# Proceedings

## Stream 5: SB13 Vancouver
## Pushing the Boundary – Net Positive Buildings

BUILDING LASTING CHANGE

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CONTENTS

# Combining Pedagogy, Research and Consulting to Promote Integrative Design

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ABSTRACT: In the Spring of 2010, The P.I. taught the sixth in a series of graduate architectural design studios partnering with Civil Engineering and Landscape Architecture courses and sponsored by the University of Wisconsin-Madison; in this case by the College of Agriculture and Life Sciences. Each of these six funded studios have explored actual building projects as a component of their project scope studies and fund raising activities. The resulting report in this case, "The CALS Horse Barn as a LEED Platinum/Living Building: An Illustrated Design Guide" combines student design work and original faculty research to lay out a strategy for adaptively reusing an existing historic barn into an interpretive center dedicated to sustainable agriculture. Though an academic design study rather than a built project, the CALS Horse Barn offers lessons for thinking through questions associated with buildings designed to be net positive with respect to human wellbeing.

## 1. FUNDED STUDIOS AS FACULTY ACTIVISM / FACULTY ACTIVISM AS INTEGRATIVE PEDAGOGY

The Green Building Sponsored Studio Project represents a relationship between the P.I. and the UW-Madison Office of Facilities Planning and Management that has evolved organically to the point where the campus architect identifies upcoming building projects and secures funding from the concerned School as a normal component of the campus' scope investigation. From the P.I.s perspective, the point of the program is to promote deep green building agenda for State projects as much as it is to create a multi-disciplinary design studio experience with actual clients for the students of architecture that are the primary engine of the work. Each studio receives $20,000 in funding, which covers the cost of studio expenses such as base materials production and visiting critics, the research support of the P.I.s Carbon Neutral Design (CND) Case Study Project and the writing of the final report. The Horse Barn studio also supported the addition of Assistant Professor Greg Thomson as co-instructor, bringing expertise in historic preservation to the project.

The intention of these reports is to serve as design guides for the administrators who are seeking to have these buildings built. As such, the student work is only the raw material for the study. The problem is posed and the class structured to generate a range of solutions within tightly proscribed parameters. The resulting student work is dissected and used to illustrate possible solutions to a range of topics that emerge uniquely for each project. The structure of the assignment is set up to ensure that the issues to be addressed are as clearly identified as possible at the start of the investigation, and that the range of solutions explored is broad. In the case of the Horse Barn, this rigor fit well with the studio's role in fulfilling the department's 'Comprehensive Design' requirement.

This typological framing of issues is reflected both in the structure of the class experience and the formal analysis that interprets the work of the class for the final report.

During the studio, students work individually but are constantly encouraged to see their work within the spectrum of possible solutions represented by the class as a whole. In this way, the students are treated as members of a team effort to elucidate the range of possible design solutions, and individual design solutions are separated from their owners intentions and treated as the property of the class as a whole. Students are constantly encouraged to appropriate solutions from others as they all work towards their individual synthesis of the available solutions.

After the studio is complete, the funding allows for the author to hire individual students to continue this process and produce diagrammatic studies that further abstract and catalog the emergent themes of the studio investigation and the resulting range of solutions.

## 2. THE HORSE BARN AND ITS EXPANDED PROGRAM

The Horse Barn is an existing historic structure in the heart of the Madison campus that is currently used for the storage of grounds equipment and up until very recently housed horses. A typical investment allowed by sponsorship of the studio is the student production of base drawings and/or models the summer before the class is offered, and in this case the client was persuaded to additionally fund a professional 3-D laser scan of the structure to provide an accurate assessment of existing conditions.

According to the College of Agriculture and Life Sciences (CALS) Vision Statement, "the vision for the UW-Madison Horse Barn focuses on the building being adaptively reused as an outreach center for CALS with the theme of "Sustainable Agriculture". The facility will become a much needed social center for the central campus area. Major functions to be accommodated include: café, learning center, distance education, flexible office space, a visitor's center and CALS student organization space."

