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Identifying Key Decisions for Net-Zero Energy Building Early Design Process Through Process Mapping Techniques

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Abstract

The lack of a structured approach to help the Architecture, Engineering, and Construction (AEC) industry in making informed decisions (Korkmaz et al. 2007) for the Net-Zero Energy Building (NZEB) context establishes the need to evaluate the argumentation of the NZEB design decision process (Author, 2014). This research qualitatively analyzes the early design process of NZEB case studies that informs decision-making in the early design phase. The four components that were studied in the early design phases included key stakeholders involved (roles played), phases of assessments (design approach), processes (key processes, sub-processes, and design activities affecting performance) and technology (knowledge type and flow).

Semi structured interviews were used to ask open-ended questions to the key stakeholders involved in the early design process. A priori theory was used to frame the initial questions and initial level of coding schemes. Grounded theory approach was used to discover codes and emerging themes while working through the interview transcripts. The qualitative data analysis was performed through content analysis and cognitive mapping techniques. Process mapping technique was adapted to capture the practice-based complex NZEB design approach and draw insights of the teamwork and interdisciplinary communication to enable more comprehensive understanding of linkages between processes, sub-processes and design activities, knowledge exchange, and decision rationale.

Keywords: *Net-zero energy, process mapping, decision-making, design decision support, integrated design, early design phase, cognitive mapping, key performance indicators*

1. Introduction

Unlike traditional design, Net-Zero Energy Building (NZEB) design not only rely on project budget, project schedule, and project quality as some of the measures for success of the project, but are driven by energy performance (Torcellini et al. 2006) as a more dominating factor for the success of the project. Project performance is a measure of energy performance (Torcellini et al. 2006) and other indicators; these indicators drive the way the design process is set up for these projects. Current Net-Zero Energy Building (NZEB) certification system and green building assessment systems lack in elaborating on the decision-making aspect of design processes (Korkmaz et al. 2007) for the Net-Zero Energy (NZE) context. The NZEB design process is a complex process that is highly iterative and evolves through different stages that comprise of different processes involving various interdis-ciplinary stakeholders (Author, 2014). Each stage

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is a collection of processes, sub-processes, and design activities that are centered on achieving the project objectives (Riley and Horman, 2005; Lapinski et al. 2006; Korkmaz et al. 2010). The International Green Construction Code (IgCC) development committee recently introduced the "first-ever outcome-based compliance path in a model energy code" as per the New Building Institute's report in the article "New approach to energy code compliance clears hurdle" (New Building Institute, 2014). As emphasized in the article, prescriptive approach is more of an inhibitor than a facilitator for High-Performance Buildings design process. This research stresses the need to use a combination of descriptive as well as proscriptive approach that will ensure the performance outcome of NZE while allowing the design teams flexibility in design. Clear definition of performance goals and then mandating them through contractual requirements can help owners share the risk and in the process facilitate innovation.

This paper identifies the need for facilitation of integration of the design team through stakeholder commitment for developing innovative ideas (Riley and Horman, 2005; Lapinski et al. 2006; Korkmaz et al. 2007) to be equally important as the integration of efficient systems and innovative technologies. This paper also identifies flexibility as key in design, system design, and design decision support. This paper serves two purposes. First, it examines the NZEB case study design process in detail as the design was performed by attempting to map the processes and sub-processes in the early design phase through extensive semi-structured interviews conducted with the key decision makers and decision facilitators of the project. Then, it identifies the process-based key performance indicators that drive the processes that should be considered in developing a design decision support framework for NZEB early design phase by identifying the most important issues within the identified processes and sub-processes and map how they relate to design decision-making (Lapinski et al. 2006; Korkmaz et al. 2010; Horman et al. 2006).

Four decision-mapping components were identified in each of the design phases (Author, 2014). These four components (refer to Figure 1) were identified to be critical to understand and map the NZEB design decisions and knowledge exchange affecting the NZE design goal and performance outcome (GSA 2004; Riley and Horman, 2005).

(a) **Stakeholders** – In order to understand the essential roles played and the tasks performed on the project by a design team member, it is imperative to identify the stakeholder's role in decision-making, decision facilitation, technical expertise, or regulatory role for decision mapping (Magent et al. 2009).

(b) **Phases of assessment** – Within each design phase the design approach is centred on various iterative cycles of phases of assessments.

(c) **Processes** – Identifying the key design processes, sub-processes and design activities that led to the effective project performance and achieving of the project objectives was an essential part of the decision mapping to establish the decision phases (Korkmaz et al. 2007; Korkmaz et al. 2010).

(d) **Technology** – Identifying knowledge type and flow for the assessments used by the stakeholders, tools selection, team communication, and collaboration were captured.

The results discussed in this paper are only limited to the case study presented but the NZEB decision support framework will be developed based on the collective analysis of all four NZEB case studies conducted for the research study. The mapped design process model for NZEB case study can suggest ways to improve the current early design process and project delivery method by identifying gaps in the current design approach (Yin, 2003).

2. Case Study Background

For the Ph.D. research, four NZEB case studies were studied and mapped to eventually come up with a decision support process map for NZEB early design process. This paper presents the second case study and explains the design decision mapping. The second case study selected was the Aldo Leopold Legacy Center that is an interpretive center and a commercial office space owned by the Aldo Leopold Foundation located in Baraboo, Wisconsin.

