Sustainability and the Built Environment:
A Metric and Process for Prioritizing Improvement Opportunities

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Problem Description

- Increasing sustainability of built facilities:
  - Many options
  - Limited resources
- Need a method to evaluate and prioritize improvement options for specific built facilities, according to their relative impact on facility sustainability

Background

- Existing facility sustainability resources:
  - Heuristics/guidelines, Resource guides, Models/frameworks, Assessment/evaluation tools
- Differing definitions of built environment sustainability
- Lack of context-specificity or generalizability
- Inability to prioritize improvement options on a facility scale

Objective & Scope

- Research Objective:
  - To create a method for prioritizing improvement options for existing, operating facilities in terms of their relative improvement in the sustainability of those facilities
- Research Scope:
  - Built Environment $\cap$ Sustainability $\cap$ Decision Making

Hypothesis

- It is possible to develop a model of built facility sustainability that allows decision makers to prioritize facility improvement options according to their relative influence on facility sustainability

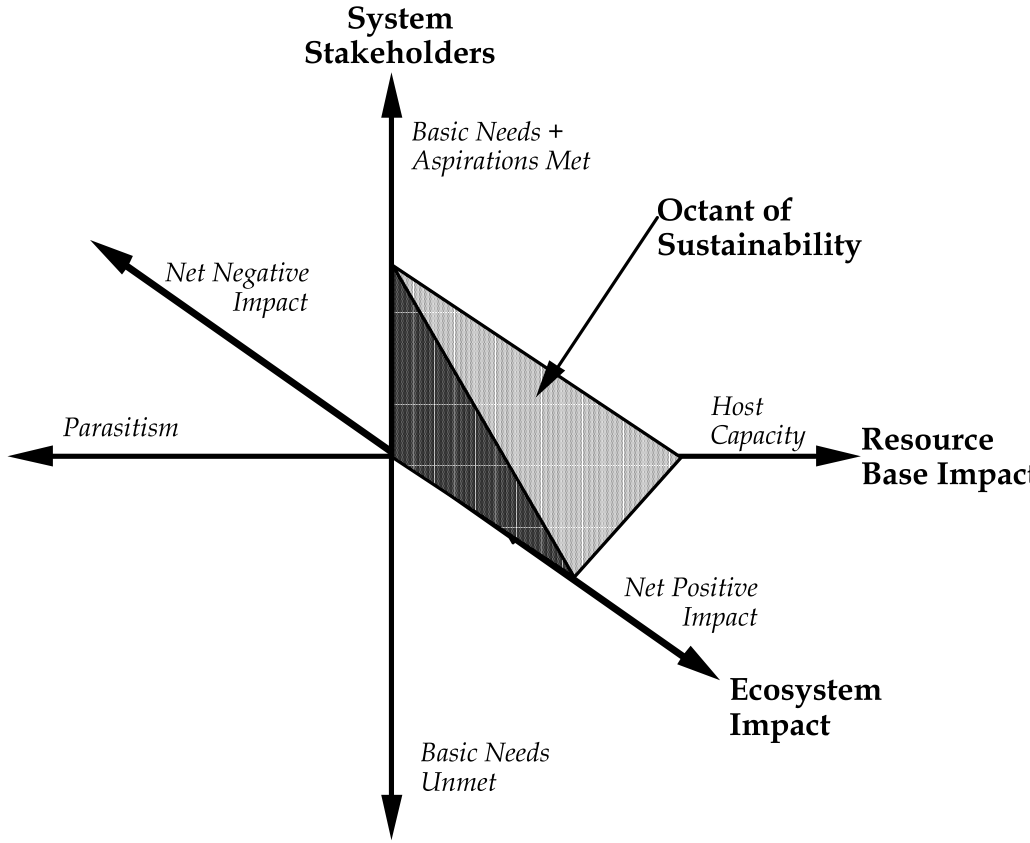
Research Approach

- Three Phases:
  - Alignment & Construct Development
  - Construct Operationalization & Model Building
  - Process Development & Model Application

1) Alignment & Construct Development

- **Objective:** to develop a unified construct of sustainability for systems
- **Approach:** constraint search corroborated by content analysis of sustainability definitions
- **Rationale:** disparity in understanding of sustainability reflected in the current literature