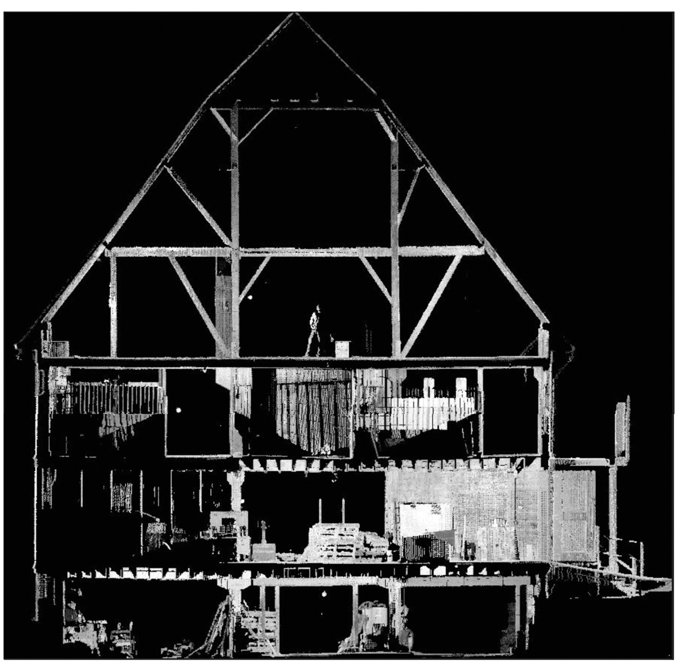


Figure 1. Three Dimensional Laser Scan of the Horse Barn.

For the architectural design studio and the civil engineering capstone class, the issues of historic preservation and the adaptive reuse of a heavy timber structure with severe spatial and structural constraints and equally engaging environmental challenges and characteristics was a primary focus of the project. These questions would also be most critical real-life question that the study would address. An on-site waste water treatment system was added to the program in support of the ecologically regenerative performance standard that CALS had expressed interest in during programming sessions that were held with key stakeholders and paid student assistants the summer before the studio was offered. And a large lecture hall was offered as an optional program element to provide the added complexity of building an architecturally compatible addition to the Horse Barn for those students compelled to build outside the existing footprint.

## 3. THE ILLUSTRATED DESIGN GUIDE

The structure of the resulting Illustrated Design Guide presents a matrix of issues in two parts. Part I: Mapping a LEED Platinum/ Living Building Strategy presents the P.I.s research on the history of academic buildings being certified at the Platinum level and then steps through the credit structure of LEED and the Living Building Challenge, offering an assessment of the most appropriate strategy to achieve these standards, each point or topic illustrated with both case study buildings and student work.

Part II: Elements of an Integrated Response cuts across this inventory of strictly environmental issues with a post-semester examination of fifteen design challenges that emerged from the project and gave form to the student work (figure 2). These issues are not necessarily environmental but they are all architectural in the sense that they have strong spatial implications.

Taken together, this matrix illustrates the synthetic potentials of the problem of adaptively reusing this historic structure with the goal of creating a work of regenerative design. For this paper, we will selectively sample a handful of these cross-cutting issues that seem to offer the greatest insight into the question of eco-positive architecture.

## 4. ELEMENTS OF AN INTEGRATED RESPONSE: A 15 POINT MANIFESTO FOR THE HORSE BARN

The distillation of the work of the studio down to a comprehensible primer on the relevant issues produces a 'manifesto' or list of topical imperatives for the client to focus on and argue for (figure 2). These imperatives reflect the challenges posed in the design studio, but are only fully articulated in hind-sight as a way to codify lessons learned and organize and explain the material. In each studio offered to date, general issues of ecological design compete with site, program and client specific issues for attention. In the case of the Horse Barn, the client's programmatic ambitions and almost all of the resulting 15 imperatives reflect environmental concerns, but this is not always the case.

As much as these 15 imperatives were the program of the studio, the work of the students and the subsequent analysis of that work by the faculty are both directed towards identifying strategies for their simultaneous solution. The goal of the design primer is to explain the patterns of integrated solutions that a seasoned green building professional might be expected to see but that both the students and the client would otherwise be overwhelmed by. The premise of the research, and of this account of it as a path towards a net-positive architecture, is that this 'pattern recognition' accelerates the learning process and raises the bar for both the students and the eventual design team. Not to say that these twelve schemes represent all of the possible or the best integrative solutions, but they do provide a framework by which the students and the client can place other proposed solutions in context.

