

Validating Content of a Sustainable Design Rubric Using Established Frameworks

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Abstract

Because engineers are increasingly called upon to develop sustainable solutions, it has become imperative to adapt engineering education to equip students with the knowledge and skills to engage in sustainable design. Recognizing the potential benefits of sustainable engineering, as identified by an international community, many organizations, including ABET, the American Association of Engineering Societies (AAES), and the American Society of Civil Engineers (ASCE) advocate for curricular reforms. Successful educational reform efforts require effective methods for assessing student sustainable design abilities. One approach for both stimulating student learning and facilitating assessment is the use of rubrics. Rubrics can be used by instructors to evaluate the quality of student work, but can also be used prior to assignments to help students learn about different dimensions of sustainability, establish expectations for sustainable design, and self-assess how well principles were applied to design projects.

The goal of this project is to develop and validate a sustainable design rubric that can be easily adapted and applied across engineering disciplines or for interdisciplinary problem-solving. A sustainable design rubric was previously developed based on the Nine Principles of Sustainable Engineering for application in civil and environmental engineering (CEE) courses, and was recently updated through systematic literature review to reflect a broader set of evaluation criteria. The rubric's constructs of sustainable design and their measures are being validated in three phases consistent with the Benson model of construct validity.

This paper will focus on efforts to iteratively validate the new rubric's content by benchmarking the criteria against well-established sustainable development and design frameworks, including the UN Sustainable Development Goals, STAUNCH© (Sustainability Tool for Auditing for University Curricula in Higher-Education), and the Envision™ Infrastructure Rating System. These three frameworks contain global, program/curriculum-level, and project-level criteria applicable to engineering challenges, respectively. The iterative validation confirmed the importance of many rubric criteria, but also revealed opportunities to add or refine criteria that were not adequately represented in the rubric. In addition, iterative validation supported potential removal or consolidation of criteria that did not seem to be broadly applicable to sustainability or across disciplines. Since the sustainable design rubric is intended for undergraduate student projects, there were also categories within the frameworks deemed inappropriate for student-level projects. This paper reviews the validation process and results and presents changes to the draft rubric criteria, which will undergo further validation from an expert panel of engineering educators prior to testing on multiple student design projects.

Introduction

To train future engineers to practice in accordance with a sustainable development paradigm, undergraduate curricula need to guide students in developing a conceptual understanding of sustainability topics, as well as provide them with opportunities to apply sustainability principles during design. As many educators are designing and implementing educational interventions to foster sustainability learning, assessment tools are needed to benchmark student knowledge (both

conceptual and applied) to quantify the impacts of these interventions and provide insights for improvements. Most assessment tools have been aimed at capturing students' conceptual understanding of sustainability using surveys¹ and concept maps.² While it is critical to ensure that students grasp the complexity of sustainability topics, it is especially important for engineering students to be able to apply this knowledge in the design process. Unfortunately, less discussion in the literature has been devoted to how to assess student sustainable design abilities.³

One approach to capturing student sustainable design abilities is the use of rubrics. Rubrics are advantageous because in addition to allowing for assessment of student work, they can also be used to scaffold student learning.³ Some authors have used or adapted professional rating systems for assessment of student projects.⁴ While use of professional rating systems such as LEED (Leadership in Energy and Environmental Design) can illustrate for students the importance of sustainability in professional practice, the rating systems may not be appropriate for all disciplines (e.g., many focus on infrastructure) and/or the criteria may be too sophisticated for student-level projects.⁵

Pilot Development and Application of a Sustainable Design Rubric

In our previous work, we developed a sustainable design rubric to assess student-level design projects.^{5,6,8} Based on the Nine Principles of Sustainable Engineering⁷, we created the rubric to include 16 criteria related to environmental, social and economic aspects of design, as well as the use of sustainable design tools (see full list in Table 1). While the rubric was designed to allow for assessment of a variety of project types, it has only been applied to civil engineering student design projects.⁵

The rubric includes two four-point rating scales to aid evaluators in judging capstone reports based on the 16 sustainable design criteria. The earned points scale [0-3] captures the extent to which students consider each sustainable design criterion in their capstone projects. Evaluators assign a score of 0 to projects that show no evidence of incorporating the design criterion, while a score of 3 is assigned if the project shows evidence of extensive criterion application. The potential points scale [0-3] describes the extent to which each sustainable design criterion is applicable to a given capstone project. Evaluators assign a score of 0 if the criterion is not applicable to the project. A score of 3 is assigned if the criterion is applicable, as well as required by an instructor or project sponsor. Rating projects on both the extent of consideration and level of applicability is intended to capture the fact that some projects may more easily lend themselves to incorporating sustainable design criteria than other projects.^{5,6,8}

