Building Institute 2009, National Research Council 2009, McGraw-Hill 2011, Yunnus and Yang 2012) means that the resources that must be provided to oversee the construction site (often referred to as general conditions) will be reduced. Fewer weeks of general conditions means fewer weeks where general contractor staff need to drive to the worksite and work out of field trailers requiring electricity for air conditioning, computers and lighting.

The final advantage of off-site construction to note is the social sustainability benefits that results from having a portion of the work performed in controlled factory conditions using automatic equipment with engineered safeguards and controlled air quality (Modular Building Institute 2009, Luo et al 2008, McGraw-Hill 2011). Shifting work from being performed at height (i.e., elevated above the surrounding ground) to a factory reduces fall hazards. Shifting work from being performed in a trench reduces the risk of trench collapse. Shifting work from being performed in a confined space (such as inside a manhole, vault, or tank) reduces the risk of injury or death due to insufficient oxygen (Behm 2005, Toole and Gambatese 2008).

EXPLICIT REFERENCES TO OFF-SITE CONSTRUCTION

Given the ways in which off-site construction provides inherent sustainability advantages over stick-built construction discussed in the previous section and the fact that the results of a national survey conducted by McGraw-Hill (2011) indicate design and construction professionals believe prefabrication has strong green benefits, one might expect to find numerous instances in the sustainability ratings that gives credit for off-site construction. Unfortunately, this is definitely not the case. But it is appropriate to explain why several important aspects of the content and goals of the current sustainability rating systems will likely keep credits for off-site construction low for decades to come. One aspect to note is a significant portion of sustainability rating systems are associated with site issues for the completed facility, such as how occupants can get to the building, rainwater management, light pollution management, and wildlife habitat protection. Off-site construction's sustainability advantages are not related to such issues in that these issues are not associated with materials that can be prefabricated.

A second aspect to note is that the majority of sustainability rating systems are associated with building operations (that is, after the project is completed) performance criteria. This emphasis is appropriate given that building operations has a much higher impact than construction over a building's life cycle (Quale et al 2012), but operational performance is often neutral with regards to off-site construction. For example, performance criteria associated with water conserving plumbing fixtures are typically not achieved easier or better through using off-site production of the piping leading to the fixtures.

Even with the warning given in the previous paragraph, the reader is likely to find the number of explicit references to prefabrication in current sustainability ratings surprising low. Neither LEED nor the Living Building Challenge have any explicit reference to prefabricated or modular construction at all. (Modular Building Institute 2009 reported that LEED for Homes explicitly gave credit for prefabrication but this is not the case in the current version V4.) However, Green Globes does give 2 points credit through 3.4.6.1.1: "Does the design specify the use of prefabricated, pre-assembled and/or modular products?"

LEED does include one prerequisite and several credits that one could argue influence the use of off-site construction. LEED requires that the project team develop a plan to achieve the intent "To reduce construction and demolition waste disposed of in landfills and incineration facilities by recovering, reusing, and recycling materials." (USGBC 2016b, p. 87)

Note that both the intent and the guidance text presume that waste reduction will occur through recovery, reuse or recycling, not by moving upstream and reducing the amount of material being shipped to the site in the first place. This presumption disfavors off-site production because it prevents the project from receiving a credit for choosing a path (procuring pre-fabricated assemblies) that better achieves the ultimate goal better than the option that results in the credits! The MR credit for reducing materials heading to landfill (USGBC 2016b, p. 106), however, is less unfair in that option 2 is worded to allow more systemic waste reduction that would favor the use of off-site production: "Do not generate more than 2.5 pounds of construction waste per square foot (12.2 kilograms of waste per square meter) of the building's floor area."

The second credit offered by LEED that could be used to encourage off-site production is the credit for innovation. The guidance text reads: “Achieve significant, measurable environmental performance using a strategy not addressed in the LEED green building rating system.” (USGBC 2016b, p. 141) The tactic here would be to request this credit based on the argument that substantial use of off-site production provides the host of environmental and social benefits discussed earlier in this paper and should therefore be regarded as desirable innovation.

Green Globes also has a credit that does not explicitly refer to off-site production, but does seem to encourage it. The actual text is: “3.5.6.1.2 Criteria: Does the building design use materials efficiently and/or minimizes the use of raw materials as compared with typical construction practices?” (Green Building Initiative 2015, p. 156) It seems that a project could justify requesting this credit if the materials produced off-site construction were specifically addressed in the drawings and/or technical specifications and therefore clearly associated with the design, not just the contractor’s procurement tactics.

The Living Building Challenge has a similar requirement that would seem to favor prefabrication: “The project team must strive to reduce or eliminate the production of waste during design, construction, operation, and end of life in order to conserve natural resources and to find ways to integrate waste back into either an industrial loop or natural nutrient loop.” (International Living Future Institute 2014b, p. 40). However, the requirement immediately following the above quoted text to have “at least one salvaged material per 500 square meters of gross building area” would seem to disfavor prefabrication, as discussed in the next section.

SUSTAINABILITY CREDITS THAT DO NOT FAVOR OFF-SITE

This section of the paper identifies several credits or requirements found in all three sustainability rating systems that pose challenges to off-site production.

Prefabricated elements are often larger, heavier and more easily damaged by physical motion than are the raw materials used in the prefabricated elements. As such, prefabricated elements may arrive on site protected by significant packaging. Such packaging counts as construction waste and therefore makes it more difficult to earn waste reduction credits.