A MANIFESTO FOR THE HORSE BARN

1. *Program Fit*
   The building must accommodate the program.
2. *Core Placement*
   Vertical circulation, egress and other services must be integrated with the existing structure in ways that promote the goals of the program.
3. *Volumetric Interconnection*
   The creation of voids in the existing fabric should be explored as a means of enhancing both programmatic interconnection and environmental performance.
4. *Onsite Wastewater Treatment*
   The project must include a solar greenhouse capable of supporting a Living Machine for blackwater waste treatment, or a composting toilet system.
5. *A Large Lecture Hall*
   The project may include a large lecture hall not originally specified in the program. This addition should enhance the Horse Barn's role as a Visitors' Center as well as serve the UW community.
6. *Site Circulation + Exterior Rooms*
   The project must accommodate multiple points of entry for pedestrian traffic and provide for both public arrival by school bus and service access by truck. The project must include strong programmatic relationships between interior and exterior 'rooms,' recognizing and enhancing local micro-climates conducive to exterior programming.
7. *Structure*
   The structure of the Barn must be made adequate while remaining expressive.
8. *Envelope*
   The envelope of the Barn must be super-insulated without sacrificing its character.
9. *Daylighting*
   Daylight should be considered the primary means of illuminating the building. Every space not required to be dark should have access to daylight, preferably from more than one direction.
10. *Solar Gain and its Control*
    The sun should be used to heat the building. At the same time, apertures designed for daylighting and solar gain must prevent those gains when the sun's heat is unwelcome.
11. *Air is for Breathing*
    The building must be both naturally ventilated and mechanically supplied with fresh air. The class rooms and kitchen additionally require a separate stack ventilation system to maximize passive performance.
12. *Water is for Moving Heat*
    The building must integrate hydronic heating and cooling strategies alongside its fresh-air only ventilation systems!
13. *On-Site Renewable Energy*
    Once the building's loads have been reduced through good design and high-efficiency systems integration, the remaining power required must be generated on-site.
14. *Stormwater Management*
    All stormwater must be managed on-site.
15. *Interpretive Program*
    The Horse Barn is as much a children's museum as anything else. Space for both large and small 2-D and 3-D exhibits must be provided as part of the primary public spatial sequence.

Figure 2. The Horse Barn Manifesto

### 4.1 *On-site Wastewater Treatment*

One cluster of program related imperatives that emerge as critical in the analysis are the related design challenges of (3.) creating volumetric interconnection, (4.) architecturally integrating a solar aquatic greenhouse for on-site waste treatment, and (5.) the option of adding a large lecture hall. In terms of the Topic Integration Matrix, it is compelling that four of the fi ve schemes in some way associate the greenhouse with the lecture hall. This makes explicit the fact that both program elements are emblematic of the interpretive function of the Horse Barn, and that the living machine is the perfect 'lobby exhibit' for people waiting to enter the hall. It is also a relationship that is predicted by the example of academic living machines referenced in the LEED strategy section of the design primer; the A.J. Lewis Center at Oberlin College. Figure 3, the location of the on-site wastewater treatment system in relation to the lecture hall, illustrates the plan diagrams that are the design primer's primary means of arraying the range of student solutions for discussion.

### 4.2 *Structure*

The Horse Barn presented a distinctly technical challenge as a design problem. The structure is large enough on paper to accommodate the CALS program, but cramped by a shallow but aesthetically compelling stone basement level, a dense heavy timber structural grid with varying floor heights on the first and second floor and a majestic loft that is equally a forest of columns. The old-growth oak frame is both ecologically and culturally significant and structurally inadequate in every aspect. A second imperative that the Barn's structural system be systematically reinforced ended up producing solutions that forced a different kind of integration between the Civil Engineering students in Madison and the Architecture students in Milwaukee. Local restoration experts were brought in to advise on the feasibility of various structural and construction strategies and the two groups of students shared and advanced each others solutions.

### 4.3 *Envelope*

Consideration of the structure as a historical artifact also links to the topic of the thermal envelope (8.) and the question of reconciling the dictates of historic preservation with the need for a super-insulated envelope. The studio explored the full range of possibilities, from leaving the historic exterior intact and insulating from the inside to leaving the experiential character of the barn intact and reconceiving the exterior, to seeking to finesse the difference. This choice became more nuanced with the students who also sought to integrate daylighting strategies (9.) such as white window splays or selected walls being treated as light reflectors.

