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Decision-making for UBC High Performance Buildings: Multi-criteria Analysis for Integrated Life Cycle Models

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Foreword

This report describes a research project during Stefan Storey's participation in the 2010 Young Scientists Summer Program (YSSP) with the Integrated Modeling Environment research group at the International Institute of Applied Systems Analysis in Laxenburg, Austria. The focus of this research is on the development of a Decision Support System (DSS) for sustainable building design at the University of British Columbia. The framework includes the use of Multi-Criteria Decision Analysis (MCDA) to assist building designers, developers and operators in using a broad spectrum of life cycle financial and environmental impacts to inform their decision-making process.

The DSS model is not aimed at simulating an optimal building design, rather, the model helps the decision-makers to examine trade-offs between the environmental, social and economic impacts of a given building design, and compare them against other competing designs, as well as against local benchmark performance data.

The DSS structure, schedule and timeframe are harmonized with the current use of the Integrated Design Process (IDP) at UBC. Although the DSS is tailored to the specific requirements of UBC, the DSS framework can be applied to other institutions across North America. Therein, DSS serves as a blueprint for improving and streamlining decision-making for sustainable buildings with decision criteria sourced in both locally contextualized metrics and internationally recognized metrics such as ISO 21912-1.

Although this paper does not examine the technical details that exist internally within MCDA it is important to acknowledge that there are various methodological and mathematical challenges to each algorithm. Instead, this paper focuses on the use of MCDA for integrating life cycle model information with other related quantitative inputs and qualitative inputs.

The work completed during the YSSP involved integrating the outputs of life cycle models already constructed for use by UBC. The life cycle models produce a broad set of simulated quantified impacts but have not yet been unified by a single DSS tool. The DSS project outlines a framework for bringing the outputs together and utilizing the data within the context of decision structures and decision flows at UBC. This framework is defined as the (UBC LC MCDA) framework. Although it is applicable to current LC models that have already been developed by the UBC Sustainability Office and Infrastructure Development, it can serve as a blueprint for other institutions.

Abstract

The current paradigm of building design is evolving rapidly and building developers are beginning to adopt sustainable building practices across Canada. Attaining a sustainable built environment is challenged by the complexity of decision-making and stakeholders need to examine a large number of sustainability metrics to support a ‘good’ decision. Each sustainable building development has a design path unique to the values of the building stakeholders. This project outlines a framework that assists decision-makers in achieving a building design that is closely aligned to their values and requirements.

This paper outlines a decision-support system that brings together a broad set of sustainability metrics, both quantitative and qualitative, into a multi-criteria decision analysis tool where decision-makers can contrast and compare the simulated performance of competing building designs. The performance modeling tools include environmental life cycle analysis (Athena EIE), financial modeling by life cycle costing (UBC ID), energy modeling (eQuest). Benchmark information, required for informing decision-makers of baseline conditions, is derived from the UBC_LCA database, UBCPT, and UBC Operations data. Social benchmarks are determined from the UBC Post occupancy protocol under development at UBC. These metrics and benchmarks are synthesized and integrated into the multi-criteria decision analysis framework as optional attributes from which decision-makers can select as decision criteria

The multi-criteria decision analysis framework includes a method to harmonize decision-making within the decision-flow defined by the Integrated Design Process. A best-practices set of sustainability indicators are developed from metrics specified by ISO 21912-1, LBL, ASHRAE and UBC’s own criteria developed as part of the UBC Buchanan and CIRS projects. Finally, the paper discusses how decision-makers can express their preference for each criteria so that their expertise and values are accurately reflected when analyzing the criteria performance results. Methods to check for ‘future-proofing’ are also discussed in terms of checking the life cycle models for resilience to future change.

Acknowledgments

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About the Author

Stefan holds a Masters degree in Mechanical Engineering from the University of British Columbia. His current research is focused on assessment methods that evaluate the life cycle social, financial and environmental impacts of commercial buildings. He is currently collaborating with BC Hydro and Stantec Consulting Ltd with research work at the Centre of Interactive Research and Sustainability (CIRS). Stefan plans to construct a scenario and analytical framework that will enable an integrated model to handle both temporal change and uncertainty.

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DSS:	Decision Support System
LEED:	Leadership in Energy and Environmental Design
CIRS:	Center for Interactive Research in Sustainability
LCA:	Life Cycle Analysis
LCC:	Life Cycle Costing
NIST:	National Institute of Standards and Techonology
OMB:	Office of Management and Budget
FEMP:	Federal Energy Management Program
ISO:	International Standards Organization
POE:	Post Occupancy Evaluation
LC:	Life Cycle
MCA:	Multi Criteria Analysis
MCDA:	Multi Criteria Decision Analysis

Decision-making for UBC Sustainable Buildings: Multi-criteria Analysis for Integrated Life Cycle Models

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1. Introduction

1.1. Background

Maintaining, renewing and expanding the current global building stock has a large impact on the global environment, economy and society. Economically, building construction and renovation is a major global industry (OECD 2003). At $4.7 trillion annually, it constitutes 9-10% of the global GDP. In the United States and Canada, construction investments amount to $1.2 trillion and $193 billion per year respectively (WGBC 2008) (UNEP 2007). Increasingly, a large proportion of those buildings are built to locally defined "sustainable" standards. Sustainability is a malleable and interpretable concept that is strongly contextualized by regional, cultural and social values. In Canada and the US, a sustainable building or community can be defined as a high performance system that minimizes its use of finite resources such as water, materials and energy while maintaining a comfortable and healthy indoor environment (Lucuik 2008). The uptake of sustainable building practices in North America has shown to be exponential. In the USA, it is predicted that nearly 20% of all construction projects will be sustainable by 2013 (WGBC 2008). Supporting good decision-making practices has become paramount in finding appropriate solutions for sustainability, particularly with regards to the correct choice and mix of integrated technologies to ensure high building performance during operation. It is high building performance that is the signature and mark of success of strong sustainable design.

Currently, there are many initiatives to support the adoption of 'green' building practices, including commercial green certification tools such as LEED®TM and Green Globes building rating systems. Rating systems, as exemplified by LEED®, are prescription based point systems. However, they are of limited use as design tools. The output of a rating is not a sustainability assessment, but rather a claim of sustainable building practices that is certified by a commercial third party. The prescriptive rating system can be useful as an easy-to-use guide, but unfortunately diverts the attention of decision-makers towards 'point-grabbing' and away from attaining high performance. Recent studies have shown that the LEED® rating system has certified buildings with highly variable performance profiles (Scofield 2003; Turner and Frankel 2008). Ensuring performance requires a new approach; moving away from lists of disconnected technologies and strategies and towards a whole-building integrated performance approach (Horman, Riley et al.) that is informed by scientific tools and impact assessments. A focus on performance enables innovation by focusing on a performance *goal* and removing restrictions that accompany prescriptive pathways[1]. For performance to be meaningful to a building's stakeholders, it must conform to local expectations of impact reduction and uphold the social

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[1] British Columbia Context: The shift to a performance approach is underway in British Columbia. The performance approach has had many successes including two pioneering projects; CIRS at the individual building scale and Dockside Green at the community scale.

utility, comfort, health and safety for all future building inhabitants. Cole and many other leading researchers state that it is of paramount importance that the future well-being of the inhabitants must be considered at the design outset (Cole 2001; Cole and Howard ; Brager and deDear 2005). This includes provision for adaptive and interactive controls (Brager and de Dear 2000). Without due consideration of inhabitant behavior, even low energy building performance will be compromised by inhabitants attempting to attain an acceptable level of comfort (Brown 2009).

A focus on performance necessarily entails a careful characterization of the meaning of performance metrics such as resource use reduction and inhabitant comfort support. For buildings, which are a highly persistent feature in our built environment, performance must be framed over long time frames. With life times often in excess of fifty years, performance must be considered from a life cycle analysis context. Additionally, in order to ensure that high performance is defined correctly, building stakeholders and decision-makers must examine best-practices, benchmark standards, and most importantly, pinpoint the appropriate performance metrics that they regard as collectively important. These performance metrics are hereby defined as '*attributes*'. Before a building is rebuilt or renovated, these life cycle attributes are defined by decision-makers so that various building solutions can be compared against one another. The goal is that the building with the most favorable characteristics, and hence best performance profile, will be selected for construction.

An additional design focus that has become influential in defining sustainability for UBC, and more broadly in the general built environment, is resilience to future change. While future conditions cannot be predicted or forecasted, a relative measure of resilience can be tested with sensitivity analysis. This involves perturbing individual variables, such as energy prices, over long time frames to produce simulated data of total lifecycle impacts. While this concept is simplistic and does not measure uncertainty, it serves to provide insight for designers wishing to 'future-proof' new buildings.