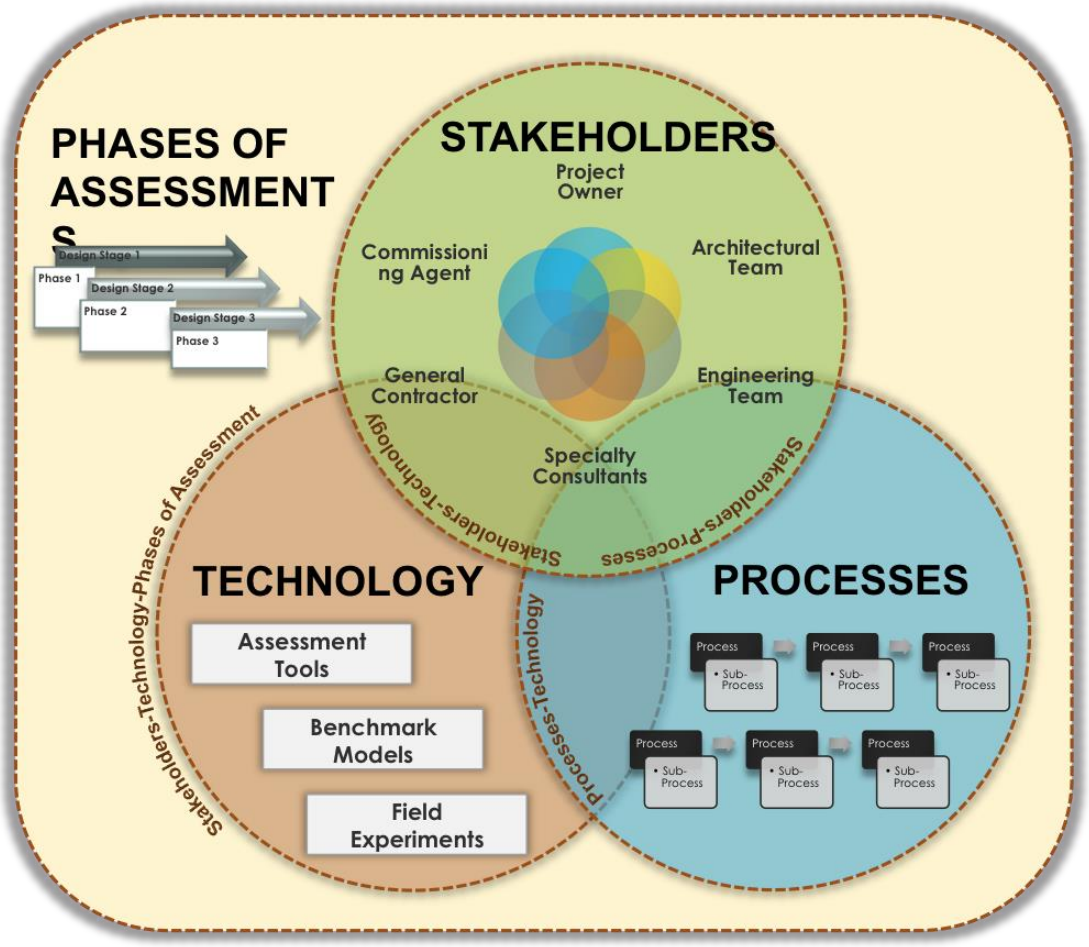


Figure 1: Four NZEB design process components studied

Construction of the 1,100 m^2 legacy center was completed in April 2007 (U.S. Department of Energy, Zero Energy Buildings Database, 2008) with a project cost of $3,943,418 (AIA/COTE – Top Ten Green Projects, 2008). This project set the record for the highest obtained points in LEED Platinum rating (61 points) any project had achieved at the time (2007) and also by being the first Carbon-Neutral building built in the US at the time (2007) (U.S. Department of Energy, Zero Energy Buildings Database, 2008). The mission of the foundation and of the program were aligned without sacrificing their purpose. Ethical land management, education, and community outreach were part of the project goals apart from the Net-Zero Energy and Carbon-Neutral goals in line with the foundation mission. The Aldo Leopold Foundation is the legacy of Aldo Leopold who truly believed and practiced the "land ethic" (AIA/COTE – Top Ten Green Projects, 2008) through conservation of the ecological system as a whole. The purpose of the legacy center was to share the Aldo Leopold philosophy with the world and practically show how one can live on a piece of land without spoiling it (AIA/COTE – Top Ten Green Projects, 2008). Other important project goals complimentary to their mission were to stay local and use local constructors, harvest the wood available on site and use it effectively for construction. The legacy center construction incorporated sustainable harvesting of wood from the forests owned by the Aldo Leopold Foundation, in order to improve the health of the forests. Wood harvesting was an integral part of the process since the beginning and was one of the biggest contributors towards achieving Carbon-Neutrality and Net-Zero Energy goal.

Daughter of the owner was a driving force behind the project concept and guiding philosophy. The owner's family was involved in the selection of teams, the vision for developing the concept, and decision-making. The Executive Director who was representing the Owner ensured the programming for the building met the Aldo Leopold Foundation's needs. He was integral to the selection of the architectural firm, selection of the general contractor, and other consultants. The Executive Director helped raise money by fundraising. He helped with public relations and education work about the project, coordinated the committee of board, and staff members. The Executive Director was actively and closely involved with the entire design and construction process. The Commissions Agent on the project began as a consultant to the owner, educating on kind of steps involved, what the important factors are, stands, and benchmarks. He stressed the importance of selecting the architectural and engineering firms to do the design, helped the owner as owner's representative in interviewing the architectural and engineering firms. He then joined the design team as a Commissioning Agent. In the later phases, his role was to use commissioning as a template to influence the design. He was guiding design to make sure that design confirmed to what they agreed they wanted to do in the earlier stages. The Ecologist working for the Aldo Leopold Foundation was instrumental in wood harvesting and planning the design and construction process around wood harvesting.

The Project Architect who was also the Project Manager for the architectural team for the project was chosen as the single source for disseminating information. He headed up the whole process, meeting with all the consultants, and coming agent. In the preliminary stages, the Project Architect managed all the meetings, goal setting, and took records. He was also responsible for site supervision of the whole construction phase, supervision of wood harvesting, and was instrumental in the design process and material selection process. The Sustainability Director took a leading role in driving the team to achieve the project objectives through the early design phases by acting as an internal Commissioning Agent on the process of energy flows of the building. His role was to make sure that the architecture and the systems are well integrated. He conceived of a process to do a Net-Zero Energy and Carbon-Neutral building by overseeing integration of design and simulation to achieve the goals. He took the lead on determining the mechanical system, helped the architects understand their capabilities and helped the owner in decision-making with what the energy goals would be. The Energy Consultant performed dual function by supporting the research function as well as the consulting function and helped with field experiments. His role was to work in response to the architecture and engineering team needs for inputs on systems and their performance. The independent Controls Engineer provided oversight on the systems design and simulation. The project involved the participation of the entire integrated team of members from the owner appointed committee of board and staff members, daughter of the owner, executive director, ecologist, project architect, principle architect, sustainability director, energy consultant, structural engineer, commissioning agent, general contractors, and controls engineer among other disciplines. The next section explains the methodology used to understand and map this integration of various stakeholders from these disciplines that was critical to the success of the Aldo Leopold Legacy Center design process to achieve the Net-Zero Energy goal.

3. Research Methodology

The research methodology used to document and map the integration of the various interdisciplinary stakeholders was started with a clean slate. The data collected through the interview process was the basis for mapping the design process used by the stakeholders for the project and to identify the emerging issues relevant to each stakeholder group. Literature review on theories and concepts allowed a deeper understanding of the process linked to designing of High Performance Buildings and NZEBs thereby helping in the development of the semi-structured interview protocols and questions (Author, 2014). The interview process was begun with the Project Architect and then followed by the key decision makers identified by the architect. As each key stakeholder was interviewed, they were asked to identify other key members of the design team based on their role and involvement in the project in the early design

phase. Each interviewee was first asked to explain their background, experience with high-performance buildings and Net-Zero Energy building design, building types they have worked on, and their role and responsibilities on the project. They were asked to explain the overall design team structure including all the key stakeholders, their internal organizational team structure, process of team selection, basis of team selection and decision-makers involved in the process. The interviewees were then asked to explain in detail how the design process happened from conception to the major stages of decision-making. Along the interview process, specific questions were asked to understand the underlying issues or concerns relevant to each stakeholder thereby capturing the rationale for decision-making. They were asked common questions such as the most important considerations for NZEB design process, challenges in achieving the NZE goal for this project, what really helped in achieving the NZE goal for this project, their perspective about the influence of project delivery method, building size, building use, selection of tools. Therefore, the mapping of the design process was an exercise that resulted from the analysis and coding of the interview transcripts by stitching them together for the entire project along the phases and stakeholders involvement.

Further, supporting information and literature related to the case study was collected from the interviewees and through published articles in order to get in-depth information regarding the processes as well as to verify the conceptual mapping. Through inductive approach, the researcher analyzed the case study to identify the underlying structural constructs of the design process used. The results of the investigation were analyzed from the researchers interpretation to describe the NZEB design process of this particular case study and explain how it occurred and why. Interpretation of the key issues, considerations, challenges from the interviews, and supporting literature, helped in the definition of the structural constructs and the emerging key process indicators of the design process.

Structure of the interview phases was adapted from methodology suggested by Klotz et al. (2007). The interviews were split into the following three phases and each phase was further split into two-three rounds of interviews (Author, 2014):

(a) **Interview phase one** – Rounds of interviews was conducted with the Project Architect and Project Manager, Sustainability Director, Commissioning Agent and Energy Consultant.