All three sustainability rating systems require or provide credits for using material that is re-used or recycled. Automated equipment associated with off-site production often cannot handle recycled or re-used materials because the automated systems require a higher quality and/or more uniform stream of raw materials. For example, machinery producing engineered lumber products such as trusses and wall panels cannot use re-used wood because it is too non-uninform and cannot used recycled wood because the wood fiber products do not have the same properties as sawn lumber. As such, extensive use of prefabrication may make it more difficult to achieve a re-used/recycled material credit.

Prefabrication often requires the producer to incur substantial capital and/or fixed costs. Off-site producers often find it necessary to cover high fixed costs and leverage the lower marginal costs associated with automated production by selling large quantities of product, which often requires a manufacturer to ship products to geographic markets located further from the plant than typical shipping distances associated with conventional materials. For example, a producer of precast concrete components such as panels, columns and stairs will typically seek to ship further distances than the radius typically served by a plant producing ready-mix concrete. As such, extensive use of off-site production may make it more difficult to receive credit for having a certain percentage of project materials sourced from within a relatively short distance from the project site.

The need for rapid and structurally adequate on-site assembly of pre-fabricated components occasionally require the components to have additional material installed in them (Nishioka et al 2000). For example, the marriage walls between modular building units have 25% more material in them (Quale et al 2012). While such additional materials do not directly affect the ability to earn a specific credit, they do negatively affect calculations (if performed) of total materials used on site and the energy and greenhouse gases embodied in the materials.

POTENTIAL CHANGES TO ENCOURAGE OFF-SITE CONSTRUCTION

This section builds on the previous sections by identifying ways that off-site producers can either modify their products and processes to secure credits as well as ways that off-site producers might seek to change sustainability rating systems to better recognize and reward off-site construction's inherent sustainability.

There are at least four potential actions off-site producers can undertake to better match with the existing sustainability rating systems. First, producers can work with contractor clients to improve packaging in order to generate waste on site without raising the risk that prefabricated components will be damaged during shipping. Construction projects are unique in most ways. Packaging may be a serious issue on one project but not a concern on a project that appears to be quite similar, so discussion with the general contractor and/or installers is warranted. Second, prefabricated producers can review the sustainability ratings related to supply chain and take steps to ensure they can help the project earn credit for having a supply chain that has appropriate sourcing of materials, management of pollution, and provides a commendable safety and health environment for its workers.

Third, producers can upgrade their production equipment and improve their overall procurement and production system to allow the use of materials that have been recycled or re-used. In past years, the challenge was not only that automated equipment could not handle non-virgin materials but that manufactures could not ensure a reliable supply of acceptable recycled/re-used materials. Given the growth in recycling across the consumer and manufacturing sectors over the past two decades and the maturation of the recycling industry, off-site producers should constantly seek opportunities to increase the use of non-virgin materials within their plants. Fourth and finally, off-site producers should refine their existing products and develop new products that provide multiple functions in order to secure sustainability rating credits for using multi-functional materials. One example is structural systems that do not require separate insulation or finish surfaces to be applied on site. The increasing use of CNC machinery and even true robotics within factories will allow off-site producers to produce more complex assemblies containing multiple subsystems and further leverage the low marginal cost, fast production and high quality advantages of automated production without losing the ability to customize small batches of product required for specific projects.

Producers of off-site construction components should also seek to have existing sustainability system rating systems modified to more appropriately recognize the inherent superiority of prefabrication with regards to sustainability. The terminology regarding construction waste should be changed from recycling waste that arrives on site to minimizing the total waste produced from cradle to grave. Additional credit should be sought to reflect the lower levels of energy, pollution and greenhouse gases embodied in prefabricated components as compared to levels embodied in stick-built materials. Credit should also be sought for the shorter project construction durations associated with off-site production, to reflect the fact that there are fewer miles driven to the jobsite, fewer BTUs expended heating or cooling jobsite trailers, etc.

Finally, credit should also be sought for the fact that off-site production is inherently safer and therefore more socially sustainable than 100% on-site construction. There is currently a pilot program within LEED BDC that provides 1 point if a project can demonstrate the design applied Prevention through Design principles. Credit for designs in which excessive hazards have been designed out should be permanent (not just pilot) and result in multiple credits (not just 1) for LEED, and be added to the Green Globes and Living Building Challenge systems as well.

CONCLUSIONS

In examining the relationship between off-site construction and sustainability rating systems, this paper has discussed both the positive and negative aspects. The positive aspects are the many ways that off-site construction has inherent advantages over 100% site-built construction in terms of reduced quantities of raw materials needed, reduced waste generated and sent to landfills, reduced energy used and pollutants and greenhouse gases generated for materials from extraction to installation on site, and reduced energy used and pollutants and greenhouse gases generated by workers and site coordination staff during shortened project durations. The negative aspects are the fact that current sustainability rating systems do not fully recognize or reward off-site production's sustainability-related strengths.

The paper suggested several ways that off-site producers to change their products and operations to better match existing sustainability rating systems as well as ways to seek changes to existing sustainability rating credits to more appropriately recognize the inherent sustainability advantages of off-site construction. Two themes underlie these recommended changes. First, off-site producers must be fully aware of the details of all three sustainability rating systems, including of the Living Building Challenge, which has market influence well beyond the limited number of LBC-certified buildings. Second, off-site producers must demand their seats at the table during the integrated design process that is required by LEED and LBC and credited by Green Globes. Achieving project goals of low cost, short schedule, high quality and high sustainability requires a true team effort during design and construction, and off-site producers have important roles to play throughout the project cycle.

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