To assist UBC in constructing performance based sustainable buildings, this research sets out to provide a framework for a future Decision Support System (DSS). This research is composed by three main goals. The first goal is to provide a comprehensive set of attributes that can act as a template for use by UBC. This is sourced from several leading industrial and research organizations including ASHRAE and ISO. The second goal is to suggest an appropriate MCDA tool that will calculate an optimal solution based on attribute performance levels and user preferences. The last goal is to suggest how the Decision-Support System can be harmonized with UBC's favored design approach: the Integrated Design Process. This report does not examine methods to calculate or quantify uncertainty. A formal treatment of uncertainty will be provided in a subsequent work on back casting techniques for dealing with uncertainties in sustainable building life cycles and will follow the methodologies of (Robinson 1989; Dreborg 1996; Becker 2010)

This report is structured as follow. Section 2 reviews the general approach to Decision-Support systems for sustainable design and an overview of UBC requirements is discussed, along with UBC vision and long-term goals. Sections 3 and 4 discuss the selection process of local and globally defined sustainability metrics and how to use these metrics during the Integrated Design Process. Section 4.2 discusses the use of the IIASA MCA tool to assist and streamline the use of sustainability metrics during the decision-making process. Supporting details regarding stakeholder participation are provided in Appendix A.

2. Decision-Support: Context and background

The design of buildings is reflective of the needs and goals of the building developers, architects, clients and users.

In the past, conventional design approaches to commercial buildings have been product oriented with their design process viewed as a cascade of high-level developer decisions flowing linearly down to building construction. Approximately, in sequential order, the conventional process sequence is from client to building developer, and on to architect, engineer, and finally to construction (Pearl 2004). This 'product delivery' path has led to a host of operational problems including increased costs due to energy inefficiency and social costs due to sub standard indoor environments (iiSbe 2004). Building owners, tenants, and occupants all suffer different aspects of unsustainable economic, social and environmental impacts due to poor performance long after the ‘product’ was built or ‘delivered’.

For the successful implementation of performance targets, a design process must be participatory and be balanced between different types of expertise and stakeholder needs. In building design, who, when and why each participant is involved depends on the project scale and impacts on the community. Critically, roles and intentions of participants, and the depth of involvement are governed by a choice of whether to build to conventional standards or to green standards (Cole 2005). The typology of a particular participatory design process is typically problem-centered and is defined by stakeholders and guided by appropriate expertise (Robinson, Carmichael et al. 2006; Carlsson-Kanyama, Dreborg et al. 2008). In the case of decision-making for building design, this may involve use of quantitative tools such as LCA and LCC (Trusty and Horst 2002; Fuller and Petersen 2008). With life cycle approaches being recommended and respected as powerful and quantitative (ASHRAE 2010), the DSS framework will draw upon the use of LCA and LCC.

2.1. UBC Context

To be effective, a decision-making support system must be able to address a wide spectrum of sustainability indicators to address economic, social and environmental concerns. The current approach taken at UBC is progressive; recent developments on campus buildings involved the use of the triple-bottom-line approach within the context of the Integrated Design Process (IDP). IDP involves getting project stakeholders around the design table early in the process and has been shown to be highly effective at implementing green design. UBC campus now hosts at least 6 ‘green buildings’ constructed to LEED® Gold standards. The recent and successful design of the Centre for Inactive Research in Sustainability (CIRS) exemplifies the UBC approach. During the design process of CIRS, stakeholders gathered around the table early on so that decision-makers were working with self-defined performance targets at the outset. The result is that CIRS is expected to be net energy and net carbon *positive* and will be *reducing* UBC’s energy requirements and carbon emissions when in operation (construction complete in 2011). Building on the success of CIRS is critical to making sure that UBC attains the highest performance standards in Canada.

The CIRS approach to sustainability is a small part a broad general commitment to sustainability for UBC buildings. The University has both aspirational and hard targets for environmental impact minimization. Aspirational targets include net water positive and net energy positive for the entire campus. UBC also has firmly committed to hard targets. UBC guidelines require mandatory diversion of 75 per cent of construction waste for residential construction and divert 50 per cent of construction waste from landfill for new institutional buildings. Additionally, all buildings must achieve a minimum Leadership in Energy and Environmental Design (LEED®) Gold or equivalent rating. UBC has committed to reduce GHGs by an additional 33 per cent from 2007 levels by 2015, reduce 67 per cent below 2007 levels by 2020 and finally eliminate 100 per cent of GHGs by 2050. Attaining these targets is a major technical and financial challenge and decision-makers at UBC need a decision support system (DSS) that clearly shows the trade-offs between competing options. The trade-offs often straddle different dimensions of sustainability and it is critical that decision-makers get a clear picture of how increasing the performance in one attribute may negatively or positively affect a number of other attributes.

Additionally, decision-makers need to understand how changes that occur during building life can influence the performance level of different attributes. Uncertainty in building utilization and operation is pervasive over long time frames and decision-makers need to be able to see how perturbations in resource usage, cost and availability will impact performance over the life-cycle of a building. Resiliency to change gives a measure of future-proofing that is critical to the stability of long term budgeting and resource use.

Current 'Whole-building' assessment tools in development at UBC

There are a number of different initiatives underway at UBC that support life cycle thinking. There are three separate models that are in development; a life cycle environmental impact estimator (ATHENA EIE), a life cycle costing calculator (ID LCC) and building energy modeling that is completed as part of the LEED process. Each model delivers quantitative impact data for financial, environmental and energy metrics respectively.

- The UBC Infrastructure Development department has developed a life cycle costing (ID LCC) tool that is applicable for institutional buildings across campus. The tool provides detailed cost estimates for the construction, operational and demolition costs that are calculated as net present value estimates. LCC is regarded as a major step forward for sustainability planning (GSA 2005) and LCC is required for US governmental development by OMB Circular A-94, the Code of Federal Regulations 10 (CFR) 436A and the Federal Acquisition Regulations (FAR). Life Cycle Costing is the most conservative of costing methods and is restricted to measurable and recognized direct and contingent expenses (Aloisio ; Langdon ; Pelzeter). The UBC model adheres to guidelines specified by the National Institute on Standards in Technology (NIST) that are based on Federal Energy Management Program (FEMP) accounting methods which are typically used for long term planning for institutional and governmental projects. NIST standards are closely aligned with ISO/DIS 15686-5 and ASTM E917 - 05e1. As specified by NIST, LCC evaluates budgetary impacts for each life phase, maps them into constant dollars and projects them into a net present value (NPV) using locally accepted discount and escalations rates (Fuller and Petersen 2008). The financial impacts for each phase of building life are calculated and aggregated to a total cost of ownership.
- UBC now has developed a strong LCA capacity as part of the Sustainability Academic Strategy and the University Sustainability Initiative. The collective efforts of the Sustainability Office, Infrastructure Development, Rob Sianchuk and two generations of CVL 498C students along with UBC Civil Engineering has conducted LCA studies for 51% of the campus core structures and has developed North America's largest LCA database for buildings. The database contains key benchmark environmental

information about many different building types, including several LEED certified buildings.

- The British Columbia government mandates the construction of all new government buildings to a minimal standard of LEED Gold. As part of the LEED certification process, energy modeling is now standard practice across BC for all governmental buildings. Energy modeling is critical to simulating the energy usage over the building life time along with any associated carbon emissions.
- UBC is creating a Post Occupancy Evaluation protocol which will be used, in part, to measure occupant satisfaction for new and renovated buildings. Once implemented, the POE tool will generate data that will allow for a database of benchmark occupant satisfaction. Future building design will use this data to improve occupancy standards across campus.

The combined life cycle models currently calculates thirteen outputs, with metric selections from a broad spectrum of simulated environmental and economic impacts as recommended by (ISO ; Helgeson and Lippiatt 2009). These variables represent the currently available quantified core attributes that are used for decision-making.

Requirements for a UBC DSS framework

Currently, the life cycle impact information (from the LCC, LCA and energy models) is available to stakeholders but the complexity of the data means that resulting information is difficult to synthesize by decision-makers. One of the consequences is that decision-makers will mainly rely on a combination of first impressions, heuristics and intuition to navigate the decision process (Kiker, Bridges et al. 2004; Seager and Linkov 2007). For the LC information to be relevant to decision-makers at UBC, the data needs to be structured so that they can better understand the trade-offs and relationships between various criteria (Hertwich and Hammitt 2008). They also need their preferences to be expressed and applied during the comparison and to see how their values and opinions can affect the ordering of alternative outcomes. Finally, they need to know how resilient the alternatives are to future changes in building operation and use.