Round one - The objective of the first interview round was to develop an overall understanding of the project, role of the interviewee, overall team organization, procedure for goal setting, and unique project specific considerations.

Round two – The objective of the next interview was to understand the development of pre-design strategies and innovative approaches, how the strategies started shaping the concept design, understanding iterations of concepts and design options, type of analysis performed, tools used for analysis and other key team members involved in the above processes.

Round three – The intent of this interview round was identification of key processes and sub-processes in the early phases of design, knowledge exchange at key decision nodes, knowledge flow, specific roles of other team members and basis of decision-making.

(b) **Interview phase two** – Multiple interviews were conducted with the Executive Director, General Contractors.

Round one – The goal of this interview was similar to the round one interview of phase one but additionally capturing the specific role of the interviewee, their understanding of the project goals and their team organization.

Round two – This interview focused on identifying their pre-design and concept design processes or steps taken, in which phase did they get involved in the project, their integration with the architectural team, owner and other teams, knowledge exchange and decision-rationale.

Round three – The purpose of this interview round was to identify the sub-processes and activities performed in various early design phases, tools used for analysis, benchmarks referred to, rationale for analysis and decision-

making, identifying collaboration with other teams.

(c) **Interview phase three** – Interviews were conducted with the Ecologist.

Round one – This interview was based on input from previous interviews from phase one and two and identification of specific roles performed by the interviewee for this project, kind of analysis performed, information exchange, how and where they fit into the overall project phases, their rationale for decision-making and tools used for analysis.

4. Interview Results

The design decision process was captured through a combination of process mapping and network mapping techniques after the data collection through the interview process. Based on the interview results from the decision makers and decision facilitators, the processes and sub-processes were identified and grouped into phases that reflect the steps taken on the project development in practice. The mapping process involved an iterative coding procedure where the interview transcripts were coded in multiple levels to identify the design process as well as the rationale for decision-making used for the case study. Apart from direct responses from the interviewee, the researcher used their interpretation to discover the emerging themes of issues, important considerations and challenges by coding the interview transcripts. As a result, the final mapping of the key processes and sub-processes and the key phases depict the comprehensive summation of the design decision processes used by the owner and the integrated design team for the Aldo Leopold Legacy Center project.

The audio interviews conducted with all the experts were first transcribed and coded to identify how they were successful in designing a NZEB. For this, the first level of coding and mapping was to capture "HOW" it was done in this particular case study. Mapping of "HOW" meant documenting the strategies used and steps taken by each stakeholder group relevant to the context of the Aldo Leopold Legacy Center project. The initial coding was done manually going over the interview transcripts to identify the strategies and steps of the design process. Next, MAXQDA qualitative data analysis software was used to code the transcripts for this project to refine the codes and group them around each stakeholder and design phase. Thirdly, the steps taken by the stakeholders were mapped manually using sticky notes on the wall placed along stakeholders on the Y-axis and design phases on the X-axis. The sticky note process (refer to Figure 2) helped in stitching the transcripts and codes together; identify the integration and interaction points between the teams.



Figure 2: Level 3 coding and mapping strategy using sticky notes. This analysis methodology was an iterative exercise to create stable sets of items and construct sets of taxonomies from the stable sets derived.

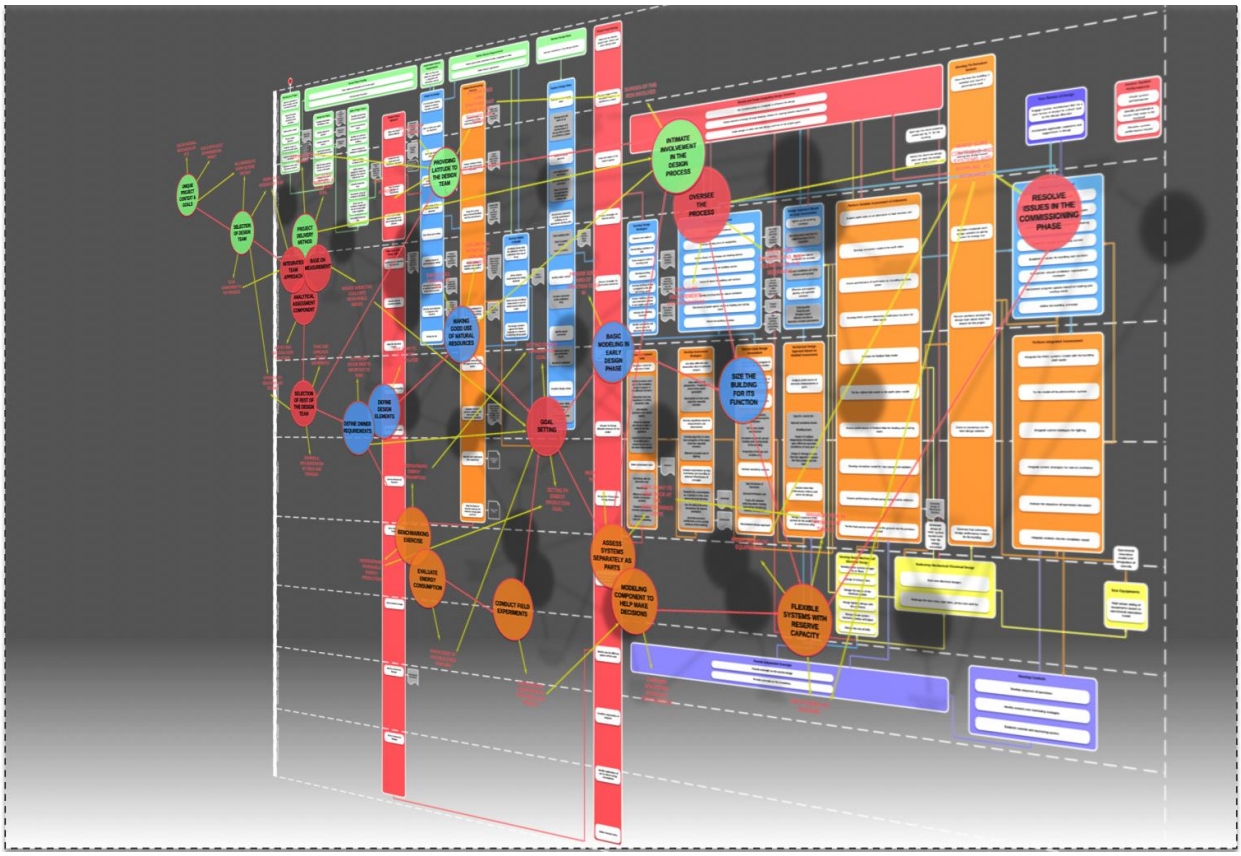


Figure 3: Mapping of emerging issues and themes from the detailed process map

After identifying and mapping "HOW" it was done for this case study and placing the processes along phases, the next level of coding involved abstraction to "WHAT" were the processes and sub-processes grouped along the relevant stages of progression of the project. In the process mapping, the phases have been shown sequentially and return arrows have depicted the iterative loops of feedback/ interaction. The processes within each phase are not necessarily ordered in any sequence. They could be parallel, sequential and/or iterative. Based on the comments of the experts on main processes, sub-processes, and design activities performed within each phase, the following phases were identified (refer to Figure 4 and Figure 6 on next pages) for the Aldo Leopold Legacy Center project.