A set of 40 CEE capstone design projects were scored by three expert judges using the pilot sustainable design rubric, and several needed improvements were summarized. Specifically, we concluded that criteria should be added and reinterpreted to distinguish between required elements of design that benefit stakeholders and truly innovative practices that go beyond the norm to achieve social sustainability.^{3,5,6} First, we observed the need to separate routine elements of promoting safety from more innovative practices for “promoting human health and well-being.” Actions to ensure the safety of the public, which are required for most projects, may need to be captured in a new “ensures safety during the design process” criterion. Creation of this new

criterion would allow the “promotes human health and well-being category” to capture non-safety related actions that are often not required of engineers.^{3,5,6}

Second, we observed that the “addresses community and stakeholder requests” criterion should also be re-interpreted. Students received credit for meeting the needs of their project sponsors, as well as those of broader stakeholders. While it was not possible for students to receive the maximum earned score by only addressing technical stakeholders’ needs, they were given credit for such efforts. Perhaps a re-interpretation of the earned points scale for this criterion, or a creation of a new sponsor-specific criterion, would more clearly capture students’ efforts to ensure inclusiveness during the design process.^{3,5,6} Interrater reliability in the original pilot was deemed acceptable via Krippendorff’s alpha (all $\alpha \geq .73$).⁸

Updating and Revising the Sustainable Design Rubric

In addition to the aforementioned limitations, we recognized the opportunity to refine the rubric and scoring process to broaden applicability to engineering design projects outside of civil and environmental engineering. In order to apply the rubric more broadly across engineering projects, it needs to capture criteria reflective of multiple engineering disciplines and be flexible in how criteria are weighted and evaluated. Consequently, we are revising the rubric in several major stages.

First, we conducted a systematic review of recent literature on sustainability/sustainable design instruction and evaluation to identify several themes in the literature that were not reflected in the original sustainable design rubric, as summarized in Figure 1. Across disciplines, themes of ethics, affordability and equity, as well as innovation emerged from the literature but were not explicitly reflected in the rubric’s criteria. Specifically within the chemical engineering literature, many key themes were already reflected in the rubric, with the exception of uncertainty. From the electrical and mechanical engineering literature, themes such as industrial ecology, technological adaptability, e-waste, and user experience were missing from the rubric. In addition, design for “X” (DfX) approaches, such as design for disassembly, were commonly discussed in the electrical and mechanical literature.³

Ethics (Across Disciplines)	Affordability and Equity (Across Disciplines)	Innovation (Across Disciplines)
Uncertainty (Chemical)	Industrial Ecology (Mechanical)	Technological Adaptability (Electrical)
E-Waste (Electrical)	User Experience (Electrical, Mechanical)	DfX Approaches (Electrical, Mechanical)

Figure 1: Sustainable design themes identified from systematic literature review³.

The current version of the sustainable design rubric reflects the original 16 criteria⁵ derived from the Nine Principles of Sustainable Engineering, as well as criteria associated with themes from the literature review.³ The set of 34 criteria are loosely grouped into four categories (Table 1).

Table 1: Draft criteria for cross-disciplinary sustainable design rubric (the original 16 criteria from the pilot phase are shown in *italics*)³.

Category	Criterion
Environmental	<i>Minimizes natural resource depletion</i>
	<i>Prevents waste</i>
	<i>Protects natural ecosystems</i>
	<i>Uses renewable energy sources</i>
	Provides for low-energy production
	Provides for technological adaptability
	<i>Uses inherently safe and benign materials (to environment)</i>
	Uses footprint analysis to estimate impact
	Analyzes embedded energy of alternatives
Social	<i>Addresses stakeholder or client requests</i>
	<i>Considers local circumstances and cultures</i>
	Incorporates public/stakeholder participation
	Incorporates user experience
	<i>Protects human health and well-being</i>
	<i>Uses inherently safe and benign materials (to humans)</i>
	Demonstrates ethics/ethical reasoning
	Reflects social responsibility
	Manufacturing complies with safety regulations
Economic	<i>Considers economic impacts of environmental design criterion</i>
	<i>Considers economic impacts of a social design criterion</i>
	<i>Conducts a cost and/or cost-benefit analysis</i>
	Demonstrates cost competitiveness or cost reduction
	Stimulates labor/jobs
	Considers affordability
	Promotes low-carbon economy
Other, including Tools	<i>Incorporates life cycle analysis</i>
	Uses DfX in design process (indicate “X”)
	Reflects cradle-to-cradle design
	Uses industrial ecology principles
	<i>Incorporates environmental impact assessment tools</i>
	<i>Incorporates systems analysis</i>
	Incorporates uncertainty analysis
	<i>Uses innovative technologies to achieve sustainability</i>
Reflects leadership	

Project Scope

We are engaged in an ongoing effort to refine and validate the cross-disciplinary sustainable design rubric to promote learning during and assessment of student-level design projects. The criteria identified as part of the previously-discussed literature review are being validated^{8,9} based on a survey of multi-disciplinary experts¹⁶, as well as comparison to existing sustainable design frameworks. Once rubric criteria are finalized, analytic Hierarchy Process, a multi-objective decision-making methodology¹⁰, will guide the refinement of rubric rating scales (Figure 2).