1) Alignment & Construct Development



2) Construct Operationalization & Model Development

- **Objective:** to express the construct of sustainability in terms of built facility variables and to specify logical relationships among the variables
- **Approach:** development of a systems model for built facilities and deduction of variables and relationships from the model
- **Rationale:** operationalization of the model is needed to evaluate the sustainability of options

2a) Construct Operationalization & Model Development

	Intra-System Impacts	**Extra-System Impacts**
Stakeholder Satisfaction	• Stakeholder expectations met • Relative importance of stakeholder expectations	NA – See §5.1.2
Resource Base Impacts	• Change in intra-system resource bases • Significance of change	• Resource flow into/out of facility system • Unit impact exerted by flow on source/sink system • Significance of unit impact
Ecosystem Impacts	• Change in intra-system ecosystems • Significance of change	• Resource flows into/out of facility system • Unit impact exerted by flow on source/sink system • Significance of unit impact

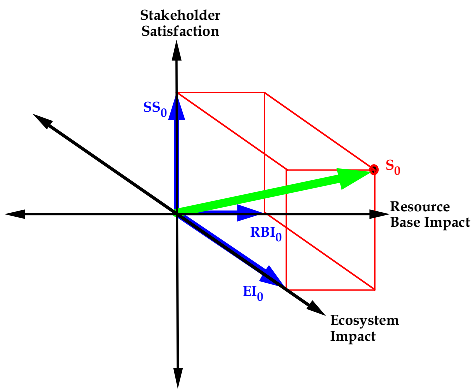
2b) Construct Operationalization & Model Development

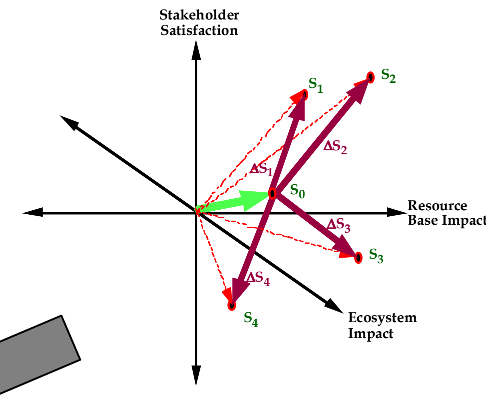
Parameters/Variables	Description	Range
SS = $(E_E - E_{NM}) / E_T$	**Stakeholder Satisfaction Parameter**	**[-1, 1]**
E_M	Number of Stakeholder Expectations Met	[0,∞]
E_{NM}	Number of Stakeholder Expectations Not Met	[0,∞]
E_E	Number of Stakeholder Expectations Exceeded	[0,∞]
$E_T = E_M + E_{NM} + E_E$	Total Number of Stakeholder Expectations	[0,∞]
RBI = $\tanh(RBI_I + RBI_E)$	**Resource Base Impact Parameter**	**[-1, 1]**
$RBI_I = \Delta RB_I * \omega_{\Delta RB}$	Intra-system Resource Base Impact	[-1, 1]
ΔRB_I	Change in Intra-system Resource Base for unit time	[-1, 1]
$\omega_{\Delta RB}$	Significance of Change in Intra-system Resource Base	[-1, 1]
$RBI_E = Q * RBI_S/Q_T$	Extra-system Resource Base Impact	[-1, 1]
Q	Quantity of Flow between System & Source/Sink System	[0, ∞]
RBI_S	Resource Base Impact of Source/Sink System	[-1, 1]
Q_T	Total Quantity of Flow Served by Source/Sink System	[0, ∞]
EI = $\tanh(EI_I + EI_E)$	**Ecosystem Impact Parameter**	**[-1, 1]**
$EI_I = \Delta EI_I * \omega_{\Delta EI}$	Intra-system Ecosystem Impact	[-1, 1]
ΔEI_I	Change in Intra-system Ecosystems for unit time	[-1, 1]
$\omega_{\Delta E}$	Significance of Change in Intra-system Ecosystems	[-1, 1]
$EI_E = Q * EI_S/Q_T$	Extra-system Ecosystem Impact	[-1, 1]
Q	Quantity of Flow between System & Source/Sink System	[0, ∞]
EI_S	Ecosystem Impact of Source/Sink System	[-1, 1]
Q_T	Total Quantity of Flow served by Source/Sink System	[0, ∞]