The next level of coding after identifying "WHAT" processes were performed along what phases was to map the important considerations and challenges faced by all key stakeholder groups specific to the Aldo Leopold Legacy Center project. A network map was developed over the process map phases (refer to Figure 3 and Figure 5) to portray the important considerations and challenges specifically color coded to each stakeholder group. The key decisions were mapped along the phases mapped in the design process map to depict the timeline of when they were considered along the design process. The critical considerations are marked in red and the texts around the considerations are the relevant issues that needed to be addressed. The green arrows show the relationship between the issues and therefore between the considerations/ decisions. The issues mapped explain "WHY" the decisions were made that resulted in "WHAT" processes to perform by the design team.

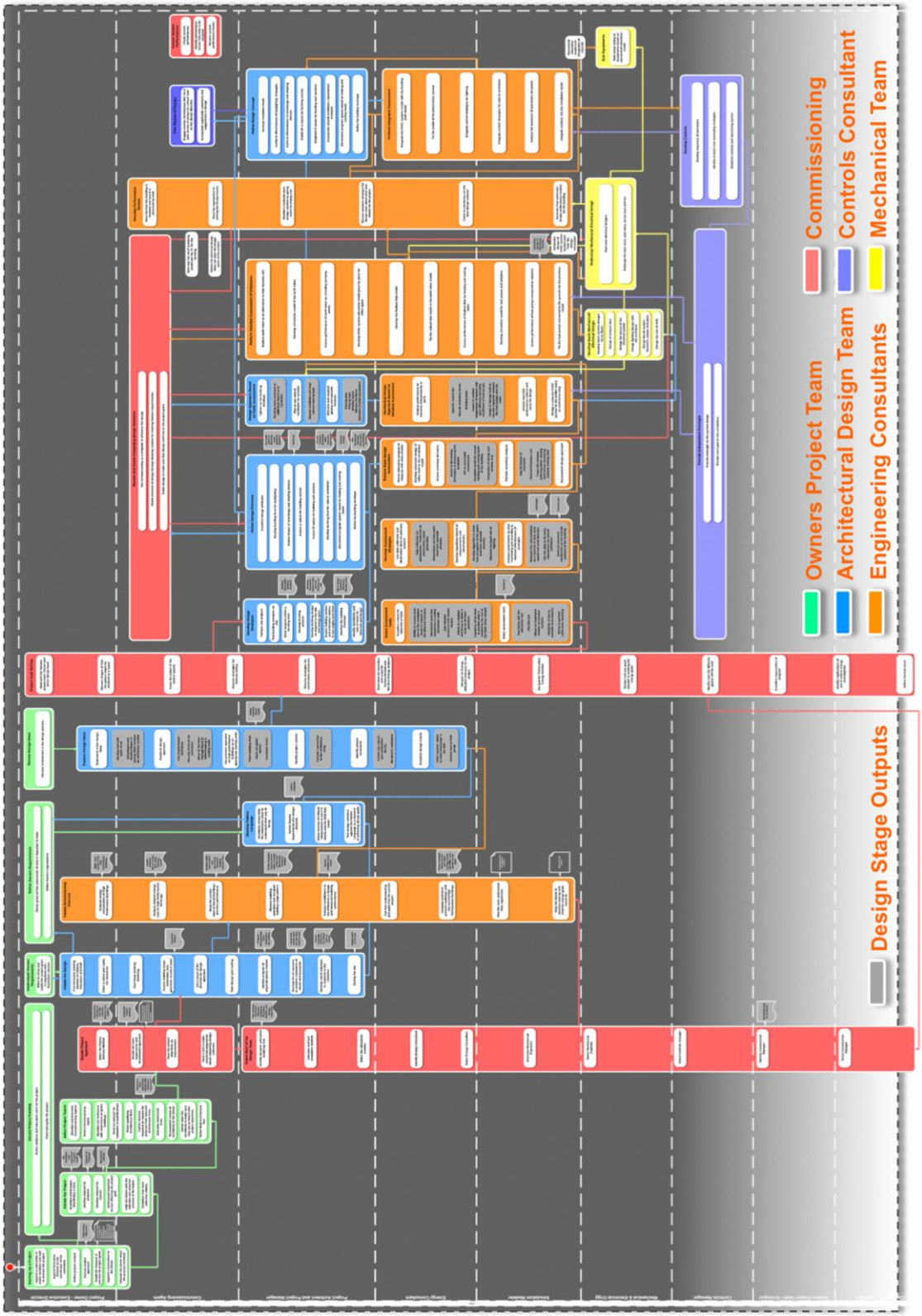


Figure 4: Detailed process map of the Aldo Leopold Legacy Center early design process