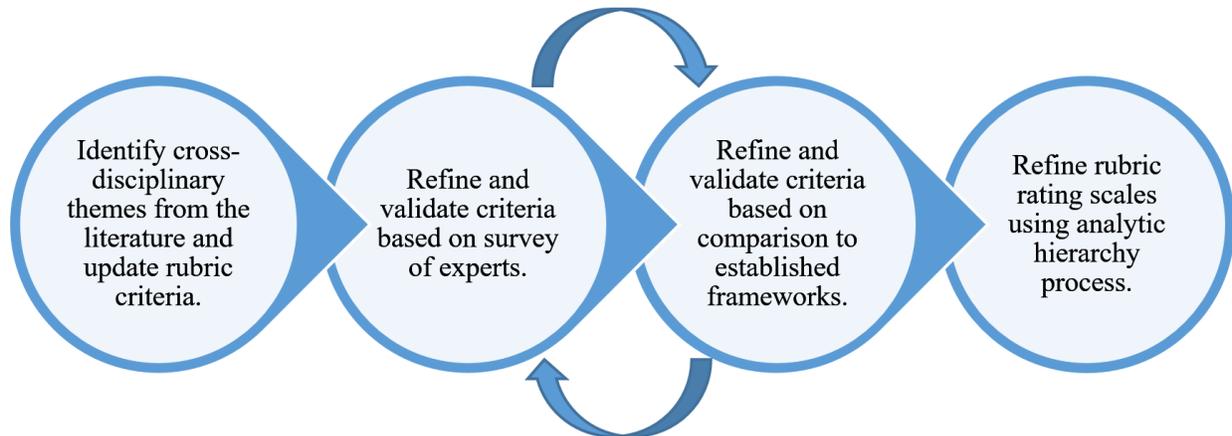


Figure 2: Process to refine and validate a sustainable design rubric for student-level projects.

In the context of our larger effort to produce a multi-disciplinary sustainable design rubric, the goal for this study was to compare sustainable design criteria from our rubric with widely-published sustainable development and design frameworks, including EnvisionTM, the Sustainability Tool for Auditing University Curricula in Higher-Education (STAUNCH), and the United Nations (UN) Sustainable Development Goals (UNSDGs). This study was designed to complement the systematic literature review previously discussed³ as a component of the *substantive* stage of construct validation⁸. Consequently, we address the following research questions in this study:

1. How do overlaps between the three published frameworks define the domain of sustainable design (i.e., *what is sustainable design*)?
2. Which criteria in the updated sustainable design rubric are validated by the overlaps between the published frameworks (i.e., *which criteria should be retained within the rubric*)?
3. Which overlaps between the published frameworks are not reflected in the updated sustainable design rubric (i.e., *are there criteria missing from the rubric*)?
4. Which criteria in the updated sustainable design rubric are not reflected in the published frameworks? (i.e., *are there criteria that should be omitted from the rubric*)?

Review of Sustainable Development and Design Frameworks

Several different frameworks were considered during the development of the initial rubric and during the current process of updating and validating the rubric's content. In addition to the three frameworks being used for comparison in this paper (Envision, STAUNCH, and Envision), a

special note should be given to the United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) rating system and the Association of American Colleges and Universities' (AACU) Valid Assessment of Learning in Undergraduate Education (VALUE) frameworks. Both of these frameworks contain themes relevant to this study and have been used by academics to teach and assess sustainability and related topics. LEED is a framework specifically targeted at improving the sustainability of all buildings, ranging from homes to corporate office complexes. Though this framework is focused on sustainability and like the Envision™ framework is also used for civil infrastructure, the focus of the LEED framework was deemed too specific for the cross-disciplinary rubric that we aim to develop. The AACU has several VALUE rubrics with themes of civic engagement, social responsibility and others related to sustainable design, however these frameworks are broad in nature, particularly with respect to academic discipline.

The following paragraphs provide more details on the Envision™, STAUNCH©, and UN Sustainable Development Goals, and Figure 3 provides a comparison of the major themes or categories included in each framework.

The Envision™ framework is a resource for planning, designing, building, and maintaining civil infrastructure that contains 60 criteria. The Envision™ framework was created and published in 2012 by the Institute for Sustainable Infrastructure, a Washington, DC based non-profit organization. As of January 2017, over 100 companies have an Envision™ sustainability professional trained on staff. Envision™ is unique in this regard, as it is specifically used to guide developers in designing sustainable infrastructure.¹¹

STAUNCH© is a framework consisting of 36 criteria divided into economic, environmental, and social items that is used to evaluate universities' integration of sustainability into curricula, via the evaluation of course descriptions. The STAUNCH framework was first piloted in 2007 at Cardiff University in the United Kingdom, and has been applied numerous times since the pilot.¹² As of January 2017, the STAUNCH framework is commercially available to other institutions. Due to the commercial nature of STAUNCH, this framework was the most difficult to evaluate, as specific detailed descriptions of the categories included within STAUNCH are not publicly available.