There are additional developments at UBC that will provide data and attribute benchmarks for the UBC LC MDCA. UBC is also at an advanced stage of negotiation with Pulse Energy who will enable real-time monitoring of energy consumption for all core buildings on campus. The data will be stored and be available to create benchmark energy performance for attributes. Finally, a UBC Post Occupancy Evaluation (POE) framework is in development which will provide feedback with regards to inhabitant comfort and expectations. The POE framework will provide inhabitant comfort metrics and benchmark data. The POE framework and Pulse data are in development and anticipated to be fully operational by 2011. Figure 1 shows a summary of the life cycle and benchmarking data inputs.

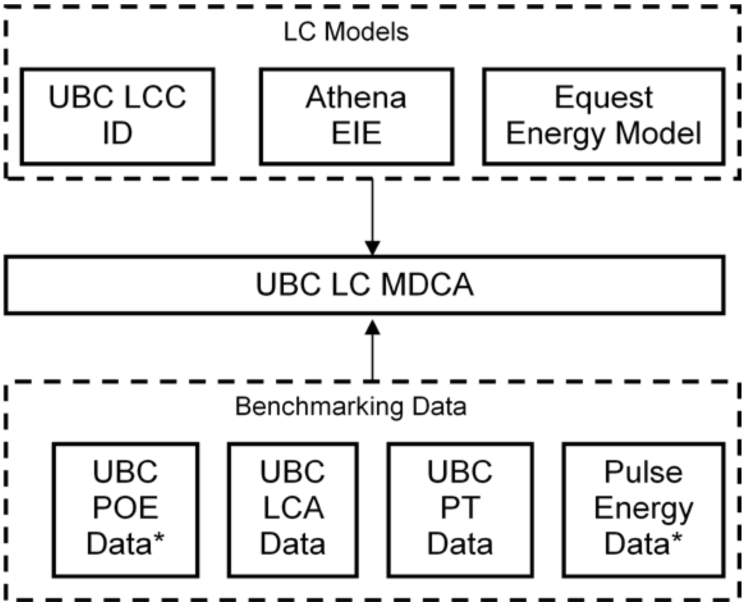

Figure 1: Model and data inputs for UBC LC MDCA: The LC models are already constructed, tested and operational. The energy model is a mandatory requirement for UBC (as part of LEED® guidelines). The local benchmarking data is available and is used to show typical performance for various building types. An asterisk denotes data metrics under development

3. State-of-the Art: MCDA for Life Cycle Models

A Decision Support System (DSS) is a structured, typically model-based, approach to problem solving with a primary goal to assist groups of "decision makers" and/or other "stakeholders" to develop a shared understanding of different world views (Stewart 2009). A DSS helps decision-makers to identify their concerns and to clarify the choices and actions required to make the 'right' choice.
The most favoured methods for building a decision-making interface for life cycle models is multi-criteria decision analysis (MCDA) (Hertwich and Hammitt 2001; Seppala, Basson et al. 2001; Roulet, Flourentzou et al. 2006; Rowley and Peters ; Jeswani, Azapagic et al.).

MCDA can be regarded as an aid to integrating scientific measurement with value judgment, and "to coherent management of subjectivity" (Stewart 2009). MCDA allows a decision-maker to observe the performance of multiple criteria side-by-side while being able express preferences, or subjective level of importance, for each criterion individually. This enables a decision-maker to interpret a MCDA best-choice result as a subjective indicator of the collective strength of various preferences.

The goal of any MCDA is to provide a decision support framework that will enable decision-makers to find a Pareto Optimal solution that best matches the user preferences. For the UBC LC MCDA, this involves determining a framework that will enable UBC stakeholders to systematically select the most appropriate building design. The DSS, which is defined here as the MCDA and the life cycle outputs combined, will be integrated into the Technical Guidelines suite that is currently used by UBC infrastructure development, UBC contracted architects, and supporting consultants. Although the selection of MCDA method will be focused on UBC, it will be broadly applicable to buildings in an urban context across North America.

3.1. MCDA Limitations

While MCDA offers an opportunity to assist decision-makers during the process of design, it should not be viewed as an exact and stable analytical tool to ‘produce’ solutions. There are many theoretical challenges to MCDA and many critiques have been offered in the past three decades (Ustinovichius, Zavadkas et al. 2007; Hertwich and Hammitt 2008). MCDA packages contain various algorithms that use quantified criteria, along with user preferences, to calculate an optimal solution. However, the resulting solution should be viewed only as suggestive of a best-choice and not as an absolute answer. As Stewart points out, it is a common misperception that MCDA can “solve” the problem. With problems being constructed subjectively, there is certainly no objective problem and clearly no “right” answer. Nonetheless, MCDA has potential to engage problem identification, structuring, modeling and exploring.

3.2. Decision Support Systems: MCDA and the Integrated Design Process

The UBC DSS structure is based on the participation input of stakeholders, knowledge accessibility (via the lifecycle models) and the current decision-flow based on the Integrated Design Process protocol (as currently used at UBC). IDP is defined as a structure that allows for distributed and selective participation amongst a combination of industrial and scientific expertise. In contrast to traditional linear design, where the interactions are minimized to over-the-wall planning, IDP offers a framework that allows the construction team to be directly involved with the design process. Furthermore, IDP encourages all major stakeholders and external experts to work together towards a plan for achieving project goals and outcomes. IDP encourages the involvement of subject specialists, such as energy modelers, and requires the appointment of a facilitator to guide the process through each design phase (iiSbe 2004). IDP is a cyclical flow of meetings during which the design team works to devise, express and understand the design goals of the project, and provides a collective forum to find innovate solutions to site-specific design problems. IDP, as used by UBC and Busby, Perkins + Will, has integrated many of the key process requirements for green building design (Bp+W 2007; Bp+W 2007). The design of CIRS and many other UBC buildings has shown that the IDP fosters effective and open participation and communication that leads to innovation and synthesis. Appendix A shows a breakdown of typical IDP participants, along with the timing for each participant involvement. Appendix B shows how these participants are grouped in terms of expertise applicable to a triple bottom approach shown in the impact interpretation phase in Figure 2.

To be relevant to the UBC sustainable design context, the UBC MCDA must fit within the IDP framework. Figure 2 shows the general flow structure from the decision goal – selecting a high performance sustainable building design – through to the final decision. The decision-flow is based on (iiSbe 2004; Bp+W 2007). The following steps are suggested by the imperative that the conceptualization of sustainability is framed at the beginning of any design process.