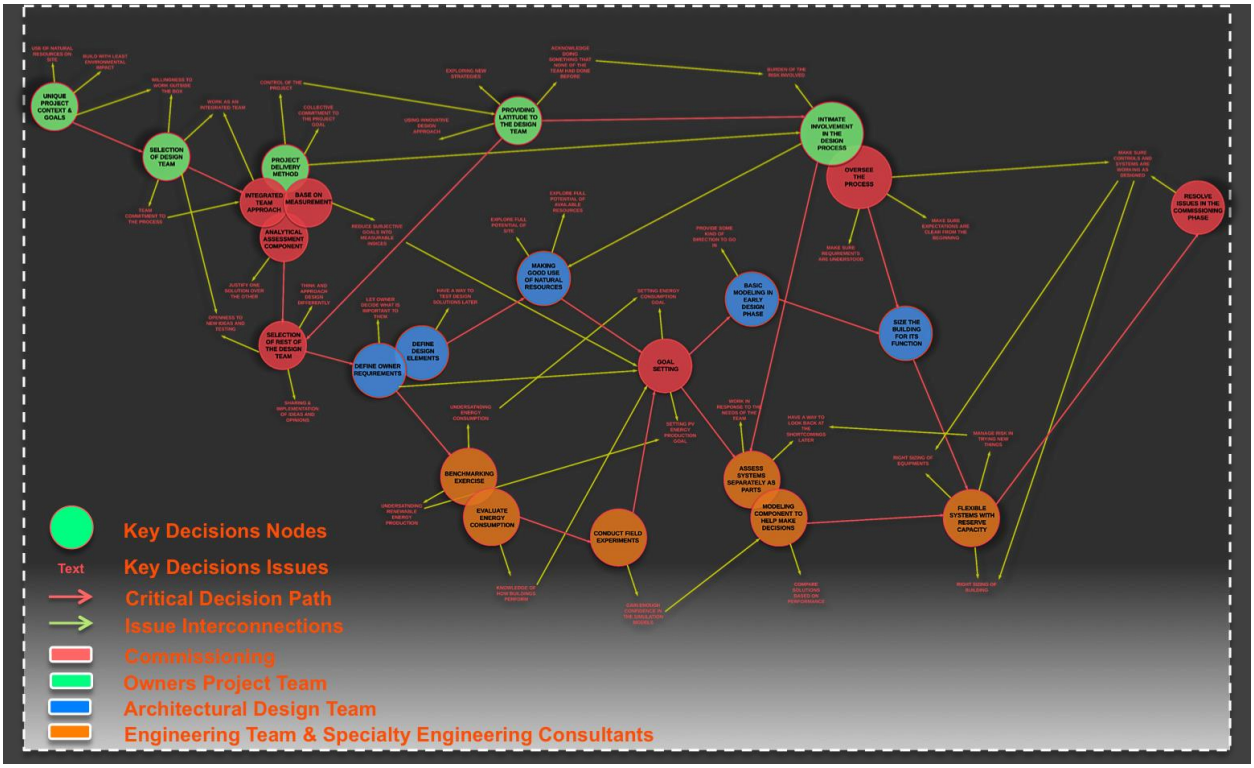


Figure 5: Network map of the issues, considerations and key decision processes

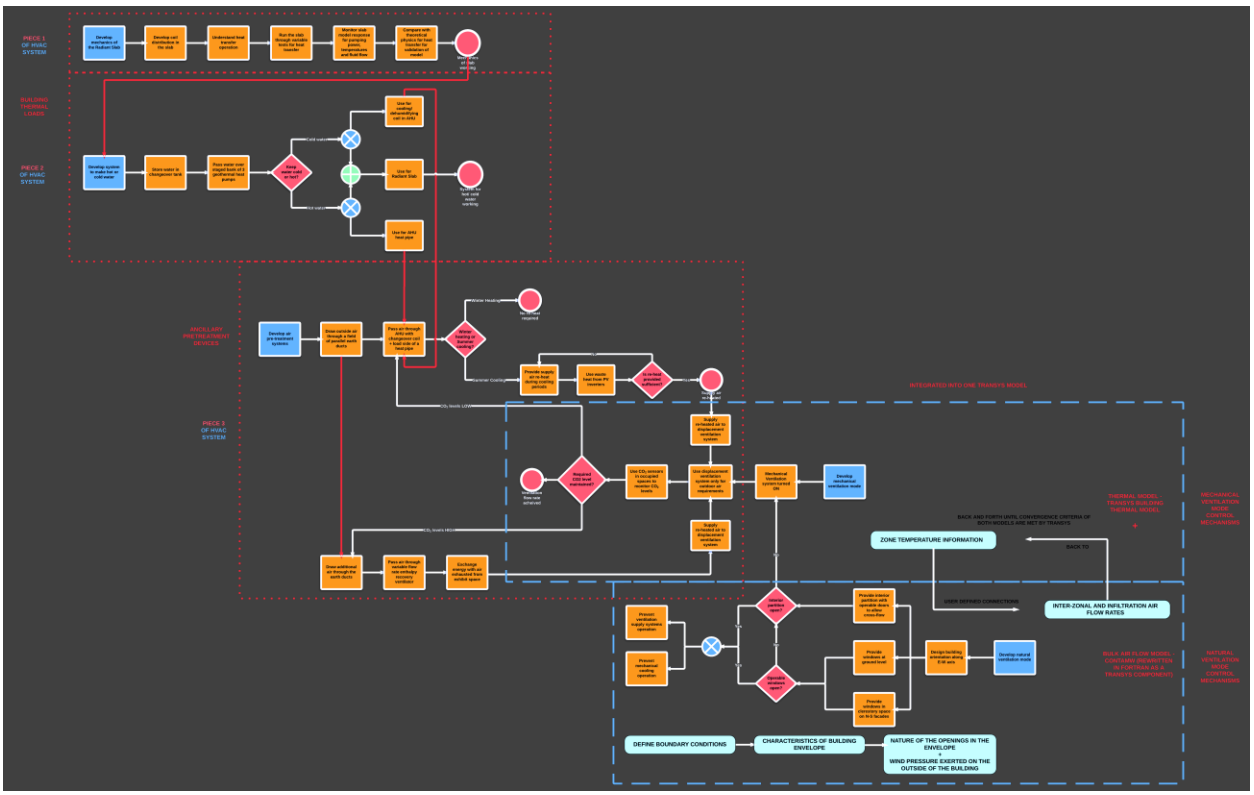


Figure 6: Level 2 and 3 mapping of the processes, sub-processes and design activities

5. Interview Analyses and Discussion

For this paper, the questions or themes that helped map the design process and derive the emerging issues, considerations and challenges for the NZEB context are presented in this section.

5.1 Interviewee Background

Eight stakeholders were interviewed in total for the Aldo Leopold Legacy Center project. All of them were key in decision-making and decision facilitation in the early phase of the design process. The stakeholders interviewed represented the disciplines of architecture, mechanical engineering, energy modeling, sustainability, commissioning, construction, ecology, and management that were important for the integrated design process (refer Figure 7).

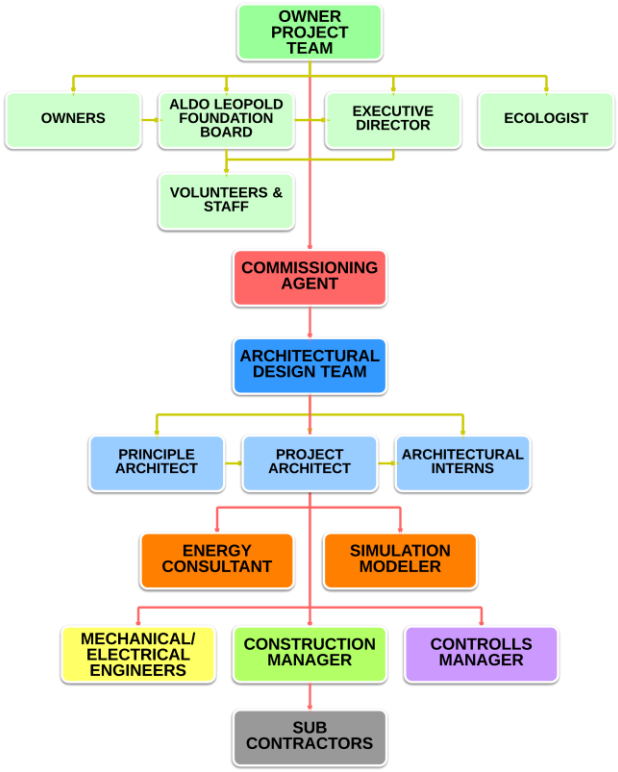


Figure 7: Organization chart of the key stakeholders involved in decision-making and decision facilitation

Three of the experts, the Project Architect, Sustainability Director, and the Energy Consultant had previous working experience of working on two or three other projects in the past. Two of the projects that were similar to the Aldo Leopold Legacy Center project were the Schlitz Audoban Nature Center and the Urban Ecology Center. This working experience played an important role in the team integration and project success due to their experience on similar High-Performance Building (HPB) projects, already established trust and respect. Based on the analysis of the interviewees' backgrounds, experiences on HPBs and attempting other NZEB projects the following parameters emerged as important to consider:

(a) Previous working experience – improved communication amongst teams

(b) Experience on HPBs (including NZEBs)

(c) Trust and respect – rapport and personal connection

(d) Team communication

5.2 Team Selection

The team characteristics to be able to 'play along' and 'adapt' were critical as per the Project Architect. The Executive Director described 'team commitment' and 'ability to think and approach design and construction differently' as important parameters for the right team. The Commissioning Agent stressed on 'team ethics', 'strong degree of integrity' and 'adaptability' as key criteria for design team selection. These parameters were identified as not just subjective characteristics but qualitative measures that are needed to be considered in team selection process apart from qualifications, experience, and other considerations. This study identifies the following qualitative measures (refer to Table 1) suggested be incorporated in the framework development for NZEBs design decision support for organizations to evaluate.

5.3 Project Delivery Method

The Construction Manager was on-board from the beginning and part of the integrated team process. At the time when this project was being designed, HPBs was an emerging new area and the concept of having a Commissioning Agent for Leadership in Energy and Environment Design (LEED) projects was still new. The role played by the Commissioning Agent was identified as critical to the NZE process due to his experience and oversight of the process to meet the project goals.

