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PERFORMANCE INDICATORS FOR SUSTAINABILITY ASSESSMENT OF BUILDINGS

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Abstract: During the past few decades, the construction industry has been exposed to “sustainable construction” processes, which address the triple bottom line (TBL) that is the environmental, economic, and social dimensions of sustainability, during the entire life cycle of a building. Due to the importance of sustainable construction, it is imperative to comprehensively assess the sustainability of the built environment, such as buildings. A significant step to evaluate the sustainability of buildings is investigating the existing building sustainability performance indicators (SPIs). In this paper, a list of building SPIs, including environmental, economic, and social, has been developed through conducting a content-analysis based literature review. The literature includes sustainable building rating systems such as Leadership in Energy and Environmental Design (LEED), Green Globes, Living Building Challenge (LBC), among others. In addition, other published literature related to sustainable construction is reviewed. Similar SPIs or those which have some overlaps are combined or modified. Finally, refined TBL SPI sets are created, which can be used for sustainability assessment of buildings. The results of this study indicate that among various environmental performance criteria used in different publications, 16 SPIs are the most significant ones. In addition, a total number of 9 SPIs and 12 SPIs are identified as the most commonly used criteria related to the life cycle economic and social performance of buildings, respectively.

1 INTRODUCTION

Since around 30 years ago, the “sustainability” concept has been widespread and various definitions have been provided (Forsberg and von Malmborg 2004). Nowadays, the percentage of the world’s population who live in urban areas is over 50% (UN 2010) and they spend 80% - 90% of their time inside buildings. This shows the importance of the built environment, e.g., buildings, in sustainable development (Andrade and Braganca 2011). Thus, sustainability performance assessments of the existing and new buildings can play a significant role in increasing sustainability (Ding 2008, Burgan and Sansom 2006).

It is widely accepted that sustainability has three main dimensions: environmental, economic and social, termed as triple bottom line (TBL). Therefore, to make a sustainable product, all these dimensions should be considered and addressed sufficiently. To evaluate the sustainability performance of a product, Kloepffer (2008) has proposed the life cycle sustainability assessment (LCSA) framework. By using the LCSA framework, product performance can be measured with regard to TBL. The LCSA framework can be applied by the following model (Kloepffer 2008, Finkbeiner et al. 2010):

[1] LCSA = LCA + LCC + SLCA

Where LCA is the environmental life cycle assessment, LCC stands for life cycle costing and SLCA is social life cycle assessment.

According to Traverso et al. (2012), the primary purpose of the LCSA framework, similar to LCA, is not to decide if a product should be produced, but to assist stakeholders and decision makers in making a more sustainable decision, thus producing a more sustainable product. In addition, one of the challenges faced by decision makers is to explore how separate environmental, economic, and social assessments can be used in practical situations to make trade-offs explicit (Swarr et al. 2011).

In order to enhance the likelihood of sustainable construction, the first step is to identify significant indicators of all the sustainability dimensions that can be used for assessing the sustainability performance of new and existing buildings over their life cycle. A sustainability indicator provides qualitative or quantitative information about the influence and impacts of a building project on the environment and society.

Currently, over 70 evaluation and classification tools (systems), based on sustainability indicators, have been developed. A building is regarded as a sustainable product only when all the sustainability dimensions, i.e., environmental, economic and social, are addressed and dealt with over its life cycle; however, the primary focus of most of the existing sustainability evaluation tools is on environmental characteristics (Braganca et al. 2010). In other words, they deal primarily with the environmental dimension of sustainability, and thus, they do not explicitly considering socio-cultural and economic dimensions which is a limitation. Furthermore, each sustainability evaluation tool has its own approach and accordingly provides different performance criteria and sub-criteria, which can be different from what other tools provide. Therefore, there are numerous indicators available, which can be confusing for the construction practitioners.

To address the limitations discussed above, the main objective of this paper is to develop generic and holistic building sustainability performance indicator (SPI) sets (i.e., environmental SPIs, economic SPIs, and social SPIs) that can provide a deeper insight into the most significant sustainability criteria currently used. The proposed TBL SPI sets are a key criteria list, which can be addressed in the design and construction of buildings. The results of this paper can assist different construction stakeholders in the development of sustainable construction.