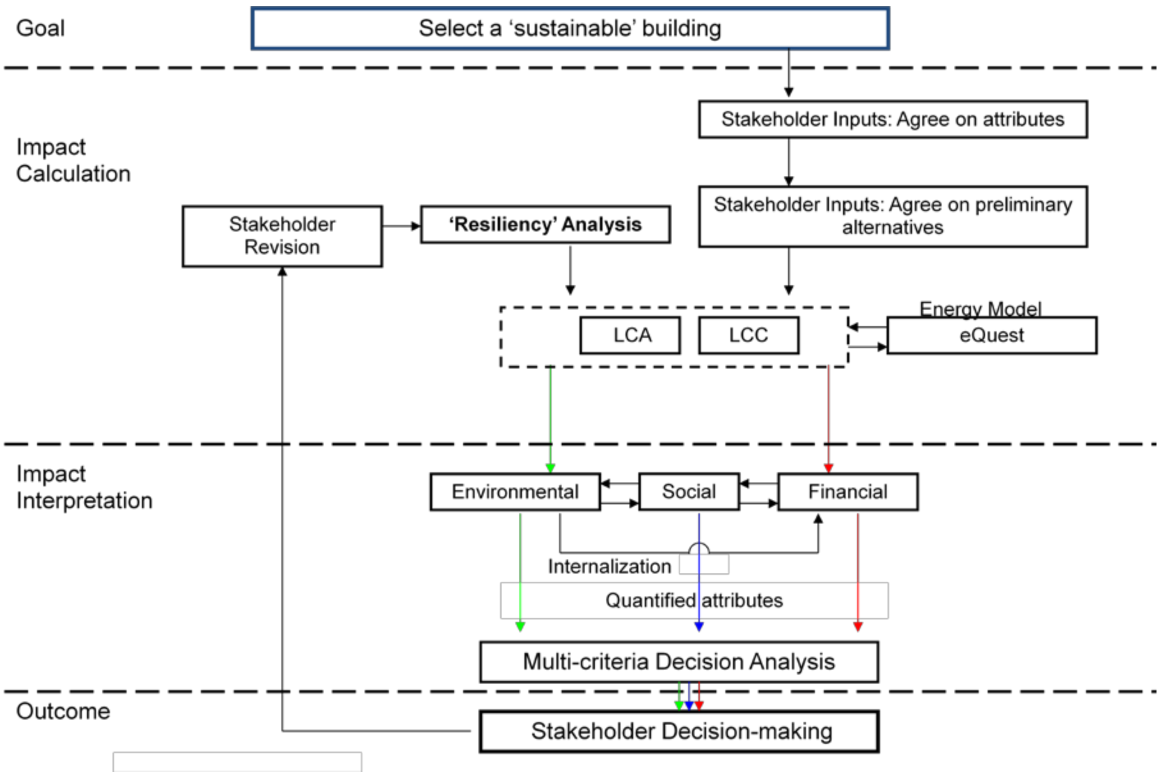

Figure 2: Schematic of DSS structure. The general decision flow is from top to bottom. Impact calculations are based on stakeholder preference with regards to alternative and attribute selection. Impact interpretation is an integrated analysis of LC model outputs with a MCDA tool. The outcome is either a final 'best-choice' selection or a further test of building resilience.

The steps to harmonizing the UBC LC MCDA design process are outlined below with the bulk of design attributes being agreed upon in the first steps of IDP. Figure 3 shows the timing and task location of each step within the context of the IDP.

List of steps

1. Stakeholders determine a broad set of UBC specific attributes
    - Selection of decision-makers who are allocated responsibility for design process
    - Selection of performance targets. These include, for example, minimum level of energy performance, carbon emissions, water targets
    - Selection of resiliency variables based on stakeholder opinions.
    - Collective decision on which attributes are initially selected. This set of attributes will be a broad set of metrics, many of which are derived from performance targets.
    - Model analyst[2] determines the cost of calculating each attribute and reports estimates back to stakeholders
    - Stakeholders review costs and select attributes both cost effective and worth quantifying

2. Stakeholders select a base set of building alternatives
    - Stakeholders work with designers to determine a base set of building alternatives to be analyzed
    - Decision-makers consult with model analyst to determine LCC model parameters including all major state variables such as escalation rates, discount rates, utility price structures, Pigovian tax rates.
    - Resiliency analysis: Decision-makers consult with model analyst to determine scale of perturbations to be applied to model inputs. An example includes deviations from energy price inflation.
    - Key model assumptions are reviewed including assumed timelines for each building life phase. For example, building operation phase which involves estimating a desirable service life for the building based on UBC benchmark building life spans and expert opinion from stakeholders.
    - Model analyst proceeds with selected alternatives and calculates attribute levels of performance with LC and any auxiliary models.

3. Stakeholders review attributes
    - Stakeholders review overall performance for each alternative
    - Alternatives are given preliminary review and discussion
    - Any alternatives that *clearly* fail performance targets are eliminated
    - Attributes that are regarded as no longer relevant are unselected and a base set of criteria are used for comparisons between alternatives
    - Preferences are specified for each attribute
    - Alternatives are compared

4. Stakeholders review alternatives
    - Alternatives have performance levels for each remaining criteria compared to UBC performance benchmark data
    - Alternatives that are regarded as unsuitable are eliminated by decision-makers
    - Alternatives that show promise are expanded by decision-makers. Sub-alternatives within set of remaining alternatives are specified by the decision-makers and generated by the architects and design consultants

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[2] The model analyst is defined as the consultant responsible for completing calculations. The calculations could be completed with the assistance of a team of graduate students from Applied Science, IRES and the Sauder Business School

5. Stakeholders review sub-alternatives
   - New sub-alternatives from step 4 are compared to each other and to benchmark performance data
   - Resiliency analysis can be modified and revisited if cost is acceptable
   - Stakeholders contract alternatives based on criteria and preference results by iterating on step 4

6. Stakeholders narrow down alternatives based on MCDA results and select best choice.

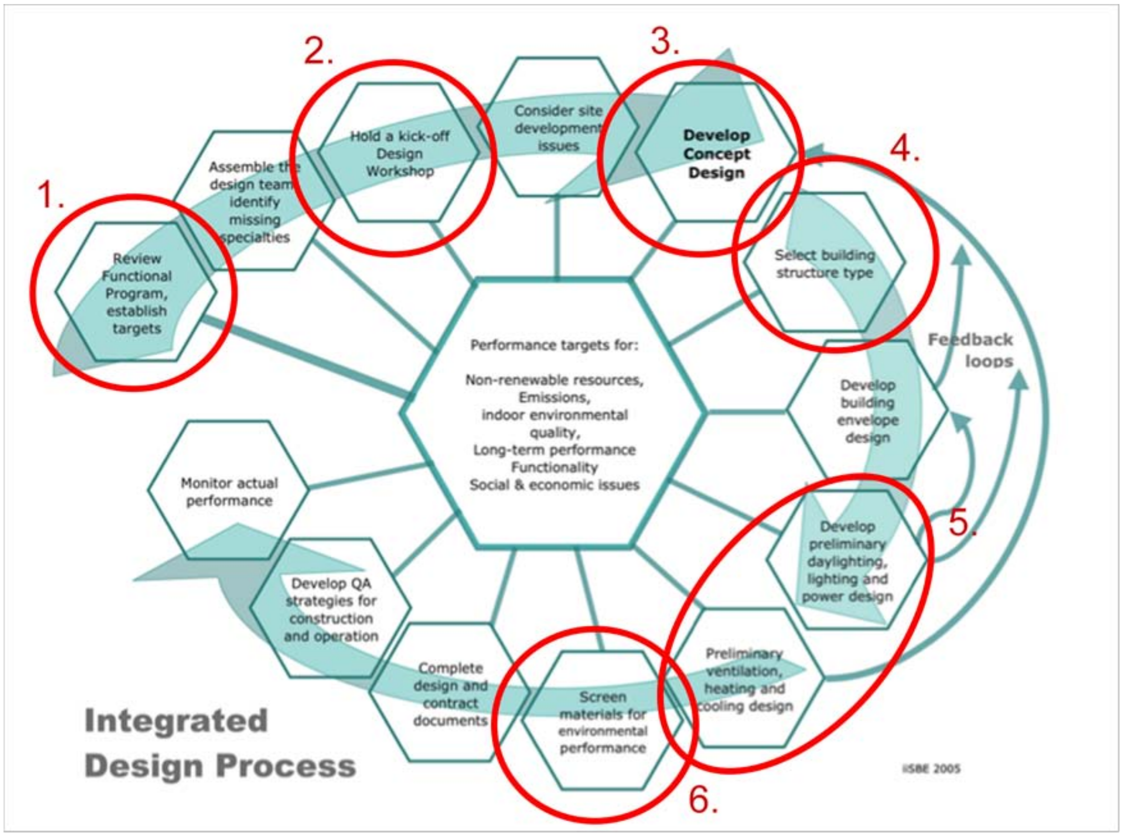
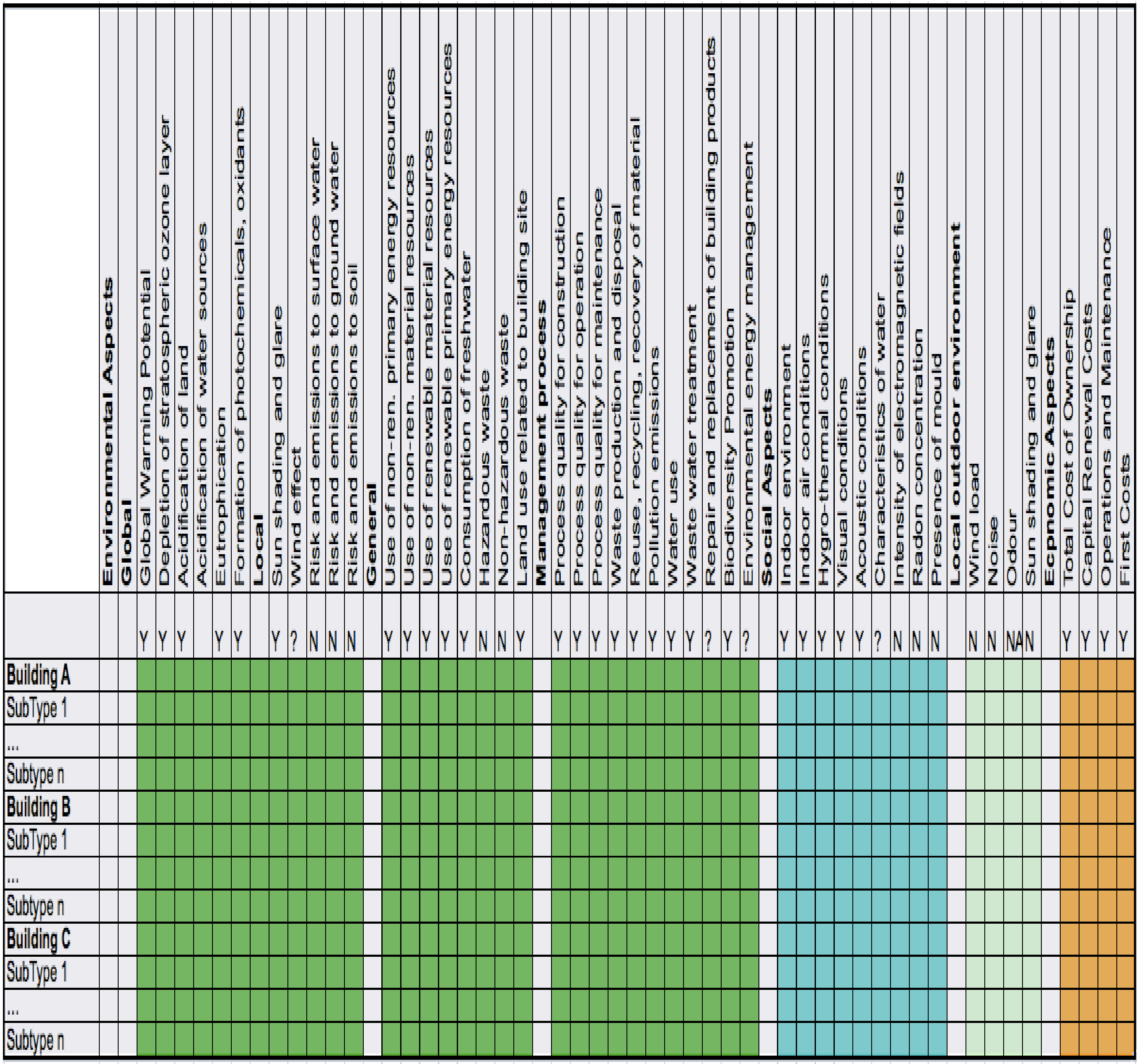