Table 1

Key phases and processes relating to team selection

Phases of Assessment	Central Stakeholders	Processes & Sub-Processes	Central Issues	Process Based Key Performance Indicators
Starting up a project	Owner's project team Consultant to Owner	Appoint committee to oversee the project Appoint coordinator of the committee Define project context Discuss project approach Establish project goals Appoint a consultant to the owner Understand the process involved	Use of natural resources on site Build with least environmental impact Unique project and context goals	Resource management Context specific performance goals
Initiate the project	Owner's project team Consultant to Owner	Establish initial teams short listing criteria Develop request for proposal Develop request for interest Understand important factors affecting project goals Define protocol for interview and team selection process Establish final team selection criteria	Willingness to work outside the box	Adaptability – play along with project changes and hanging needs of technology Team commitment – complete buy-in and willingness to test new ideas to achieve the goals
Select project teams	Owner's project team Commissioning Agent	Shortlist & interview commissioning agents Select Commissioning agent Shortlist architectural firms Send out request for statement of qualifications Select qualifying architectural firms Call for detailed response to request for proposal Interview shortlisted firms Recommend choice of architects to the owner Owner makes sure architects on board with the project objectives Select final architectural firm	Work as an integrated team Team commitment to the process Openness to new ideas and testing Selection of design team	Team ability – come up with innovative thinking for design solutions Team ethics – doing things for the right reasons and not just because they have to Team integrity – accept not knowing all the answers but open to feedback/ new ideas
Secure project funding	Owner's project team	Public relations and education work for the project Fund-raising for the project		Project budget

Table 2

Important phases and processes relevant to project delivery method and team selection

Phases of assessment	Central Stakeholders	Processes & Sub-Processes	Central Issues	Process Based Key Performance Indicators
Decide project approach	Owner's project team Commissioning Agent Project Architect	Select project delivery method Decide team organization and involvement approach Base project objectives on measurement Have a tool to make analytical judgments	Control of the project Collective commitment to project goal Base on measurement Analytical assessment component Justify one solution over the other Integrated team approach	Risk assessment – share the burden of the risk Performance objectives – specific energy performance goal Contractual requirements – binding requirement to ensure performance Owner involvement – not to be mistaken for control Process oversight – specific assigned role to oversee the process to meet the goals Post-Occupancy commissioning Performance verification Owner commitment – complete buy-in
Select rest of design team	Owner's project team Commissioning Agent Project Architect Sustainability Director	Select Sustainability Director Identify dynamic simulation modeling firm Interview & test simulation modeler Select simulation modeler Identify construction manager Select construction manager Interview mechanical engineers Select mechanical engineer	Think and approach design & construction differently Openness to new ideas and testing Sharing and implementation of ideas and opinions	Stakeholder involvement – integrated team process Stakeholder commitment Goal definition

The Commissioning Agent interviewed every bidder on the subcontract involved with the Heating, Ventilation and Air-Conditioning (HVAC) system making sure they understood the commissioning requirements and what he expected to see to commission the HVAC system. This was formally put in the contract requirements that the controls and HVAC sub-contractors were needed to run all the tests and correct errors in the commissioning phase (refer to Table 2).

The project delivery method adopted for this project was a hybrid of Design-Bid-Build with

lowest bid not being the criteria for selection and involving the Construction Manager in the decision-making during the early design process. There was a pre-qualification process in place to select the sub-contractors with added criteria of them being local in order to provide local employment opportunities as another dimension of sustainability. Therefore when asked about the influence of the project delivery method, the Executive Directors' perspective was as follows. Owner took the entire burden of the risk for this project. Commissioning and LEED process were the way to ensure that the performance objectives were being met. Energy performance measures were not spelled out in the contract in the beginning or codified at any point in the project. The intimate involvement in the design process did give the owner some confidence in the collective commitment of NZE. The Commissioning Agent suggested if the goal is very carefully defined with measurable indices of performance expectations, Design-Build could work if you get the right Design-Build firm. The key is definition – reducing the subjective goals into measurable indices.

5.4 Program Requirements

As per the Project Architect, it was really critical to understand the way the occupants (owner and staff) live. Pattern language by Christopher Alexander was used as a method to capture the owner's needs. The development of the pattern language lets the owner decide what is important to them and see it written down. The Architect interprets what the statements mean and gets the interpretation reviewed to see if that means exactly what they said. It is an iterative process (refer to Table 3) through which owner's requirements are defined first, in an attempt to define them into design elements. Later design solutions were tested against this pattern language as a way to look back.

From the energy perspective, the integration of building usage to thermal zones was key as explained by the Sustainability Director. Space planning or zoning to accommodate the needs of staff members that had varied tolerances for comfort levels and educating the staff about natural ventilation control and lighting controls for the building to function as designed was key. Consideration of the types of tasks performed by the occupants was important to provide the right light levels needed.

5.5 Goal Setting

For this particular project, the Sustainability Director did pre-design work before the goal setting. He studied in detail the case studies published by National renewable Energy Laboratory on six HPBs, observed building operation, occupant building usage pattern, and energy use from websites and site visits. He researched what the current state-of-the-art buildings were in terms of performance at the time, how the architects previous buildings fit into the state-of-the-art, he helped the architects understand their capabilities and helped the owner in decision-making with what the energy goals would be. The informal goal setting began with the brainstorming session before the programming meetings where the design approach was decided and appropriate starting points were set based on previous experience on other HPB projects.

By the goal setting meeting, images of how the pattern might be resolved as a space, the notion of the kind of spaces were already known. The basic idea of transit spaces were already known enough to talk about strategies of thermal zoning, construction processes, strategy for Carbon-Neutral and Net-Zero Energy analysis. Goal setting exercise for determining the Energy Use Intensity and renewable energy needed to set the energy goals were performed (refer to Table 4). Design end use goals relevant to meeting the energy goals were set.

5.6 Design Simulation Accuracy

In their past working experience of working on similar projects, the Sustainability Director and the Energy Consultant had conducted previous research and field experiments that unintentionally became pre-design work for this project. They measured and modeled natural ventilation with CONTAMW (Multizone Airflow and Contaminant Transport Analysis Software) in the auditorium of the Schlitz Audoban Nature Center. Used Cp-Generator (program to predict wind pressure coefficients) to generate pressure coefficients on the outside surfaces of the building. The results of the analysis gave them enough confidence in the accuracy of the simulation model.

Table 3

Overview of key phases and processes related to owner requirements

Phases of Assessment	Central Stakeholders	Processes & Sub-Processes	Central Issues	Process Based Key Performance Indicators
Understand owner requirements	Executive Director Owner Project Architect	Effort to refine & clarify project goals in alignment with foundation mission		Understand owner needs
Initiate the design	Owner's project team Commissioning Agent Project Architect Sustainability Director	First formative meeting between architects and owner's committee Effort to refine and clarify objectives Start basic building modeling Assess building shape, orientation, size, geometric structure types Get a sense of the direction for design approach Start design goal-setting Identify program of physical spaces needed Develop list of concerns or problem statements Develop set of solutions in response to concerns Test the site organization	Let owner decide what is important to them	Define owner requirements
Refine owner requirements	Owner Committee and staff Executive Director Project Architect	Owner gives written statements of what is important to them Define owner requirements		Establish design criteria
Develop pattern language	Owner's project team Project Architect	Review what the statements mean Define owner requirements into design elements Review architects interpretation Test design solutions against pattern language	Have a way to test design solutions later	Define design elements Test design solutions Design traceability
Review design ideas	Owner's project team Commissioning Agent	Intimate involvement in the design process	Using innovative design approach Exploring new strategies Acknowledge doing something that none of the team had done before Providing latitude to design team	Design innovation Design flexibility