2 METHODOLOGY

The research method in this paper is content analysis, which is a qualitative type of document analysis. Content analysis is a qualitative and systematic method to review and evaluate different documents. In other words, content analysis is the process of collecting and organizing information related to the primary research questions (Bowen 2009). Holsti (1969) gives a broad definition of content analysis as, "any technique for making inferences by objectively and systematically identifying specified characteristics of messages". All forms of documents, including electronic and printed, such as letters, books, survey reports, organizational papers, advertisements, etc., can be used as references.

First, a preliminary list of building SPIs was developed based on the review of two reference categories:

1- Sustainable building rating systems, such as Leadership in Energy & Environmental Design (LEED), Green Globes, Living Building Challenge (LBC), among others.

2- Journal and conference articles. The University of British Columbia (UBC) library databases, “Compendex Engineering Village” and American Society of Civil Engineers (ASCE), were used to retrieve the appropriate journal and conference articles. Key words used were combinations of: “building”, “sustainability”, “performance”, “life cycle”, “indicator”, “criteria”, “evaluation”, and “assessment”. These articles were further refined by reviewing abstracts and conclusions.

Then, using the content analysis method, the common SPIs were prepared, modified, and combined to form the refined SPI set for each of the sustainability dimensions.

3 SUSTAINABILE BUILDING RATING SYSTEMS

Sustainable building rating systems (also called green building rating systems or sustainability rating systems) that were developed to assist in the management of "green" building projects have a vital role in informing on progress in sustainability practices (Siew et al. 2013). Rating systems are qualitative tools that deal with sustainability performance of buildings by providing a set of performance criteria and scoring each building project based on those criteria. Rating systems examine the performance level or expected performance of a "whole building" and allow comparison of different buildings (Fowler and Rauch 2006).

Applications of rating systems are increasing worldwide and many tools have been developed for the environmental evaluation of the built environment, e.g. over 60 in the US (Economist 2007). The tools are not usually mandatory even though some jurisdictions have made them so (CEC 2014). The main focus of sustainability rating systems is on the environmental dimension of sustainability. Table 1 lists the well-known sustainable building rating systems around the world. In this paper, only the rating systems that are intended to be used internationally (LEED, LBC, BREEAM and SBTool) or in North America (Green Globes) have been selected for review.

Table 1: Worldwide known sustainability rating systems

Rating System	Countries	Year of Launch	Organization(s)
LEED	International	1998	US Green Building Council (USGBC), Canada Green Building Council (CGBC)
Green Globes	US and Canada	2002	Green Building Initiative (GBI), BOMA Canada, ECD Energy and Environment Canada
LBC	International	2006	International Living Future Institute
BREEAM	International	1990	Building Research Establishment (BRE)
SBTool	International	1996	International Initiative for a Sustainable Built Environment (iiSBE)
CASBEE	Japan	2001	Japan Green Build Council (JaGBC)
Green Star	Australia	2003	Green Building Council Australia (GBCA)
ESGB	China	2006	Ministry of Housing and Urban Rural Development of China (MOHURD)
BCA-GM	Singapore	2005	National Environment Agency
HK BEAM	Hong Kong	1996	BEAM Society

3.1 Leadership in Energy and Environmental Design (LEED)

USGBC developed the Leadership in Energy and Environmental Design (LEED) rating system by using a coalition of construction industry practitioners, decision makers, contractors, owners and manufactures. LEED is one of the widely adopted rating systems worldwide. Over 148000 square meters of building space are daily certified by LEED in 147 countries. As of January 2015, nearly 50000 construction projects have registered and are participating in LEED (equal to over 800 million square meters of building space). This system is a voluntary, market-driven and consensus-based system that verifies green buildings. LEED was intended to be used for different building types, by which solutions to the green design, construction, use and maintenance of buildings can be identified and implemented. The latest LEED version (v.4) provides the following rating systems that address various project types (USGBC 2015):

- Building Design and Construction (LEED BD+C). Applies to new construction and major renovation projects;
- Interior Design and Construction (LEED ID+C). Applies to projects that are a complete interior fit-out;

- Building Operations and Maintenance (LEED O+M). Applies to existing buildings that are undergoing improvement work or little to no construction;
- Neighborhood Development (LEED ND). Applies to new land development projects or redevelopment projects; and
- Homes (LEED-H). Applies to single family homes, low-rise multi-family (one to three stories), or mid-rise multi-family (four to six stories).