Figure 3: The UBC LC MDCA timeline harmonized with the Integrated Design Process.

4. Sustainability Indicators: Choosing appropriate attributes

Selecting sustainability attributes is a challenge for any decision-maker, especially for complex problems that couple different dimensions of sustainability. The selection process has been shown to be important for ‘learning’ about the problem (Reed, Fraser et al. 2006). While rating systems such as LEED offer a starting point in terms of ‘green’ prescriptive measures, each building project must develop it’s own selection of indicators and hence enable the stakeholders to develop a deeper understanding of any pertinent issues.

In addition to local UBC Sustainability goals, several international collaborative efforts for developing indicators have been recently finalized and are available to inform decision-makers. The most prominent agreement is the ISO 21931-1 standard. Table 1 below shows the ISO base set of indicators as agreed by participants of over twenty nation states and organizations. Local projects can add to this normative set to produce a set of metrics appropriate to local regional and cultural contexts



	Environmental Aspects	**Global**	Global Warming Potential	Depletion of stratospheric ozone layer	Acidification of land	Acidification of water sources	Eutrophication	Formation of photochemicals, oxidants	**Local**	Sun shading and glare	Wind effect	Risk and emissions to surface water	Risk and emissions to ground water	Risk and emissions to soil	**General**	Use of non-ren. primary energy resources	Use of non-ren. material resources	Use of renewable material resources	Use of renewable primary energy resources	Consumption of freshwater	Hazardous waste	Non-hazardous waste	Land use related to building site	**Management process**	Process quality for construction	Process quality for operation	Process quality for maintenance	Waste production and disposal	Reuse, recycling, recovery of material	Pollution emissions	Water use	Waste water treatment	Repair and replacement of building products	Biodiversity Promotion	Environmental energy management	**Social Aspects**	Indoor environment	Indoor air conditions	Hygro-thermal conditions	Visual conditions	Acoustic conditions	Characteristics of water	Intensity of electromagnetic fields	Radon concentration	Presence of mould	**Local outdoor environment**	Wind load	Noise	Odour	Sun shading and glare	**Ecpnomic Aspects**	Total Cost of Ownership	Capital Renewal Costs	Operations and Maintenance	First Costs
			Y	Y	Y		Y	Y		Y	?	N	N	N		Y	Y	Y	Y	Y	N	N	Y		Y	Y	Y	Y	Y	Y	Y	Y	?	Y	?		Y	Y	Y	Y	Y	?	N	N	N		N	N	NA	N		Y	Y	Y	Y
Building A			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		▧	▧	▧	▧		🟧	🟧	🟧	🟧
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Building B			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		▧	▧	▧	▧		🟧	🟧	🟧	🟧
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Building C			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		▧	▧	▧	▧		🟧	🟧	🟧	🟧
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Table 1: Augmented ISO 21931-1 standard for sustainability metrics for buildings. The last four columns are local additions added to the base ISO set. ‘Y’ or ‘N’ suggest which metrics are currently easily quantifiable at UBC

While the ISO 21931-1 standards give a broad starting point for developing attributes, only a small percentage are currently quantifiable by the UBC LC tools. Figure 4 shows the UBC LC outputs currently available to decision-makers. Any additional 21931-1 criteria would have to be evaluated with other tools, either within the context of LEED or externally. Many of these criteria are already required by LEED, for example indoor air quality and day-lighting, and the associated data can be relatively easily imported when it becomes available during the design process.

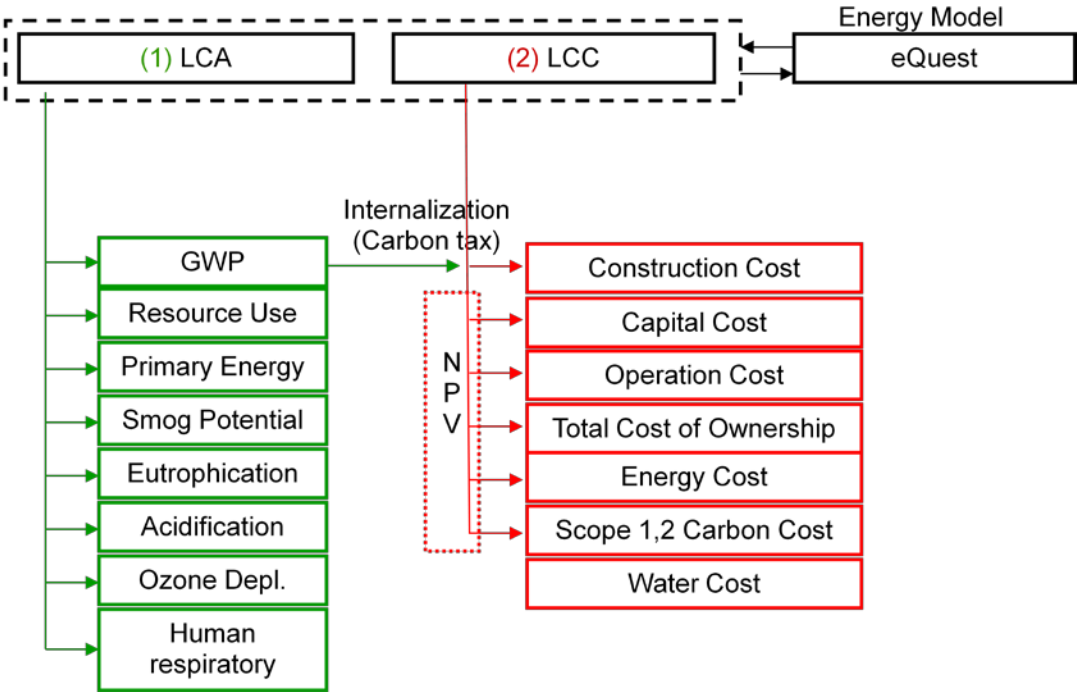

Figure 4: Life cycle metrics currently available to UBC decision-makers. The LCA metrics are calculated with Athena EIE and the LCC metrics with the UBC ID tool.