Table 4

Important phases and processes relevant to goal setting and simulation accuracy

Phases of Assessment	Central Stakeholders	Processes & Sub-Processes	Central Issues	Process based Key Performance Indicators
Initiate benchmarking exercise	Commissioning Agent Project Architect Sustainability Director Energy Consultant	Evaluate energy consumption of HPBs Analyze metered energy use of HPBs Study current state-of-the-art of buildings and their performance Observe building operation and occupant building usage pattern Analyze contributors to the difference in design & measured building performance Use the understanding to apply on current project Compare architects previous buildings with current HPBs Help the team understand their capabilities Help the owner with energy goals decision-making	Understanding energy consumption Understanding renewable energy production Benchmarking exercise Evaluate energy consumption Knowledge of how buildings perform Conduct field experiments Gain enough confidence in simulation models	Research current state-of-the-art (buildings and technologies) Building performance knowledge – knowing how your buildings actually perform Energy goal definition Simulation integration Occupant usage patterns Simulation accuracy Define modeling basis Calibrate simulation models Experimentation and measurement Plug load analysis
Explore design ideas	Executive Director Commissioning Agent Project Architect Sustainability Director Energy Consultant	Brainstorm initial design ideas Establish design approach Use previous approach on HPBs as an appropriate starting point Identify project context Identify project constraints Establish design criteria	Explore full potential of site Explore full potential of available resources Make good use of natural resources	Resource analysis Brainstorming Decide design approach Explore starting points
Project goal setting	Owner's project team Executive Director Commissioning Agent Project Architect Sustainability Director Energy Consultant Construction Manager Staff & Ecologist	Meet with owner's project team, owner and entire design team Discuss images of how the program might be resolved as spaces Know the notion of the kind of spaces Discuss strategies for thermal zoning Discuss strategies for construction processes Determine boundary and scope for NZE analysis Set goal for EUI Set goal for photovoltaic energy needed Design end-use goals relevant to meeting energy goals Identify how different spaces will be used Establish organization of program Identify implications of use to reduce energy consumption Define thermal zones	Setting energy consumption goal Setting photovoltaic energy production goal Goal setting	Explore design strategies Design end-use goals Benchmarking exercise Thermal zoning Occupant comfort Occupant education Occupant usage pattern Program organization Program balance

The TRNSYS simulation program was revised to integrate with CONTAMW. Data monitored, recorded and used in some simulations from the experiment to measure effectiveness of the natural ventilation formed the basis of modeling in the early project phase.

Data was collected on photovoltaic power generation from the Urban Ecology Center project to predict photovoltaic power generation more precisely. Observations on how users treated their operable windows were made to develop an algorithm based on measurements and observations to show how occupants of the space treated their operable windows. Modeled occupant control of lighting by measuring lighting usage from previous two projects to estimate measured occupant use of lighting. So the design approach was not to look at the overall results of the entire building (refer to Table 4) but looking at the results of parts and how they enforce and carve the design along the way.

5.7 Tool Selection

The tool used for energy modeling was TRNSYS (Transient System Simulation Tool) and the selection of building energy modeling tool was based on its flexibility in scenario assessment. It allowed modeling multiple and varied occupant behaviors to test what happened in the space. The downfall of the tool was that the run time was long and therefore the process was time consuming. The intent of selecting the simulation tool was to assess each part of the simulation model in support of the different stakeholders. Hence, assessing systems separately was critical to the simulation process. The point to note here is that the simulation team (both Sustainability Director and Energy Consultant) had experience writing simulation code and therefore had the capability of providing what was needed for the rest of the team when needed. So the basis of tool selection was to simulate in parts, add detailed questions with simple models, compare and focus in detail in areas as they had questions. What this allowed them to know was how each component worked to help make a decision than just researching the use of a system in some other project. Also, this was a strategy used by the modeling team to better allocate the resources of the expensive tool to be used primarily in parts of the design process where they had questions (refer to Table 5). So the selection of the building energy modeling tool was a tradeoff decision between flexibility and ease of implementation where project budget and team experience with simulation modeling also played a role.

Table 5

Key phases and processes for tool selection

Phases of Assessment	Central Stakeholders	Processes & Sub-Processes	Central Issues	Process Based Key Performance Indicators
Select assessment tools	Sustainability Director Energy Consultant	Establish criteria for tool selection Select assessment tools	Work in response to the needs of the team Assess systems separately as parts	Tool flexibility Simulation experience – part of team ability Tool run-time – ease of implementation
Develop assessment strategies	Sustainability Director Energy Consultant	Use data collection & observation on previous projects Develop algorithms based on measurement & observations Conduct field experiments by data monitoring & recording to measure effectiveness of strategies	Compare solutions based on performance Have a way to look back at shortcomings later Modeling component to help make decisions Gain enough confidence in simulation models	Assessment strategy

Table 6

Important phases and processes related to different stages of early design and energy assessment

Phases of Assessment	Central Stakeholders	Processes & Sub-Processes	Central Issues	Process Based Key Performance Indicators
Develop design strategies	Project Architect Sustainability Director	Perform site analysis Test building solutions on site Solve program within building form Develop building sections Develop building design to respond to site & energy goals Assess building section and orientation relative to sun angles & views Develop building envelope Identify availability & size of wood for structure & design	Provide some kind of direction to go in Basic modeling in early design phase	Develop design concepts
Refine design elements	Commissioning Agent Project Architect Sustainability Director	Establish design attributes Develop building form for daylighting Assess impact of overhangs & shading devices Assess U-values for building section Assess R-values for wall sections Develop building form for natural ventilation Disconnect program spaces based on heating & cooling needs Refine building envelope	Size the building for its function	Balance design organization
Perform early design assessment	Project Architect Sustainability Director Energy Consultant	Revise simulation program to integrate with other models Develop schematic design in simulation model Assess envelope decisions Perform sensitivity analysis Recommend design approach		Sensitivity analysis
Design approach based on early assessment	Commissioning Agent Project Architect Sustainability Director Energy Consultant	Tighten up building envelope Plan to use natural ventilation for summer Effective & required glazing and operable windows		Perform detailed assessments Refine design elements
Review & grade competing design solutions	Executive Director Commissioning Agent	Use commissioning as a template to influence design Check elements of design through drawing reviews for meeting owner requirements Guide design to make sure that design confirms to project goals	Burden of the risk involved Make sure requirements are understood Make sure expectations are clear from the beginning Intimate involvement in the design process Oversee the process	Process oversight Owner involvement Requirement specification Expectation clarification

Table 7

Key phases and processes for detailed assessments and simulation integration

Phases of Assessment	Central Stakeholders	Processes & Sub-Processes	Central Issues	Process Based Key Performance Indicators
Mechanical design approach for detailed assessment	Sustainability Director Energy Consultant	Analyze performance of elements independently in parts Assess how their performance carves design Design separate HVAC systems for thermal zones	Assess in parts	
Perform detailed assessment of unknowns	Sustainability Director Energy Consultant	Explore alternative solutions Develop simulation model of chosen alternative Assess performance of alternative Develop HVAC simulation model piece by piece Develop other mechanical components separately Tie the component models together Assess performance for heating & cooling loads Hand over schematic design of HVAC system	Manage risk in trying new things Right sizing of building Flexible systems with reserve capacity	
Develop performance module	Commissioning Agent Project Architect Sustainability Director Energy Consultant	Describe how the building is modeled and how it is perceived to work Describe approaches to solving design issues Moderate each design solution by scoring for energy use Discuss what that means amongst design team Come to consensus on best design solution Generate final schematic design performance module		
Develop controls	Controls Consultant Sustainability Director Energy Consultant	Develop sequence of operations Identify controls & monitoring strategies Establish controls & monitoring systems		
Perform integrated assessment	Commissioning Agent Sustainability Director Energy Consultant	Integrate HVAC system model with building shell model Tie the model of photovoltaic system Integrate control strategies for lighting Integrate control strategies for natural ventilation Analyze the sequence of operations document Integrate controls into simulation model Start actual sizing of equipment based on operational simulation model	Right sizing of equipment	Simulation integration Controls integration Equipment sizing