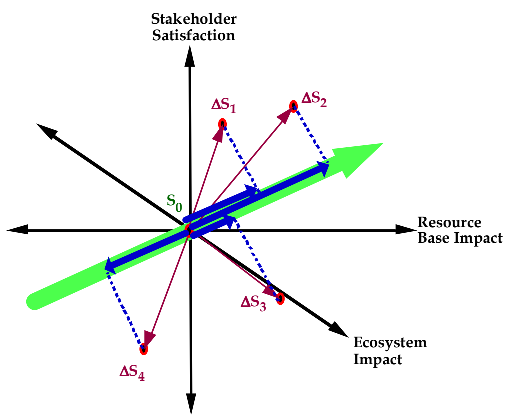
3) Process Development & Model Application

- **Objective:** to specify a process for using the model to prioritize improvement options
- **Approach:** adaptation of classical decision model plus three-dimensional comparison process
- **Rationale:** method of application needed for the sustainability model to accomplish the objective of the research, i.e., option prioritization

3) Process Development & Option Prioritization







Priority	Option	Sustainability Change
1	Pool Cover	+0.06698
2	Crawl Space Insulation	+0.03392
3	Hot Water Heater Jacket	+0.01937
4	Compact Fluorescent Light Bulbs	+0.01934
5	Low-Flow Fixtures	+0.01451
6	Gazebo	-0.00212

Stipulations

- Limits of all three parameters are [-1, +1]
- One year time period for each model run

Assumptions

- More options than resources to implement them
- Options have different relative sustainability impacts
- Parameters are scalable and can be combined as a multi-dimensional decision space
- Parameters are equally weighted

Validation Questions

- Was it possible to construct a model of built facility sustainability that can prioritize improvement options?

- Do the variables used in the model really reflect the properties of built facilities that determine their sustainability?

Validation Questions, cont'd.

- Does the model's prioritization of options make sense in terms of what is known about built environment sustainability?
- Will the model work in other situations? If so, in what other situations can it be effectively applied?

Impacts to the A/E/C Industry

- Provides a discrete and straightforward way to comprehend the concept of sustainability
- Stakeholders now know what kinds of data to collect, and how to use the data to evaluate facility sustainability
- Stakeholders now have a demonstrated method to prioritize improvement options in terms of their relative sustainability impacts

Lessons Learned and Future Research

- **Lesson 1:** Direct examination of vectors within the three-dimensional decision space provides more information than the composite sustainability index to assist with the prioritization of options.
- **Future Research:** Better ways of manipulating the three-dimensional representation are needed.

Lessons Learned and Future Research

- **Lesson 2:** The scaling of the SS parameter may visually overwhelm the other parameters, although the scaling is reasonable and the other parameters are still integral to the ranking of options.
- **Future Research:** Better visual mechanisms for comparing options with small parameter variations are needed.

Lessons Learned and Future Research

- **Lesson 3:** Measurement error in the inputs/outputs of source/sink systems may be on the same order of magnitude as the changes effected by the improvement options.
- **Future Research:** More accurate measurement/estimation techniques are needed to expand the model to an interval scale.

Lessons Learned and Future Research

- **Lesson 4:** When additivity constraints are observed, feasibility constraints play a role in how combinations of options may be ranked.
- **Future Research:** Experimentation in different decision environments and with formal preference elicitation techniques should be undertaken to evaluate the effects of the decision environment on the feasibility and ordering of improvement options.

Lessons Learned and Future Research

- **Lesson 5:** Lack of data may be a constraint to application of the model in current practice.
- **Future Research:** Better monitoring and archiving of data and more complete records and databases will improve the precision of the model if it is extended to an interval scale, and the usability of the model on an ordinal scale.

Lessons Learned and Future Research

- **Lesson 6:** As constructed, the Stakeholder Satisfaction Scale restricts the additivity of options and may be limited in its applicability to other types of facilities and stakeholder sets.
- **Future Research:** Experimentation with different scale items, Likert configurations, and mathematical properties is needed to optimize SS scale performance.

Lessons Learned and Future Research

- **Lesson 7:** How initial option impacts are distributed over time may influence the prioritization of options.
- **Future Research:** The potential for life cycle analysis using the model should be explored, along with an analysis of alternate methods for amortizing one-time impacts of improvement options.

Conclusion

- **Initial Hypothesis:** It is possible to develop a model of built facility sustainability that allows decision makers to prioritize facility improvement options according to their relative influence on facility sustainability

- **Outcome:** The research supported this hypothesis by constructing such a model and demonstrating its application