4.1. Resiliency Analysis

Understanding resiliency from a technical point of view is critical to understanding the robustness of performance over long time frames. Resiliency can be defined in terms of resistance to changes in external variables such as energy cost, or internal change such as occupant intensity. If a building is to be operationally robust with respect to change then the design team should consider the impacts of perturbations to the building and building systems with a view to examining performance under different scenarios.

The LC models are formulated so that changes to input variables can be easily undertaken. However, only small perturbations in resilience should be considered where change is reversible. Attempting to simulate large perturbations, where the building systems would be forced into a new operational mode, is inappropriate. For example, a small perturbation in energy prices would simply change operational costs whereas a large or extreme perturbations would require a different engineering solution to heating and chilling a building, such as a change from electricity to natural gas heating, hence incurring capital costs. These large perturbations caused by Black Swan[3] events are incalculable and henceforward ignored. Checking for resiliency involves agreeing on which variables are critical for ensuring high performance during the building lifecycle. Stakeholders involved with the design process need to decide early which are the most relevant variables for a resiliency check. Variables, for example, may include any of the following LCC or LCA input variables:

- Building durability (lifespan of key components)
- Secondary energy consumption (energy used in building)
- Maintenance cycles (frequency of upkeep)
- Occupant behaviour (occupant usage intensity)

To illustrate the principle behind a resiliency analysis, a worked example for analysing environmental and financial resiliency to a small perturbation is now discussed. The CIRS building design involved completing a full Life Cycle Costing during IDP. The LCC results in Figure 5 shows the total cost of ownership for the CIRS project relative to benchmark LEED standards. The results show that if CIRS had been built to a LEED Gold standard then the total cost of ownership would have been ~$4.6M more for a 25 year period. In the event of increasing durability of the CIRS building so that the service life is 50 years, then savings increase to ~$5.1M. This is a smaller but nevertheless significant increase in savings (unfortunately most of the savings are wiped out by the 5.2% BC Government standard discount rate). However, further increases in durability to 100 years yield only smaller incremental savings and the stakeholders could have decided not to invest in an incrementally more expensive 100year building. However, other criteria were examined during the decision-making process; the deciding factor for investing in a durable building was the reduced environmental impacts of CIRS. During operation, the facility actually supplies energy back to UBC and removal of CIRS at the 50 year mark would cause a small increase in energy usage and carbon emissions of UBC campus.

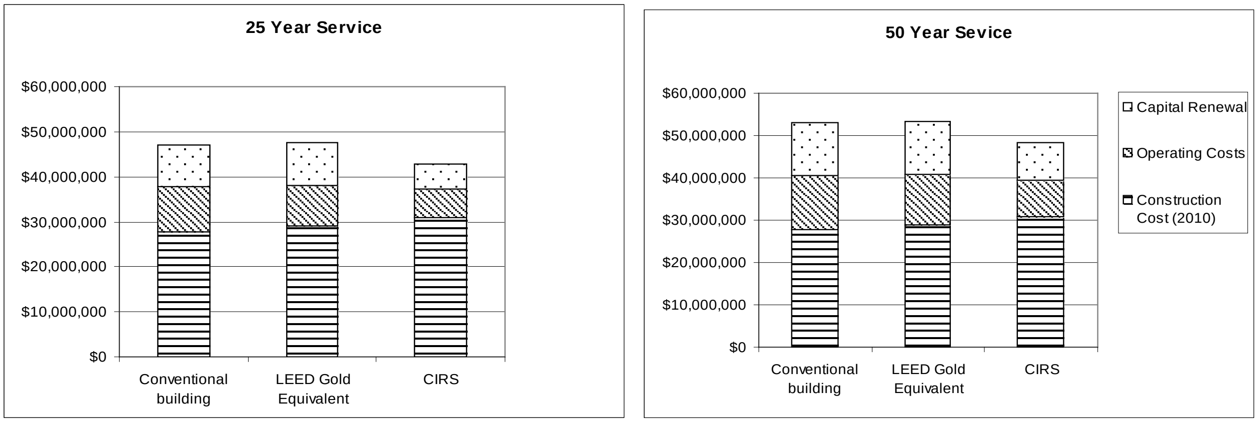

Figure 5: Total cost of ownership in 2010 dollars for CIRS, a net zero building at UBC, including soft costs, for (a) 25 years of service and (b) 50 years of service.

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[3] A Black Swan Event is defined by Nassim Taleb as a high impact, unpredictable, and rare event that are beyond the realm of normal expectations in history, science, finance and technology

In the context of MCDA, each resiliency analysis can be conducted to update the matrix of simulated LC outcomes and the MCDA algorithm re-run to check if the optimal alternative remains constant. If the MCDA result changes and a different building alternative wins then the design team can review the options available to attain the level resilience required.

4.2. The Use of the IIASA Tool

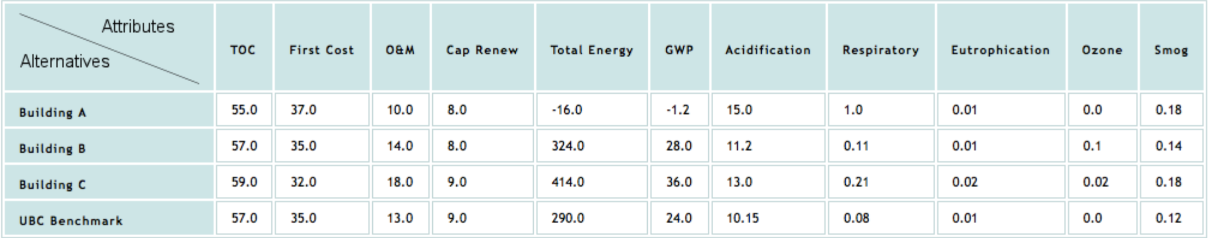
The International Institute of Applied Systems Analysis has built a straightforward and practical online tool for MCA (Makowski et al., 2009). The tool has been developed for assisting decision-makers to examine tradeoffs between competing criteria and to incorporate stakeholder preferences in terms of importance placed on each attribute. The IIASA MCA tool is mathematically rigorous, well supported and maintained. Use of the IIASA tool is an invaluable opportunity for UBC to trial MCA for decision-making during building design. Permission for use has been granted by the IME group at IIASA for non-profit research use at UBC.

The MCA inputs can be entered either manually into an online interface, or uploaded by a .csv text file containing the lists of attributes, alternatives and quantified impacts. The quantitative inputs can be generated using the LC tools or can be imported from any analytical assessment work completed by the architects and engineering consultants. The data input can be easily aligned with the Integrated Design Process as explicated in Figure 3.

The entire operation does not require extensive expertise as all of the mathematical details are ‘under the hood’. A graduate student working with the LC models and the IIASA tool could complete the modeling in less than two weeks.

Figure 6 shows the layout of a typical ‘alternatives versus attributes’ matrix as it appears in the interactive IIASA MCA tool.

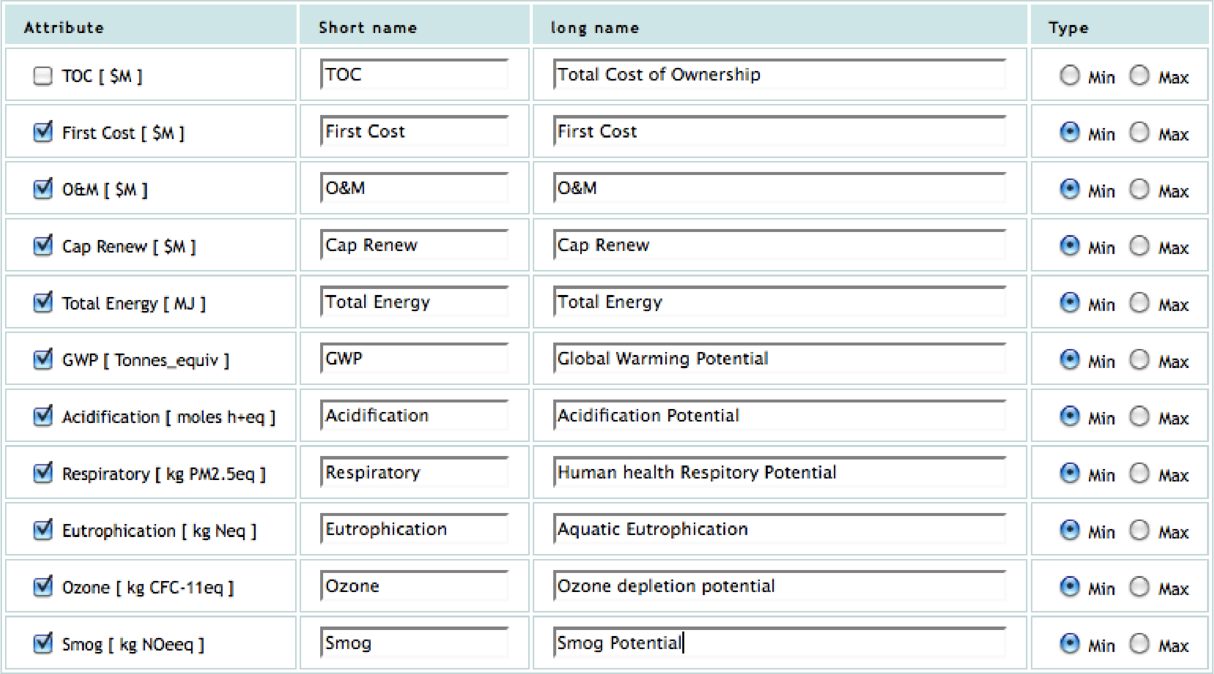
Qualitative inputs can be easily inputted by simply converting descriptive terms such as ‘good’ ‘satisfactory’ or ‘poor’ into a sliding scale of numbers. Figure 6 lists three building alternatives (A, B, and C) along with an alternative showing typical benchmark standards. The benchmark performance scores are those expected of a typical building constructed to best practices standards. The presence of the benchmark building information is critical for informing the decision-makers about the minimum level of performance to be expected for each attribute.