Table 7 *cont'd*

Phases of Assessment	Central Stakeholders	Processes & Sub-Processes	Central Issues	Process Based Key Performance Indicators
Refine design concept	Project Architect Sustainability Director Energy Consultant	Increase insulation levels Confirm effectiveness of daylighting strategies Confirm effectiveness of overhangs & shading devices Establish U-values for building section Establish R-values for wall sections Incorporate natural ventilation improvement strategies Disconnect program spaces based on heating & cooling needs Define building envelope		

5.8 Design Assessment

Based on the iterative process of simulation in parts, feedback was provided to the architectural team by the Sustainability Director and Energy Consultant on envelope issues, infiltration, insulation levels, etc. (refer to Table 6). Sensitivity analysis was performed to find out the buildings sensitivity to changes in infiltration versus changes in insulation levels.

Simultaneously, the architectural team processes included developing set of design solutions, developing and analyzing building sections, fine-tuning of design organization, detailing of the shell, etc. Design influenced amounts of glazing, placement of glazing, which glazing to be operable in clerestory. Based on the feedback from the Energy Consultant, detailing and specification to minimize thermal bridging were refined, effecti-veness and required number of operable windows were evaluated, window openings were fine-tuned and desired infiltration rates were assessed.

5.9 Simulation Integration

The HVAC system was designed and evaluated piece by piece. Earth tubes were explored as an alternative to heat recovery unit through an independent simulation model since the building or the loads did not influence its performance. Schematic design of the office shell was done to assess natural ventilation, integration of design and window opening area. The simulation of the ground source heat pumps was well understood by the Energy Consultant due to previous experience of writing simulation models. The integration of all the simulation models at the end included tying together all the separate models of the heat pumps, radiant slab model, building shell for the entire building, and the earth tubes (refer to Table 7). Then controls were integrated into the simulation model and the final piece added to the model was the photovoltaic system. Actual sizing of the equipment waited until an operational simulation model with integration of controls.

6. Summary and Conclusions

6.1 Important Considerations

The most important considerations of strategies and control mechanisms that helped in the successful achievement of the NZE goal for this project as per each stakeholder are presented below (refer to Table 8). The process based key performance indicators that emerge from the most important considerations are identified.

6.2 Challenges & Critical for NZE Goal

The challenges faced by each stakeholder in achievement of the NZE goal for this project are as follows (refer to Table 9).

Table 8

Important considerations and process based key performance indicators

Stakeholders	Important considerations	Process based Key Performance Indicators
Commissioning Agent	Putting the team together Willingness to work outside the box Making good use of natural resources Putting systems together that were flexible and with reserve capacity Manage risk in trying new things Right size the equipment Make sure sub-contractors understand the commissioning requirements Expectations of commissioning put in contract and explained in detail upfront Giving latitude/ permission to fail Reducing subjective goals into measurable indices	Team selection Stakeholder willingness Resource planning Flexible systems Risk management Performance expectations Design latitude Goal definition
Executive Director	Ideas, challenges and encouragement brought by commissioning agent to the project Kind of work done that helped invent those ideas and develop them further by the Sustainability Director and Energy Consultant Integrated team ability and willingness to let ideas percolate and get implemented	Design innovation Stakeholder commitment
Project Architect	Minimize energy consumption Manipulate the building to meet the energy goal (balance program) Consider efficient mechanical systems Produce energy to balance energy use Having Commissioning Agent, Sustainability Director, Energy Consultant, Construction Manager from day one Having modeling component to help make decisions (justify one solution over the other) Select people that can play along and adapt	Balance program Integrated team Modeling component Adaptability
Sustainability Director	Evaluate energy consumption and determine actual Energy Use Intensity (EUI) Compare with HPBs EUI (research other buildings) Knowledge of how our buildings performed and goals we could achieve Designing end use goals relevant to meeting energy goals Assess systems separately Selection of simulation tools Set EUI goal for the building and use that to determine how much solar needed in programming Perform simulation modeling in parts Have a way to look back and see what some of the shortfalls were due to Commissioning Agent critical for overseeing the process and meeting the goals Knowledge of how different systems operate	Benchmarking exercise Building performance knowledge Set EUI goal Design end-use goals Assessment approach Decision traceability Process oversight Systems operation knowledge
Energy Consultant	Owner buy-in Careful selection of project team Owner understood the need for trade-offs Owner very involved in the design process Owner had a hand in making decisions On-going monitoring of the systems and buildings Selection of building energy modeling tools	Owner commitment Owner involvement Tool selection

Table 9

Critical for NZE goal, challenges and process based key performance indicators

Stakeholders	Critical for NZE goal	Challenges	Process Based Key Performance Indicators
Commissioning Agent	Flexibility in sizing the building right for its function Flexibility in sizing the systems serving the building Putting the team together	Continuous measurement of the project No user interface to archive and analyze the information for future improvement	Program flexibility System flexibility Team selection
Executive Director	Right team that are committed to the process Team able to think and approach design and construction differently	Owner took all the burden of the risk Understanding the kind of return on investment that they needed to see Keeping the team together in doing something different than what they are used to	Team coordination Stakeholder commitment Design innovation Return of investment
Sustainability Director	Owner commitment Teams need to have understanding of how their buildings perform Post-occupancy verification by architectural team Contract to do a year of post-occupancy commissioning with the client Verification of performance	Engaging all the harvested wood Determine how to make the structural system Cut the trunks	Continuous measurement Continuous improvement Performance verification
Project Architect		Hard to find contractors and consultants that completely get the issue Cost of technology and custom wood	Stakeholder buy-in Technology cost Resource planning
Energy Consultant	Genuine interest and willingness of owner to look at comfort and energy side of the equation		Owner commitment

Based on the experience on the Aldo Leopold Legacy Center project and other HPB and NZEB projects that the interviewee have been involved with, they were asked to summarize what they would suggest to be critical or most important considerations for any NZEB design process. The conclusions of the results and analysis are as follows:

Based on experts views on main considerations for NZEBs, owner commitment, selection of design team, risk assessment, latitude/ flexibility in design, goal setting, stakeholder commitment, contract requirements, resource planning, integrated team approach, innovative design solutions, selection of tools, system flexibility, stakeholder willingness, team ability, need for trade-offs, owner involvement, on-going monitoring, balance program, modeling component, knowledge of actual building performance, design of end-use goals, assess systems separately, have a way to look back, overseeing the process, benchmarking exercise, verification of performance and understanding client requirements are significantly important.

A detailed assessment of the key processes and sub-processes in the early design phase of this case study helped in identifying the key contributors towards the success and failure points of the design implementation process. This understanding can help in generating control measures for NZEB

design process through the identification of process based key performance indicators. The key performance indicators identified through each NZEB case study for this research will ultimately result in a consolidated list of relevant control measures that will become the components of the framework development for NZEB integrated design process mapping.

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