The UN Sustainable Development Goals contains 17 detailed items, ranging from “No Poverty” to “Partnerships for the Goals”. This framework was developed to provide guidance to the global community on how to develop sustainably. Consequently, it is inherently different from Envision™ and STAUNCH because it was not intended to evaluate projects or curricula. Publication of the UN Sustainable Development Goals is quite detailed, including a list of targets associated with each goal, as well as global progress towards these goals and. The UN Sustainable Development Goals were first introduced at the United Nations Conference on Sustainable Development in 2015, with its early history dating back to the United Nations Development Programme in 1966.¹³

<u>Envision™</u>	<u>STAUNCH©</u>	<u>UN SD Goals</u>
Quality of Life	Economic	No Poverty
		Zero Hunger
		Good Health and Well-Being
Leadership	Environmental	Quality Education
		Gender Equality
		Clean Water and Sanitation
Resource Allocation	Social	Affordable and Clean Energy
		Decent Work and Economic Growth
		Industry, Innovation, and Infrastructure
Natural World	Cross-cutting themes	Reduced Inequalities
		Sustainable Cities and Communities
		Responsible Consumption and Production
Climate and Risk	Cross-cutting themes	Climate Action
		Life Below Water
		Life on Land
		Peace Justice and Strong Institutions
		Partnerships for the Goals

Figure 3: Overview of the Envision, STAUNCH, and UN SD Goals Frameworks

We conducted a content analysis to compare and contrast the Envision™, STAUNCH, and UN Sustainable Development Goals frameworks. Although the specificity of items in each of the three frameworks differs, we consistently completed the content analysis across the major categories and sub-categories for each framework. Results of the content analysis are summarized as a Venn diagram (Figure 4). Items present that appear to be redundant (such as Social Justice and Gender Equality) were placed accordingly due to the level of specificity granted to these items by their respective frameworks. The diagram indicates that a majority of categories/sub-categories overlapped across the three frameworks. We also identified unique categories/sub-categories for each framework.