Attributes / Alternatives	TOC	First Cost	O&M	Cap Renew	Total Energy	GWP	Acidification	Respiratory	Eutrophication	Ozone	Smog
Building A	55.0	37.0	10.0	8.0	-16.0	-1.2	15.0	1.0	0.01	0.0	0.18
Building B	57.0	35.0	14.0	8.0	324.0	28.0	11.2	0.11	0.01	0.1	0.14
Building C	59.0	32.0	18.0	9.0	414.0	36.0	13.0	0.21	0.02	0.02	0.18
UBC Benchmark	57.0	35.0	13.0	9.0	290.0	24.0	10.15	0.08	0.01	0.0	0.12

Figure 6: A screenshot of the IIASA MCA tool with hypothetical inputs. In this example, there are three building alternatives and eleven attributes. The numbers in the boxes are extracted from the outputs of the LC models

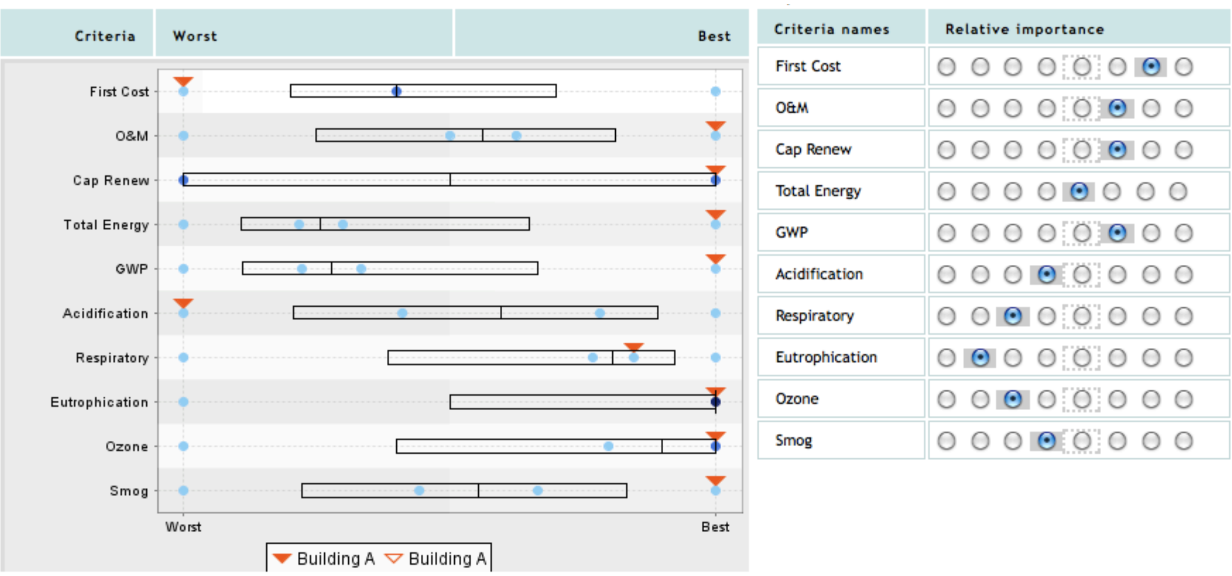
Figure 7 shows the selection process for each criterion. The stakeholders simply select from the list of attributes shown. As explained in Step 2, the selected attributes become the criteria involved during the analysis stage. Any attributes that remain unselected are hereby ignored. As the Integrated Design Process evolves and each iteration required for Steps 3, 4 and 5 is completed, then further attributes can be deselected as required. Further alternatives can be added at any time, depending on stakeholder needs, the cost of creating new alternatives and the time remaining for the design process.



Attribute	Short name	long name	Type
☐ TOC [$M]	TOC	Total Cost of Ownership	○ Min ○ Max
☑ First Cost [$M]	First Cost	First Cost	● Min ○ Max
☑ O&M [$M]	O&M	O&M	● Min ○ Max
☑ Cap Renew [$M]	Cap Renew	Cap Renew	● Min ○ Max
☑ Total Energy [MJ]	Total Energy	Total Energy	● Min ○ Max
☑ GWP [Tonnes_equiv]	GWP	Global Warming Potential	● Min ○ Max
☑ Acidification [moles h+eq]	Acidification	Acidification Potential	● Min ○ Max
☑ Respiratory [kg PM2.5eq]	Respiratory	Human health Respitory Potential	● Min ○ Max
☑ Eutrophication [kg Neq]	Eutrophication	Aquatic Eutrophication	● Min ○ Max
☑ Ozone [kg CFC-11eq]	Ozone	Ozone depletion potential	● Min ○ Max
☑ Smog [kg NOeeq]	Smog	Smog Potential	● Min ○ Max

Figure 7: A screenshot of the IIASA MCA tool showing an attribute list. Here there is a selection panel on the left where attributes can be chosen as decision criteria. The min/max selection on the right is to indicate whether the criteria level is to be maximized or minimized.

Figure 8 shows the results of a typical analysis. On the right, stakeholder preferences can be inputted on a sliding scale. On the left, the blue points represent the results of each building type relative to a criterion. The red triangle is indicates the position of the optimal, winning building.



Criteria names	Relative importance
First Cost	○ ○ ○ ○ ○ ○ ● ○
O&M	○ ○ ○ ○ ○ ● ○ ○
Cap Renew	○ ○ ○ ○ ○ ● ○ ○
Total Energy	○ ○ ○ ○ ● ○ ○ ○
GWP	○ ○ ○ ○ ○ ● ○ ○
Acidification	○ ○ ○ ● ○ ○ ○ ○
Respiratory	○ ○ ● ○ ○ ○ ○ ○
Eutrophication	○ ● ○ ○ ○ ○ ○ ○
Ozone	○ ○ ● ○ ○ ○ ○ ○
Smog	○ ○ ○ ● ○ ○ ○ ○

Figure 8: A screenshot of the IIASA MCA tool showing the results of an analysis. First, the stakeholders collectively decide on the relative importance of each criterion (shown as sliding scale on the right hand box). In this example, building A is selected as being the Pareto-optimal solution that fits best the stakeholders' preferences., However, this would change if the relative criteria importance were selected differently.

As previously mentioned, a resiliency analysis can be conducted by altering individual or bundles of variables in the LC models and then passing the updated results into the MCA tool. The stakeholders can then see if the optimal solution remains stable after a system wide perturbation to the building.

5. Conclusion

The approach outlined for an MCDA DSS is a simple and effective method to integrate LC tools into the decision-making process at UBC. The MCDA approach allows stakeholders to interactively and transparently apply their values into the decision process by enabling a level of preference on the critical attributes agreed at the project outset. The MCDA assisted design process moves the design closer to stakeholder needs, which is in sharp contrast to inflexible prescriptive rating systems such as LEED.