### 4.4 *Air is for Breathing*

A final integration topic that proved to be unexpectedly vivid was the integration of systems for the provision of fresh air. This system is always a comprehensive design consideration, but in this case it became a dominant formal and symbolic element. It did so because it slowly dawned on both the students and faculty that what appeared to be a large chimney in the barn was also a fully functional stack ventilation system for the horse stalls. This hybrid 19th C. technology inspired a serious investigation of its 21st C. reincarnation.

## 5. CONCLUSION

As an academic exercise rather than a built work, the lessons for practice concerning buildings that are 'net-positive with respect to human well being' are necessarily in the approach taken to the problem and not in the built results.

The pedagogical argument for the activity of design would be that the strategies for addressing the various challenges of making the project net-positive with respect to environmental criteria and socially beneficial in a host of other potentially definable ways can and should be solved in ways that are mutually compatible. By this argument, the design study seeks to identify potentially synergistic solutions- solutions that leverage each other to make their application feasible. The resulting solutions should point towards the potentials for this adaptive reuse of an existing barn to embody the quest for human well-being on both environmental and cultural grounds.

The approach to the problem is perhaps best captured in the first imperative of re-inhabiting the barn, given that it was deemed to be structurally inadequate at every level- the decking, joists, beams and columns would all require structural reinforcement to meet contemporary building codes. Though the studio did not test this in any real budgetary sense, the combination of civil engineering, historic preservation, and architectural design expertise represented by the various faculty and invited experts guided students to propose a range of possible solutions that can be evaluated as to their potential to simultaneously preserve the structural role and cultural authenticity of the heavy timber structure.

The approach also suggests a design methodology that allows independent lines of exploration generate a common understanding of the problem. Here the various student projects were the key to the distillation of the matrix of specific issues that have only subsequently been identified to critical. This also allows these individual explorations to be seen in relation to one another as instances of 'type;' as systematic and rational solutions. Again, the exploration both responds to and shapes the manifesto or program statement by testing its potential elements.

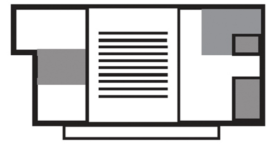
Another aspect of this approach is the articulation of conflicting objectives within the program or manifesto. "8. Envelope- the envelope of the barn must be super-insulated without sacrificing its character." This is an example of two conflicting criteria stated as an imperative to be resolved. The student work can point towards strategies that plausibly resolve this conflict.

This question of preserving historical character while radically improving performance is perhaps the central question of the studio. In the end, the work argues for a reconsideration of the norms of historic preservation that would shift away from the exterior appearance of the building as its most essential historical character and towards the experiential qualities of the interior. Justin Marshall (Figure 5) presents the clearest statement of this shift, and arguably presents the most intellectually and aesthetically coherent project in the class as a result. Nicole Hill's project (figure 6) pushes back on this clarity by taking the same basic approach and seeking additionally to integrate interior modifications supportive of good daylighting practice.

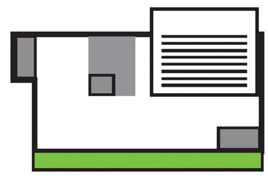
From the experience of the Studio, one could rightfully conclude that one clear path towards ecologically and socially positive architecture is to start with a structure that has deeply rooted ecological, social and cultural attributes and dedicate yourself to adapting it to a more intensive use without destroying its essence. We certainly believe this to be true, and the Horse Barn was a compelling design studio project for this reason. Of all six of the sponsored studios that this faculty member has engaged with, this is the one where the faculty, administration and potential donor were all predisposed to a regenerative standard.

The larger point remains that it is the integrative way that these sponsored studios frame the studio exercise and then blend student work and faculty research, consulting and activism that teaches the integrative design thinking necessary to produce net-positive architecture. As with all iterative design activities, this cycle takes on greater meaning with each successive design studio, as the analytic methods and graphic vocabulary evolves and each class has a greater sense of the whole that they are contributing

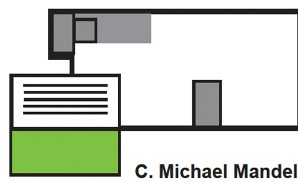
**((C.) Michael Mandelman-** Axonometric Section of Horse Barn, showing relationship between large lecture hall and Living Machine greenhouse.