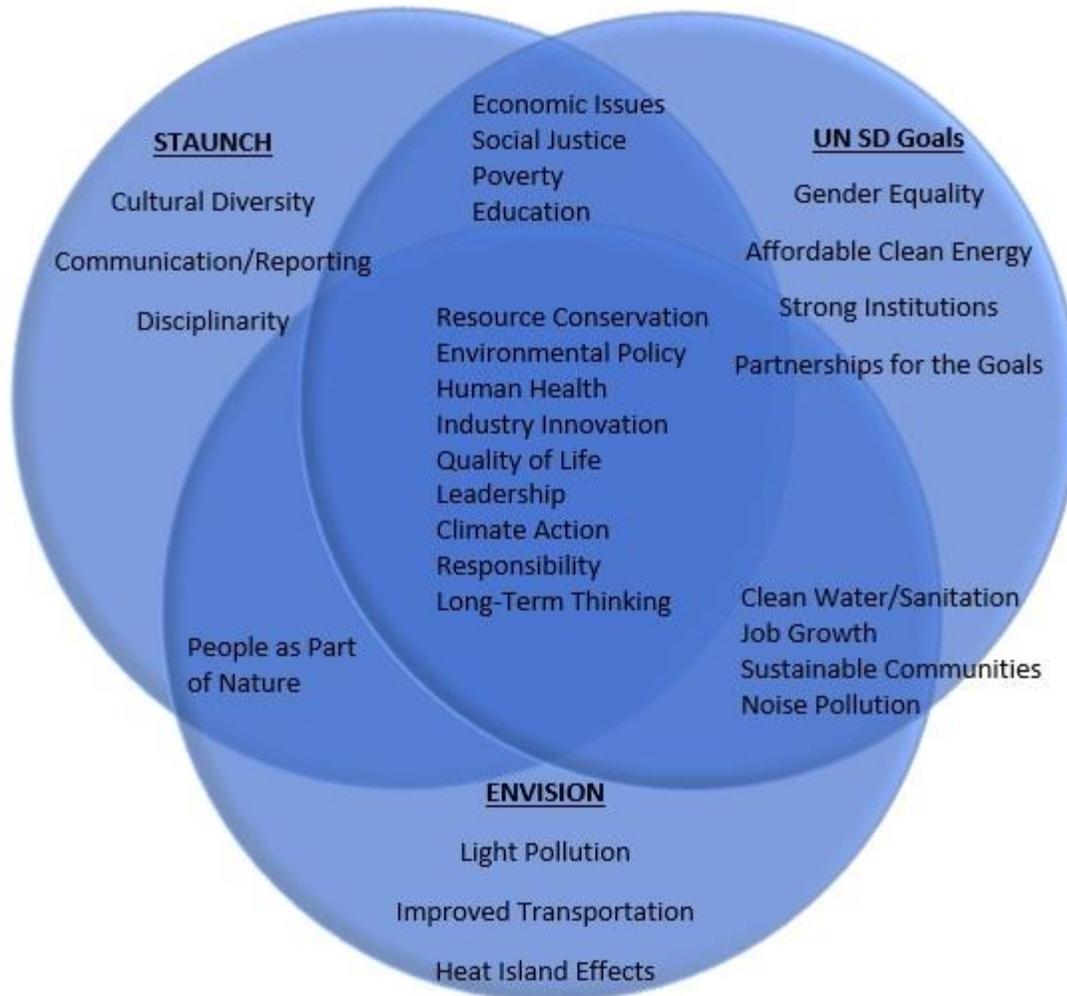


Figure 4: Comparisons between examined frameworks

When we compared the STAUNCH rubric to the Envision™ and the UN Sustainable Development goals, it had only a few categories that the other frameworks did not. “Cultural Diversity”, “Communication/Reporting”, and “Disciplinarity” were the only three categories that were not represented by the other frameworks. STAUNCH focuses more on incorporating multiple disciplines, and has greater emphasis on cultural diversity than Envision™, or even the UN Sustainable Development Goals.

The UN Sustainable Development Goals had more unique items than the other two frameworks. “Gender Equality”, “Affordable Clean Energy”, “Strong Institutions”, and “Partnerships for Achieving Goals” were categories that were relatively unique to the UN Sustainable Development Goals. “Affordable Clean Energy” was unique to the UN Sustainable Development Goals in that it emphasized affordability. “Gender Equality” was unique to this framework in the sense that it specifically emphasized the idea above and beyond cultural diversity and social justice. Overall, this framework considers almost everything the other frameworks consider, however occasionally lacks on utility for specific design applications and focuses more on using institutions to reinforce sustainability policy than the other frameworks.

Most of the criteria that were unique to the Envision™ framework can be attributed to the project-centric nature of the rating system. “Light Pollution”, “Improved Transportation”, and “Heat Island Effects” were the only broad criteria unique to Envision™. The “Improved Transportation” aspect is considered unique to Envision™ in that it emphasizes improving the utility of transportation for its users, not just making current transportation more sustainable. Overall, Envision™ focuses on high quality of life sustainable solutions but seems to fall short on considering affordability.

Method for comparing SD Rubric to Sustainability Frameworks

Procedure

As part of a larger effort to validate our Sustainable Design Rubric (Figure 2), we compared the 34 criteria listed in Table 1 to the Envision™, STAUNCH©, and UN Sustainable Development Goals (or UNSDGs) frameworks. Each of the three researchers independently compared the Sustainable Design Rubric to each of the three frameworks. Relationships between rubric and framework criteria were noted and specific quotations from the three frameworks were provided to substantiate any overlaps. For example, if one of the three researchers were evaluating the STAUNCH criteria and found that “Minimizes natural resource depletion” addressed the “Biodiversity” criterion, then the researcher would add a single point. After each of the three researchers made their respective comparisons of the Sustainable Design Rubric against the three frameworks, the researchers compared and contrasted their results.

Individual scores were compiled to aid in conducting a gap analysis between our rubric and the established frameworks. During this comparison, if an item received validation from a researcher, then it was scored as a 1. If the item did not receive validation from that specific researcher, then it was scored as a 0. Each of the three scores for each framework were totaled. If an item received a score of at least 2, then it was considered validated (out of a potential 3). If the item received a score of 0 or 1, then it was considered invalidated (score = 0) or weak (score = 1). For example, only one researcher considered that our criterion of “Prevents waste” was validated by STAUNCH’s “GNP, Productivity” category. Consequently, that item is considered to weakly apply to the “GNP, Productivity” category.

An inverse of the above analysis was conducted to determine the relevance of items on our rubric to categories in the established frameworks. This analysis sought to eliminate redundant or unused criteria on the Sustainable Design Rubric by identifying minimally used items on the rubric.

Results

Envision™ had the largest number of potential gaps with 15 unaddressed items (see Table 2), however it had no items that did not receive validation from at least one of the three researchers. The lowest-ranking item of the Envision™ framework was the “Address Conflicting Regulations & Policies” category, which received an overall score of 1 (meaning that only one researcher gave credit to this category, and only via a single item on the Sustainable Design Rubric). Specifically, with Envision™, our rubric seemed to fail to address issues of policy and conservation, which may be attributed to the project-centric nature of Envision™.