The approach outlined utilizes the lessons learned during the design process of CIRS. Stakeholders where brought together around the table early on so that decision-makers agreed on self-defined performance targets at the outset. These self-defined targets were far more stringent and visionary than any previous standards and were frequently referred to during each iterative IDP session. Life cycle modeling was successfully used during the IDP process which resulted in well informed decisions at several critical points during design. MCDA echoes and strengthens this approach creating a structured and central point for informative LC data and any other required quantitative and qualitative metrics.

MCDA allows the integration of information from many disciplines and is critical inform the process of selecting and refining a choice between building types. The proposed UBC DSS is easy to use, transparent, interactive and participatory. The use of ISO 21293 indicators can be used as a first sweep for deciding which indicators are appropriate for a given building project and can be augmented with a suite of local qualitative metrics. The IIASA MCDA tool, which has been secured for use at UBC, offers an invaluable opportunity to pilot MCDA for UBC Infrastructure Development projects.

Appendix A

IDP participants list

The list is adapted from the Busby, Perkins and Will road map for IDP (Bp+W 2007):

1. Pre-design phase

Core team: Client, architect, mechanical, structural, and electrical engineer, and landscape architect

Additional team members and stakeholders, including: Contractor (depending on project delivery type); representative of occupant's perspective; building operators (if possible)

Additional specialists (i.e. ecologist, energy engineer, etc); Schematic Design; Design Development; Construction; Documentation; Bidding, Construction, and Commissioning; Building Operation (startup); and Post Occupancy (long-term operation).

2. Schematic design phase:

Core team from previous phase.

Additional team members, including: Energy specialist; Cost consultant; Certification coordinator; Commissioning agent; Valuation professional

3. Design development phase:

Team from previous phase.

Additional team members, including: Contractor (sooner if possible); Operation and maintenance staff; Materials expert; Acoustician; Client’s marketing representative (if appropriate); Industry and academic experts

4. Construction documentation:

Team from previous phase

Additional team members, including: Specification writer; Contractor (sooner if possible); Commissioning authority

5. Bidding, construction, and commissioning

Team from previous phase

Additional team members, including: Project manager; Contractor (sooner if possible); Commissioning authority

6. Building operation and start up

Team from previous phase: Additional team members, including; Building operators; Building occupants; Commissioning agent

7. Post occupancy (Building operation start-up)

Team from previous phase

Additional team members, including: Acoustician; Thermal comfort specialist; Commissioning agent

References:

Aloisio, A. (2006). "Renewing UBC Renew: Building Full Cost Assessment into Renovate vs. Rebuild Decisions at UBC." Masters Thesis.

ASHRAE "Standard for the Design of High Performance, Green Buildings." ASHRAE 189.1. Becker, J. (2010). "Use of backcasting to integrate indicators with principles of sustainability." International Journal of Sustainable Development & World Ecology **17**(3): 189-197.

Bordass, B. (2000). "Cost and value: fact and fiction." Building Research & Information. Bp+W (2007). "Roadmap to the Integrated Design Process: Part One: Summary Guide."

Bp+W (2007). "Roadmap to the Integrated Design Process: Part Two: Reference Manual." Busby, Perkins + Will, Stantec Engineering.

Brager, G. S. and R. de Dear (2000). "A Standard for Natural Ventilation." ASHRAE Journal. Brager, G. S. and R. deDear (2005). "Operable windows personal control and occupant comfort." ASHRAE: 19.

Brown, Z. (2009). "Occupant comfort and engagement in green buildings: Examining the effects of knowledge, feedback and workplace culture." University of British Columbia (PhD Thesis). Carlsson-Kanyama, A., K. H. Dreborg, et al. (2008). "Participative backcasting: A tool for involving stakeholders in local sustainability planning." Futures.

Cole, R. J. (2001). "A Building Environmental Assessment Method for British Columbia." 64. Cole, R. J. (2005). "Building green: moving beyond regulations and voluntary initiatives." Policy Options: 8. Cole, R. J. and N. Howard (2004). "Building Environmental Assessment Tools: Current and Future Roles." 5. Dreborg, K. H. (1996). "Essence of backcasting." Futures.

Fowler, K. and E. Rauch (2006). "Sustainable Building Rating Systems Summary." PNNL: 55. Fuller, S. and S. Petersen (2008). "NIST Handbook 135: Life-Cycle Costing Manual for the Federal Energy Management Program." National Institute of Standards and Technology: 224. GDRC (2004). "The Seven Triads of Sustainability: No. 1 - Participation." Global development resource center.

GSA (2005). "Facilities Standards for the Public Buildings Service." U.S. GENERAL SERVICES ADMI NI STRATION. Helgeson, J. F. and B. C. Lippiatt (2009). "Multidisciplinary Life Cycle Metrics and Tools for Green Buildings." Integrated Environmental Assessment and ….

Hertwich, E. and J. Hammitt (2001). "A decision-analytic framework for impact assessment. Part I: LCA and decision analysis." The International Journal of Life Cycle Assessment **6**(1): 5-12. Hertwich, E. G. and J. K. Hammitt (2008). "A Decision-Analytic Framework for Impact Assessment. Part II: LCA and decision analysis." The International Journal of Life Cycle Assessment: 1-8.

Horman, M., D. Riley, et al. "Influence of Project Delivery Methods on Achieving Sustainable High Performance Buildings Report on Case Studies." Charles Pankow Foundation. iiSbe (2004). "The Integrated Design Process." International Initiative for a Sustainable Built Environment.

ISO (2007). "Sustainability in building construction -Framework for methods of assessment for environmental performance of construction works - Part 1: Buildings." ISO/21931-1. Jeswani, H. K., A. Azapagic, et al. (2009). "Options for broadening and deepening the LCA approaches." Journal of Cleaner ….

Kaatz, E., D. Root, et al. (2006). "Advancing key outcomes of sustainability building assessment." 308-320.

Kiker, G. A., T. S. Bridges, et al. (2004). "Application of multicriteria decision analysis in environmental decision making." Integrated ….

Langdon, D. (2007). "Life cycle costing (LCC) as a contribution to sustainable construction."

Lucuik, M. (2008). "A Business Case for Green Buildings in Canada." CaGBC: 68.

Makowski, M., J. Granat, H. Ren, (2009). "User Guide to MCA: Multiple Criteria Analysis of Discrete Alternatives with a Simple Preference Specification", IR-09-22, International Institute for Applied Systems Analysis, Laxenburg, Austria

OECD (2003). "Environmentally Sustainable Buildings Challenges and Policies." 194.

Pearl, D. (2004). "An Integrated Design Process (IDP): The crossover between practice and education breeds a new form of architectural representation." Canadian Architect.

Pelzeter, A. (2007). "Building optimisation with life cycle costs–the influence of calculation methods." Journal of Facilities Management.

Reed, M., E. Fraser, et al. (2006). "An adaptive learning process for developing and applying sustainability indicators with local communities." Ecological Economics **59**(4): 406-418.

Robinson, J. (1989). "Futures under glass: A recipe for people who hate to predict." Futures.

Robinson, J., J. Carmichael, et al. (2006). "Sustainability as a Problem of Design: Interactive Science in the Georgia Basin." The Integrated Assessment Journal.

Roulet, C., F. Flourentzou, et al. (2006). "Multicriteria analysis of health, comfort and energy efficiency in buildings." Building Research & Information **34**(5): 475-482.

Rowley, H. and G. Peters (2007). "Multi-Criteria Methods For The Aggregation Of Life Cycle Impacts." UNSW Water Research Centre.

Scofield, J. (2003). "Early performance evaluation of a Green Academic Building." ASHRAE Transactions: 17.

Seager, T. P. and I. Linkov (2007). "Coupling multicriteria decision analysis and life cycle assessment for nanomaterials." Journal Of Industrial Ecology.

Seppala, J., L. Basson, et al. (2001). "Decision Analysis Frameworks for Life-Cycle Impact Assessment." Journal Of Industrial Ecology.

Stewart, T. (2009). "Goal directed benchmarking for organizational efficiency." Omega.

Trusty, W. and S. Horst (2002). "Integrating LCA Tools in Green Building Rating Systems." Austin Papers: Best of the 2002 International Green Building ….

Turner, C. and M. Frankel (2008). "Energy Performance of LEED for New Construction." New Buildings Institute: 46. UNEP (2007). "Buildings and Climate Change: Status, Challenges and Opportunities." United Nations Environmental Program.

Ustinovichius, L., E. Zavadkas, et al. (2007). "Application of a quantitative multiple criteria decision making (MCDM-1) approach to the analysis of investments in construction." Control and cybernetics **36**(1): 251.

WGBC (2008). "Global Green Building Trends." Smart Market Report.