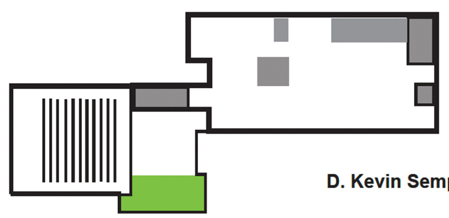
**A. Zachary Rasmussen**



**B. Kristin Reichart**

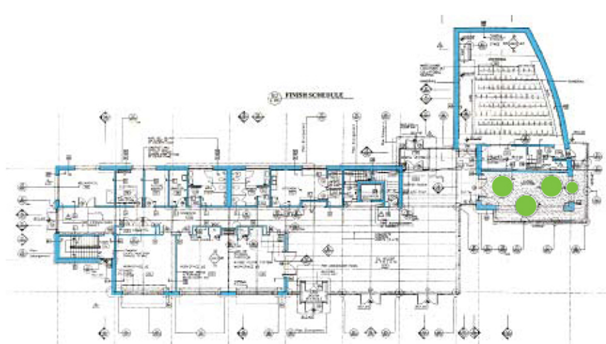


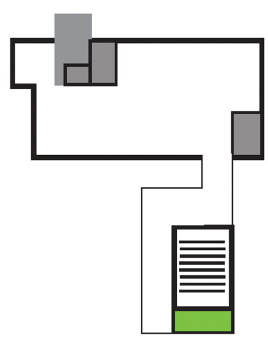
**C. Michael Mandelman**



**D. Kevin Semple**

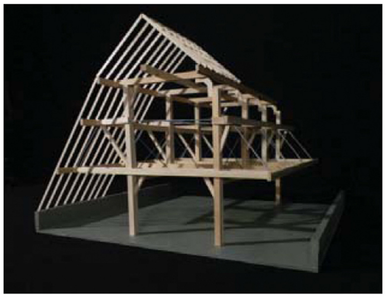
**Adam Joseph Lewis Center for Environmental Studies, Oberlin College.**
William McDonough and Associates Architects. First floor plan. The lecture hall is a separate single story volume attached to a two story east-west classroom bar. One passes by the glass doors to the greenhouse when entering the lecture hall from the lobby.



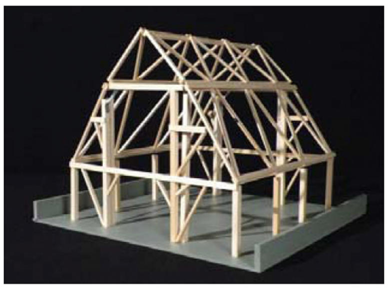


**E. Nicole Hill**

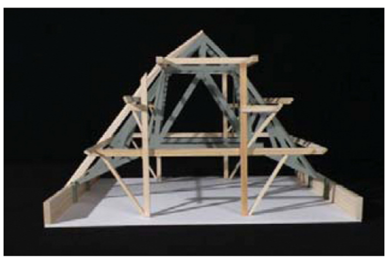

Figure 3. On-site wastewater treatment in relation to lecture hall with case study example