Table 2: Envision™ Gap Analysis

	<u>Specific Items</u>
<i>Minimally Applied Items (from our rubric)</i> (Score < 4; Range 0-50; TR 0-162; Mean = 8.82)	8/34 = 24% Potentially Irrelevant
<i>Unaddressed Items (on the compared framework)</i> (Score < 4; Range 1-15; Mean = 5.00)	15/54 = 25% Potential Gap
<i>Strongly Addressed Items (on the compared)</i> (Score > 8; Range 1-15)	5/54 = 9% Strongly Addressed

Nearly all items on the Sustainable Design Rubric mapped to the STAUNCH criteria, as shown in Table 3, with the lowest-scoring item receiving a score of 7. That being said, STAUNCH had a significant number of items that our rubric did not account for (11 out of 36 total items), with 3 of those items being especially weak. Compared to the STAUNCH rubric, our rubric seems to struggle with issues of demography and general social issues (such as cultural diversity, general diversity, and social cohesion). The three lowest-scoring items may be underscored due to lack of specific criteria, apart from “Disciplinarity”, which may be due to the university-wide nature of STAUNCH’s application. Of the 11 items that our rubric did not strongly match to, 7 items were under STAUNCH’s “Social” category.

Table 3: STAUNCH Gap Analysis

	<u>Specific Items</u>
<i>Minimally Applied Items (from our rubric)</i> (Score < 16; Range 7-40; TR 0-108; Mean = 24.21)	2/34 = 6% Potentially Irrelevant
<i>Unaddressed Items (on the compared framework)</i> (Score < 15; Range 0-43; Mean = 23.51)	11/36 = 31% Potential Gap
<i>Strongly Addressed Items (on the compared)</i> (Score > 38; Range 0-43)	4/36 = 11% Strongly Addressed

Compared to STAUNCH and Envision™, our rubric had more irrelevant items when compared to the UN SD Goals than any other framework, as shown in Table 4. We did not need to utilize all of our items to make a strong mapping to the UNSDGs framework. Out of the 17 UNSDGs, only 3 of our items mapped weakly, with the lowest of those items scoring a 9 (with Envision™ and STAUNCH receiving a lowest score of 1 and 0 on poorly mapped items, respectively).

Table 4: UN Sustainable Development Goals Gap Analysis

	<u>Specific Items</u>
<i>Minimally Applied Items (from our rubric)</i> (Score < 4; Range 0-33; TR 0-51; Mean = 8.74)	14/34 = 41% Potentially Irrelevant
<i>Unaddressed Items (on the compared framework)</i> (Score < 12; Range 9-27; Mean = 17.47)	3/17 = 18% Potential Gap
<i>Strongly Addressed Items (on the compared)</i> (Score > 19; Range 9-27)	6/17 = 35% Strongly Addressed

Though the Sustainable Design Rubric matched in acceptable fashion to the three other frameworks, there were a few specific areas in which the rubric stood out as exemplary. When compared to the Envision™ rating system, the rubric scored exceptionally well in the “Stimulate

Sustainable Growth & Development”, “Minimize Noise and Vibration”, “Reduce Net Embodied Energy”, “Support Sustainable Procurement Practices”, and “Reduce Energy Consumption” categories. When compared to the UN Sustainable Development Goals, the rubric performed exceedingly well in the “Zero Hunger”, “Clean Water and Sanitation”, “Affordable and Clean Energy”, “Industry, Innovation and Infrastructure”, “Sustainable Cities and Communities”, and “Responsible Consumption and Production” categories. When compared to the STAUNCH framework, the Sustainable Design Rubric performed exceedingly well in the “Resource use”, “Production, Consumption Patterns”, “Alternatives”, and “Holistic Thinking” categories.

The Venn diagram below (Figure 5) summarizes how well the Sustainable Design Rubric criteria mapped to all three frameworks, and highlights areas that may be gaps. In the diagram, categories and sub-categories that were mapped weakly to the rubric are highlighted in yellow, and categories and sub-categories that mapped strongly are highlighted in green. Categories that were not mapped to by any rubric criterion are not highlighted.