The performance of a building is assessed through a set of performance credits (points) (Castro-Lacouture et al. 2009). In fact, LEED assigns weighted credits to a building project based on a number of performance categories. For example, LEED for New Construction and Major Renovations addresses seven performance categories: *Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation in Design*, and finally, *Regional Priority* (USGBC 2009). The total score is obtained by summing up the credits achieved in each performance category. For example, the total score can add up to a maximum of 110 points and 136 points for commercial projects and homes, respectively. Depending on the project type and earned score, each project is rated and awarded one of the four levels of certifications below (USGBC 2015, Kubba 2010):

- Platinum: 80 points and above
- Gold: 60–79 points
- Silver: 50–59 points
- Certified: 40–49 points.

Since the year LEED was launched, despite the reported benefits, several researchers and construction experts have argued its limitations. Some literature investigated the aspects of green versus sustainable building in LEED and concluded that the LEED rating system does not explicitly consider the socio-cultural and economic issues of buildings and mostly addresses the short term aspects rather than global and long term goals of sustainable building (Coleman 2004). According to Newsham et al. (2009), even though LEED certified buildings used 18-39% less energy per floor area, 28-35% of them used more energy compared with their conventional counterparts. In addition, they argued that there is little correlation between the real energy performance and certification level of LEED buildings. In another publication, it was shown that, on average, greenhouse gas emissions are not reduced in the use phase of LEED buildings due to no energy reductions in their operations (Scofield 2009). Ahn (2007) stated that, in addition to the many advantages of LEED buildings; however, the construction cost of green buildings is significantly higher than traditional buildings. Furthermore, it was shown that more capital is required depending on the level of LEED certification, from certified to platinum (Kats 2003).

3.2 Green Globes

The Green Globes system was intended mainly to assist construction practitioners and owners to self-assess their building performance (Kubba 2010). Green Globes is well recognized in North America and is endorsed by many states and provinces. For example, it has been used by the federal government of Canada in recent years. In addition, Green Globes and LEED were recommended by the US General Services Administration (GSA) for the construction projects of the US federal government (ECD 2015)

Green Globes is an interactive and affordable tool that enables building environmental design, operation, and management. The system provides a web-based self-assessment Yes/No/NA-type questionnaire-based package that comprises a protocol, rating system, and easy-to-use interactive guidance to assist the integrated design process implementation (i.e., goal and scope definition to construction documents) (Green Globes 2015, Smith et al. 2006). In addition, it provides market recognition of the environmental attributes of buildings by using third-party verification. Green Globes is available to be used in the following construction areas (ECD 2015):

- Existing Buildings;
- New Construction/Significant Renovations; and
- Commercial Interiors (i.e., office fit-ups).

Green Globes for existing buildings was developed based on six environmental performance categories: *Project Management, Water, Energy, Resources, Emissions* and *Indoor Environment*. For new buildings, the tool uses the same performance categories adding the seventh one: *Site Impact*. The total number of points listed in the seven categories is 1000.

It was discussed that although Green Globes' is similar to LEED in terms of structure, Green Globes is more comprehensive and includes additional aspects, such as adaptability and durability. However, Green Globes does not address some aspects that are included in some other sustainability rating systems, such as project performance strategies and innovations (Kubba 2010).

3.3 Living Building Challenge (LBC)

According to ILFI (2015), the Living Building Challenge (LBC) is a building rating system that provides the most advanced sustainability criteria that can be used to measure the sustainability of buildings. LBC requires the highest and stricter standards in sustainable design and performance of buildings, and can apply to any type of building and any shape, size, and location including new, existing, single/multi-family residential, governmental, educational, and medical buildings, among others. LBC uses seven performance categories (Petals): Place, Water, Energy, Health and Happiness, Equity, Beauty, and Materials. Petals comprise of twenty mandatory Imperatives.

LBC certification is awarded based on the actual performance of projects (rather than the modeled or anticipated performance). Thus, projects are evaluated at least twelve months after the operational phase starts. However, through a preliminary audit, a number of Imperatives can be examined after construction. The latest version of LBC (v.3.0) was launched in 2014 (ILFI 2014).