A. A minimalist reconfiguration using tension cables to create a trussed platform within the existing timber frame.



B. An all timber cage creating two new near-perimeter column lines to carry the long-span roof loads to ground.



C. The two bays of bent timber frame replaced by steel trusses.

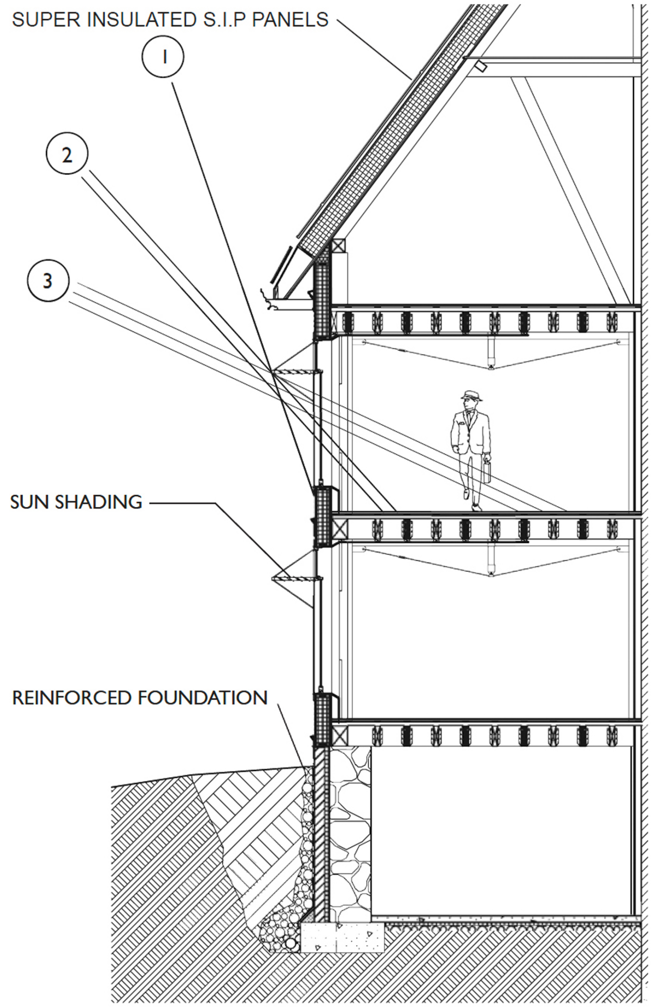



Figure 4. Structural reinforcement studies. Top Left- preliminary team exercise in adapting the loft framing to a large span space. Top right and below- Jonathan DeJardin.

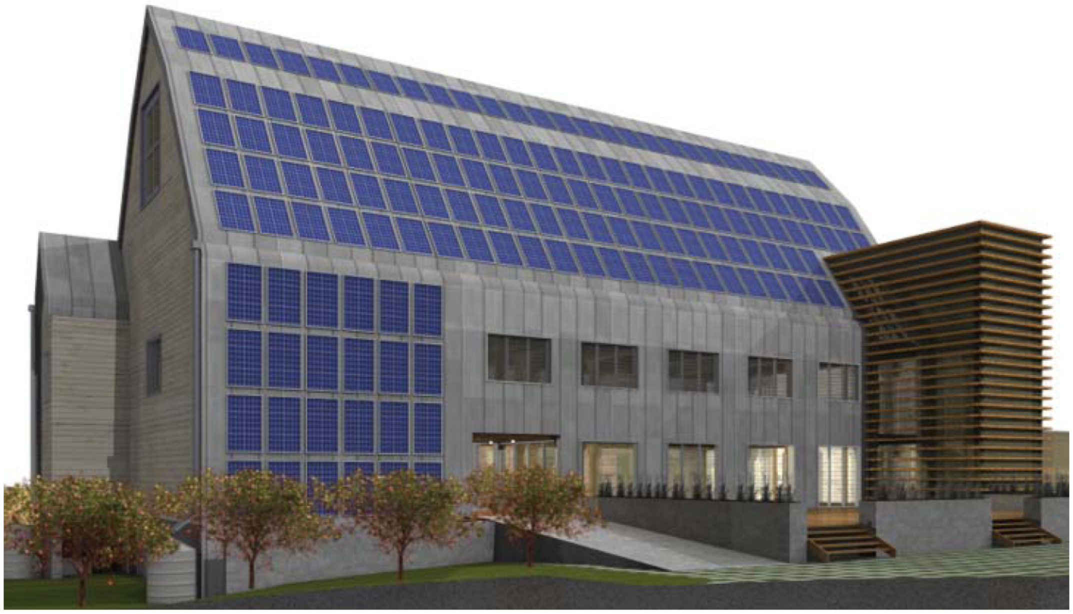


Figure 5. Thermal Envelope Study. Justin Marshall- proposal to wrap and reconceive the exterior of the Horse Barn, leaving the original entry end elevations intact.