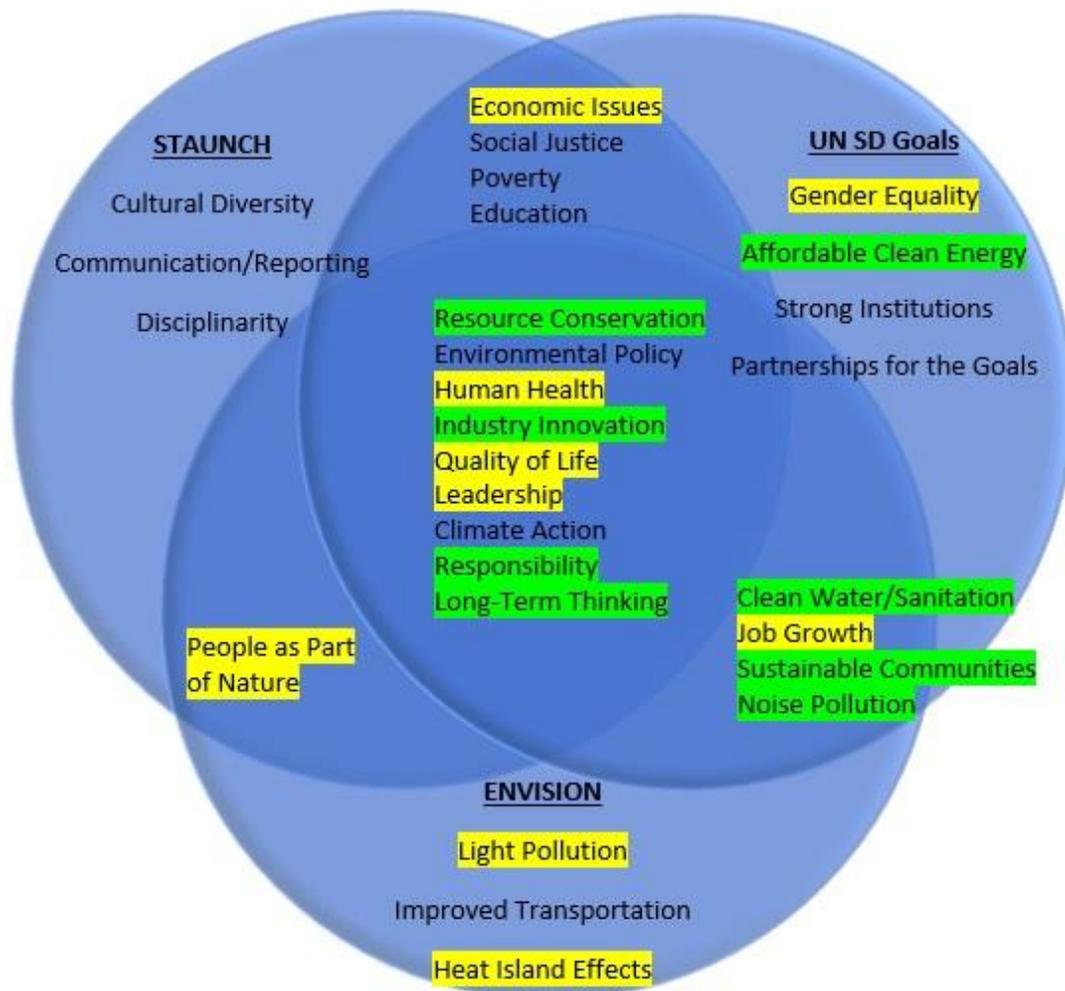


Figure 5: Summary of gap analysis when SD rubric compared to examined frameworks

Table 5 lists the eight items from our SD Rubric least used in the other frameworks; the second column indicates the number of frameworks (out of 3) to which they were minimally applied. In

this table, a "higher" score is worse and may indicate a criterion that is not widely applicable to sustainability or across disciplines.

Table 5: Minimally Applied Items on the Sustainable Design Rubric

Sustainable Design Rubric Item	Score
Incorporated user experience	3
Incorporates uncertainty analysis	2
Manufacturing complies with safety regulations	2
Used DfX in design process (indicate "X")	2
Uses footprint analysis to estimate impact	2
Uses industrial ecology principles	2
Demonstrates ethics/ethical reasoning	1
Considers affordability	1

Discussion

Based on the comparison of our 34 draft criteria against the sustainability categories included in the other three frameworks, summarized in Figure 4 and Table 5, criteria fall into three groups: (1) criteria validated by the established frameworks and thus important to keep in the rubric, (2) criteria that need to be added or modified in order to reflect important themes in the frameworks that are missing or not emphasized in our rubric, and (3) criteria included in our rubric but not emphasized in the frameworks and thus could be omitted or combined with other criteria.

Overall, the revised Sustainable Design Rubric mapped well to all three frameworks, however the rubric did perform poorly in a few areas. Our rubric demonstrated strengths in long-term planning, resource protection and conservation, cost-competitiveness of sustainability features, and industry innovation. In addition, the draft criteria satisfactorily reflect quality of life considerations, human health and safety, economic considerations, and gender equality. The rubric universally fails to address issues of policy and regulation, including environmental areas and climate action. Surprisingly, the Sustainable Design Rubric did not perform as strongly as expected with issues of environmental conservation, particularly compared to two of the other frameworks (Envision™ and UNSD Goals). Furthermore, the rubric's criteria failed to address issues of education and fighting corruption compared to two other frameworks (STAUNCH, UNSD Goals), and came up short on all STAUNCH diversity-related categories.