LBC is significantly different from the other rating systems. Wang et al. (2012) pointed out that buildings need to meet all of the design and operations strategies of LBC to be certified, which may result in user dissatisfaction. In fact, LBC is a "all-or-nothing" not a point-base system. Nevertheless, other rating systems such as LEED and Green Globes need a minimum number of points (credits) in order to award a base level of certification, i.e., the more points achieved leads to higher levels of certifications.

3.4 Building Research Establishment's Environmental Assessment Method (BREEAM)

The Building Research Establishment's Environmental Assessment Method (BREEAM) was developed in 1990 for environmental evaluation of any type of new and existing buildings. BREEAM rating system is widely used in the world. According to BRE (2015), since it was first launched, two million projects have registered for performance evaluation and currently 425,000 buildings have been awarded BREEAM certificates. Construction practitioners (e.g., engineers, developers, managers) demonstrate the level of environmental performance of their building projects by applying this flexible, clear, and easy to use scoring system. BREEAM rates various types of building project including (BRE 2011):

- Commercial Buildings (offices, shopping centers, restaurants);
- Public Buildings (schools, universities, hospitals, museums, libraries, law courts); and
- Multi-residential Buildings (residential care homes, residential college/school, military barrack).

Ten environmental categories such as water consumption, energy consumption, materials, health, transport, waste, etc. and forty nine sub-categories are dealt with by BREEAM to promote life cycle sustainable buildings. Depending on the earned score, each building project is awarded one of the six levels of assessment (score percentage) as listed below (BRE 2011):

- Outstanding: 85%
- Excellent: 70%
- Very good: 55%
- Good: 45%
- Pass: 30%
- Unclassified: <30%

Compared to the straightforward approaches used in other rating systems (e.g., LEED), a complex algorithm is applied by BREEAM in order to evaluate the environmental performance of a building (Gu et al. 2006). The literature argued that one of the main differences between BREEAM and other sustainability rating tools is that the evaluation in BREEAM is based on absolute values while in others, such as LEED, scores are achieved based on improvements in design (Lee and Burnett 2008).

3.5 Sustainable Building Tool (SBTool)

The Sustainable Building Tool (SBTool), formerly known as Green Building Tool (GBTool), is an international rating system for evaluating not only green building issues, but also the sustainability performance of building projects. SBTool was developed based on various construction experts' viewpoints and can be adopted in different regions with different building types (residential and commercial), environmental condition, economy, and cultural values. Accordingly, the scope and criteria can be modified (iiSBE 2015, Ruiz and Fernández 2009, Cole and Larsson 2002). According to Lee and Burnett (2005), SBTool is "the most comprehensive environmental assessment framework for building that explicitly includes the core elements of sustainable development".

SBTool covers different life cycle phases of new and existing building projects. This system offers two distinct evaluation modules, one is used in the pre-design phase of site assessment, and the other is used in the design, construction and occupancy phases of buildings. The two modules are then combined to assess and rank building projects (Larsson 2012).

Due to its complex framework, SBTool may be difficult to use. According to Fowler and Rauch (2006), because of the flexibility inherent (in the application of SBTool), using SBTool needs more technical knowledge than other rating tools.

4 JOURNAL AND CONFERENCE ARTICLES

As mentioned earlier, the second source category was journal and conference papers. Several articles were found during the search period which can be grouped into two source sub-categories. The first sub-category encompassed those papers that a limited number of SPIs have been used to perform life cycle analyses such as LCA. In this type of papers, there were no SPI lists provided or discussed. The second sub-category included those papers that were mainly about SPIs and they provided appropriate sets of SPIs for one or more sustainability dimensions.

The second sub-category, along with the sustainable building rating systems, was chosen to be analysed in this study. By reviewing abstracts and conclusions of the found papers, a total number of fifteen papers (Nguyena and Altan 2011, Bragança et al. 2010, Bragança et al. 2010, Chen et al. 2010, Guy and Kibert 1998, Shen et al. 2009, ALwaer and Clements-Croome 2010, Mwasha et al. 2011, Iwaro and Mwasha 2014, CRISP 2008, Montes-Delgado et al. 2011, Pan et al. 2012, Tam and Le 2014, Ali and Al-Nsairat 2009, Andrade and Braganca 2011, Yunus and Yang 2011) fell into this sub-category.