Comparison to the STAUNCH framework seemed to indicate the most gaps in our rubric. This finding is surprising given that STAUNCH is, at least conceptually, the most similar of the established frameworks to our rubric given its focus on engineering education. The unexpected findings may be attributed to the relative lack of information surrounding STAUNCH compared to the other two frameworks, which limited our ability to support the text mapping with specific examples. More likely, the poorer match is due to STAUNCH's focus on the curriculum/program-level for its categories rather than individual projects. In particular, the gaps in Disciplinarity and Communication/Reporting seem more appropriate to address with a project assignment (for example, team expectations or the type of deliverables) rather than a rubric to evaluate the completed project. A lingering question is: Why do we lack on Culture/Diversity issues and is this a problem with our rubric? Despite revisions to the social criteria after the rubric's pilot phase, it seems that the stakeholder criteria need to more explicitly

address inclusion of diverse perspectives or culturally-responsive design practices in order to resolve this issue.

Looking specifically at categories unique to the UN Sustainable Development Goals, our rubric seems to lack on institutional issues, both strengthening responsible institutions and forming effective partnerships to accomplish goals. This gap is likely due to the global nature of framework, and thus it is unlikely that undergraduate student design projects would be able to adequately address such significant institutional issues. On the other end of the spectrum, the specific gaps in comparison to the EnvisionTM Rating System's unique categories (like transportation, light pollution, and heat island effect) seem related to the relatively narrow focus of that framework on infrastructure projects and thus would not warrant new criteria in the cross-disciplinary rubric. However, each of those categories could provide examples for how a student project might address a social or environmental criterion.

Upon further reflection, many of the criteria presented in Table 5 as being weak or rarely used by the established frameworks fall into a similar situation of being more narrowly defined for specific disciplines (e.g., manufacturing complies with safety regulations), and thus could be broadened to apply to more project types or used as an example for how to achieve a related criterion (e.g., "incorporated user experience" to meet stakeholder needs). Some of the underutilized criteria, including affordability and uncertainty analysis, seem to warrant inclusion in the rubric with modification since they showed up in the systematic literature review from across disciplines.

Conclusions and Future Work

The purpose of this particular study, within the sustainable design rubric development project, was to further define both the theoretical and empirical domains of sustainable design. By analysing the three frameworks, researchers can not only examine how the three frameworks overlap but can also explore the breadth of the construct by examining those areas that are unique to each framework. Furthermore, by examining how the Sustainable Design Rubric maps back to the three frameworks, the researchers can explore how the empirical domain, as it is currently defined by the rubric, maps back to the theoretical domain represented by the established frameworks. Following gap analysis, the majority of criteria in the SD Rubric mapped well to the established frameworks, however eight criteria may not be necessary or could be incorporated into another criterion as an example of how to satisfy that criterion for a specific project type. Based on the gap analysis and the scope of the rubric for undergraduate engineering projects, a handful categories, including climate action, social justice, and cultural diversity, new criteria or revision of existing criteria became a priority. Based on the gap analysis, three researchers reviewed all current criteria. Each rubric item was then either left untouched, combined into another rubric item, or removed outright. This process aimed to make the rubric more effective, and to reduce the size of the rubric for both the sake of parsimony and for future expansion. After thorough review, the researchers came up with a new revised list of criteria, totaling 15 items as shown in Table 6, down from the original set of 34.

In future work, we will continue the content validation process with expert review of the draft criteria and will then update the criteria by reconciling differences between the expert panel

feedback and this framework analysis. Then, the scoring approach will be refined as needed and the resulting rubric will be tested on work products from completed student projects.

Table 6: Revised criteria following the review of the 34-item rubric

Category	Criterion
Environmental	A1: Minimizes natural resource depletion
	A2: Prevents waste
	A3: Protects or enhances natural ecosystems
	A4: Designs for long-term resilience or adaptability
Social	B1: Addresses needs of diverse stakeholders
	B2: Incorporated public/stakeholder participation
	B3: Protects human health and physical safety over lifecycle
	B4: Promotes human well-being and enhances quality of life
	B5: Identifies and addresses future community needs
	B6: Reflects social responsibility
Economic	C1: Considers economic impacts of environmental design criterion
	C2: Considers economic impacts of a social design criterion
	C3: Considers trade-offs between social and environmental criteria
	C4: Evaluates economic lifecycle costs and benefits
	C5: Considers affordability or demonstrates cost competitiveness or cost reduction
Additional Points	X1: Uses and/or creates innovation(s) in its specific field to achieve sustainability – up to 3 bonus points
	X2: Incorporates formal analysis or design methodologies (either quantitative or qualitative) to support criteria – up to 1 bonus point each (<i>Examples: incorporates uncertainty analysis; uses industrial ecology principles; used DfX in design process (may be field specific, indicate X); quantitative LCA; incorporates environmental impact assessment tools; systems analysis/optimization; analyzed embedded energy of alternatives; uses footprint analysis to estimate impact; stakeholder engagement best practices; risk assessment</i>)
	X3: Worked with experts from other disciplines to enhance process or final design

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