5 RESULTS AND ANALYSIS

In this section, the results of the content analysis are presented. First, the selected sustainable building rating systems and journal/conference articles were reviewed to develop a preliminary list of sustainability criteria related to each sustainability dimension (TBL). Regardless of different criteria naming styles used by different sources and also the frequency of each criterion, in this step, all of the criteria were included in the list. Second, the main ideas (concepts) that each of the above SPIs addressed were investigated and the similar SPIs that had different names but the same meaning were merged. A total number of 43 SPIs were found related to the environmental dimension. In the cases of the economic and social dimensions, 22 SPIs and 19 SPIs were identified, respectively.

The next step was to further modify the SPI list. As this study aimed to develop the main sustainability performance criteria, some of the SPIs were integrated and combined together to make the preliminary list shorter. For example, “public transportation access”, “bicycle storage and changing room”, and “adequate parking capacity” were considered as sub-criteria, thus integrated into a new main criterion named “alternative transportation”. As another example, “reused content in building”, “recycled content in building”, and “waste collection and recycling” were combined to form a new main SPI named “construction waste management”.

The final step was to narrow the list down by identifying the frequency of each SPI in the reviewed literature. Since the sustainable building rating systems were developed based on many academic and industry experts’ opinions, more attention was paid to the rating systems than journal/conference articles. To refine the SPI list, in this paper, the instructions below were applied to select the most important SPIs:

- Environmental Dimension: If a SPI is used in more than 50% of the rating systems (i.e., 3 out of 5 and more), the SPI is selected regardless of its frequency in the second source category (i.e., journal/conference articles). If not, the frequency count in all references, including the rating systems and articles, should be more than 50% (i.e., 10 out of 20) in order for a SPI to be selected.
- Economic and Social dimensions: Since rating systems were mainly developed to address the environmental performance, if the frequency count of a SPI in all references, including the rating systems and articles, is more than 20% (i.e., 4 out of 20 and more), the given SPI is selected.

Table 2 summarizes the refined sets of SPIs for all TBL as well as frequency counts of each SPI. Using the method explained above, 16 SPIs were eventually selected as the most significant SPIs related to the environmental dimension of sustainability. A total number of 9 SPIs and 12 SPIs were identified as the most commonly used criteria for buildings life cycle economic and social performance assessment, respectively.

6 DISCUSSION

Sustainability rating tools are mainly based on qualitative assessment of buildings. Therefore, criteria used in these tools can be vulnerable to wide interpretation by users (assessors). In addition, there are different performance categories and criteria used in sustainable building rating systems. For example, LEED was developed based on Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation in Design, and finally, Regional Priority; however, Green Globe’s performance categories are Project Management, Water, Energy, Resources, Emissions and Indoor Environment, and Site Impact. Accordingly, the criteria under each category were different. Furthermore, each sustainability rating tool has its own scoring criteria (weighting scheme) that can generate different performance scores for a given building. Even though there are many similarities between the various sustainability rating systems, there is a lack of full consistency due to the above mentioned reasons.

There are many published standards, reports and articles that address the environmental performance of buildings. For example, most of the current sustainable building rating systems were mainly intended to be used for buildings’ environmental performance evaluation. Therefore, numerous environmental performance criteria were developed and provided in the literature. The criteria in Table 2 show the environmental SPIs have the higher counts. Almost all of the reviewed rating systems in this study have emphasized the environmental SPIs proposed in Table 2. The next highly mentioned criteria are the economic SPIs that were mostly found in the second reference category, i.e., journal and conference articles. However, Table 2 shows lower counts of social performance criteria in both reference categories.

It should be mentioned that some references, such as LEED, provide some criteria that are mainly environmental indicators but they are indirectly related to the economic and social dimensions of sustainability. For example, “indoor air quality” is an environmental SPI that can lead to “health, comfort and well-being of occupants”, thus it has social impacts as well. As another example, using “regional (local) materials”, “renewable materials”, and “renewable energy” can save a considerable amount of money during the life cycle of buildings. However, fewer direct economic and social criteria were found in the reviewed rating systems.

Table 2: Proposed SPI sets for buildings

Environmental SPI	Count: rating systems	Count: articles	Total count
Site selection	5	6	11
Alternative transportation	5	5	10
Site disruption and appropriate strategies	5	7	12
Renewable energy use	5	4	9
Energy performance and efficiency strategies	3	8	11
Embodied energy	5	3	8
Water and wastewater efficiency strategies	4	7	11
Regional (local) materials	3	3	6
Renewable materials	5	5	10
Construction waste management	4	7	11
Low impact/unhealthy/forbidden materials	4	6	10
Greenhouse gas emissions	5	8	13
Indoor air quality	5	8	13
Daylighting and viewing comfort	5	6	11
Thermal comfort	5	5	10
Acoustic (noise) comfort	3	6	9
Economic SPI	**Count: rating systems**	**Count: articles**	**Total count**
Design and construction time	-	4	4
Design and construction costs	2	10	12
Operational costs	2	10	12
Maintenance costs	2	10	12
End of life costs	2	8	10
Durability of the building	3	4	7
Return on investment (ROI) and related risks	-	4	4
Flexibility	1	6	7
Integration of supply chains	1	3	4
Social SPI	**Count: rating systems**	**Count: articles**	**Total count**
Health, comfort and well-being of occupants	4	8	12
Influence on the local economy	-	5	5
Functionality and physical space usability	2	5	7
Aesthetic options and beauty of the building	2	5	7
Construction workforce health and safety	2	4	6
Community disturbance	-	4	4
Influence on local social development	1	3	4
Cultural and heritage conservation	2	5	7
Affordability	1	3	4
Safety and security	3	5	8
User acceptance and satisfaction	1	3	4
Neighborhood accessibility and amenities	2	2	4

As noticed during this study, sustainability performance criteria can be qualitative or quantitative. Many of the criteria developed by the reviewed references are qualitative criteria and there are no clear methods for quantifying them, although there have been advances made in the development of quantitative tools. For example, LCA and LCC are capable of evaluating the life cycle environmental and economic performance of buildings, respectively. However, there is no standard social life cycle assessment tool available. Accordingly, there is a growing need for developing comprehensive and standard evaluation systems for assessing all TBL of building, i.e., life cycle sustainability assessments (LCSAs).

7 CONCLUSION

During the last few years, there was a paradigm shift in the construction industry due to natural resources limitations. Therefore, more attention is being paid to decrease the environmental impacts of the built environment. However, it is not adequate to only protect the environment and ignore the socio-economic impacts of construction projects. In fact, sustainable construction strives to find a balance between the three primary sustainability dimensions, i.e., environmental, economic and social (TBL). Therefore, to have a sustainable building all TBL should be addressed sufficiently. A comprehensive method to address this need is a life cycle sustainability assessment (LCSA) framework, by which all TBL performances are assessed during the life cycle of a building.

In order to assess the life cycle sustainability performance of buildings (using a LCSA framework), it is necessary to identify significant indicators of all the sustainability dimensions. In this paper, the most commonly recommended criteria were identified using a content-analysis based literature review. A broad list of building sustainability performance indicators (SPIs) were collected, modified, combined and refined to form final TBL-SPI sets, i.e., environmental, economic and social SPI sets. For assessing the environmental performance of buildings, 16 SPIs were identified as the most significant SPIs. For the economic and the social dimensions of sustainability, a total number of 9 SPIs and 12 SPIs were identified as the most commonly used criteria, respectively.

This paper provides a deeper insight into sustainability in construction by providing the frequently used sustainability criteria in different publications, including the sustainability rating tools and other published references. The findings can help construction stakeholders, such as decision makers, policymakers, clients, developers, contractors, engineers, architects, and designers in the development of sustainable construction. The proposed TBL SPI sets can be applied in the design and construction phases of buildings' life cycle. In addition, they can be used as a generic reference list in order to assess after construction the extent to which buildings are sustainable.

Since the refined environmental, economic and social SPI sets consist of both qualitative and quantitative criteria, future research will need to investigate methods to measure and integrate them using appropriate LCSA frameworks. It should be mentioned that this paper is part of an ongoing comprehensive research project currently being conducted by the authors regarding the life cycle sustainability of off-site and on-site construction methods. Therefore, the developed SPI sets will be used in a LCSA framework to comparatively assess the sustainability of modular and conventional buildings.

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