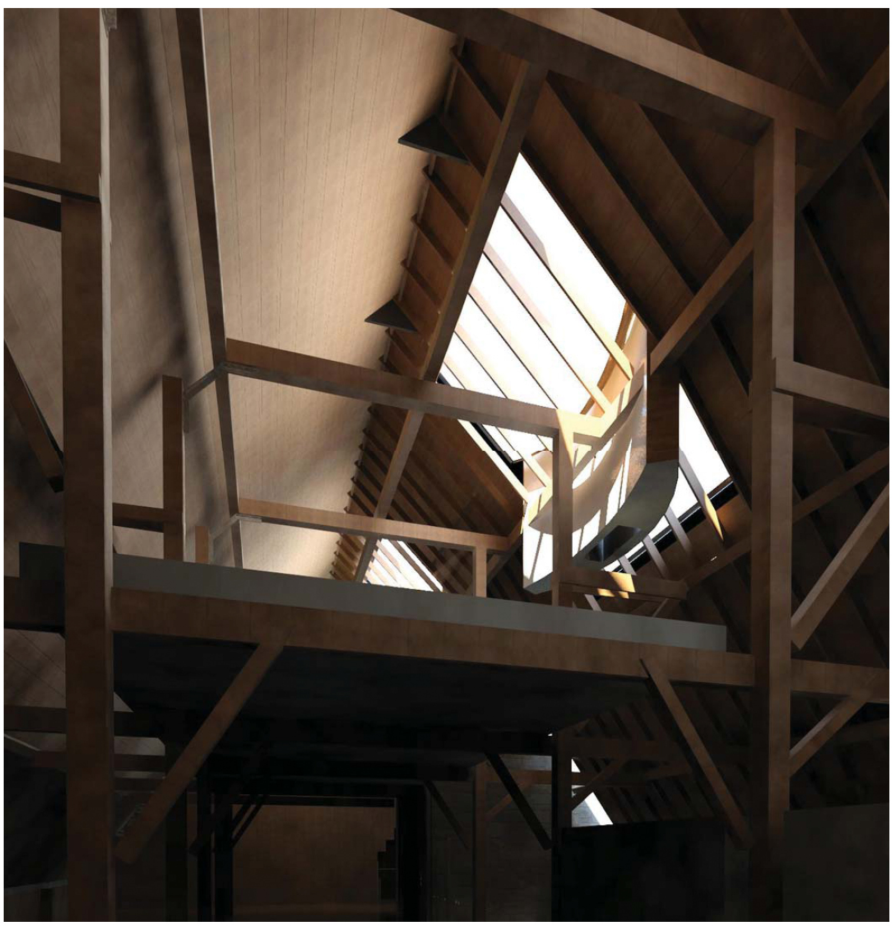


Figure 6. Daylighting Study. Nicole Hill- Integration of daylighting, stack ventilation and renewable energy generation by means of south facing light scoops/ ventilators on north slope of roof. Loft interior with light scoop and plaster reflecting surface, balancing rough framing and finished surfaces.

# Research into Action: Mining Dormant Inherent Potential so that Infrastructural Hubs can act as Catalysts for Positive Change

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ABSTRACT: Existing North American cities not only bear witness to aging physical infrastructure built beyond our planet's ecological footprint limitations, but even more challenging, they continue to expose failing lifestyle infrastructure. One of the most primed opportunities for renewing our built fabric - both in terms of infrastructure and quality of life - is by moving towards "balancing ecological resilience and social cohesion" in our inner city neighborhoods and their neighboring fringe industrial belts. One of the most challenging tasks facing us in Canada is how to re-FRAME (OR CATALYZE) the revitalization of the aged inner city fragments. Borrowing from the Ecological Urbanism model developed by the Urban Ecology Agency of Barcelona (and Salvador Rueda), and Joe Ravetz's synergistic framework, this paper will primarily address the undervalued first step of *MINING: Evaluating the dormant, inherent potential within an existing context*. Conventionally, the pre-design phase for architecture is very short, and it is undervalued. However, by investing more time and money into the pre-design phase, financial, social, and ecological benefits may be magnified. This paper argues, that the pre-design phase's importance is imperative to setting up the "winning conditions" for a successful, sustainable and resilient project. The example of the *infrastructural hub* shows how MINING can be used to promote positive, transformative change. Although the paper summarily outlines the subsequent steps of *FRAMING AND APPLYING*, they are not the focus of the paper.

## 1. INTRODUCTION

Canadians are currently facing a lifestyle conflict created by car dependency and a lack of eco-density. Census data collected in Canada in early 2012 shows that suburbs (and their long term unaffordable infrastructure) continue to grow faster than cities: while cities grew by 5.3% between 2006 and 2011, suburbs grew by 8.7% (CBC News, April 2011). The continued prevalence of urban sprawl and the suburban dream has consequences for transportation, energy consumption, use of resources, and health. Recent studies by cardiologist Dr. François Reeves in Montreal, for example, reveals that air nano-agressors are as dangerous as food nano-aggressors when it comes to common health issues, such as heart disease (2012, p54). This begs us to ask, how can the realm of design (architects, designers, planners, landscape architects and so on) begin to reverse this lifestyle crisis and systems crisis? Reversing sprawl is like throwing one's manual stick shift straight into reverse from second gear, and this '*quantum change'* will require more than just isolated design interventions. Everard and Ravetz (2009) emphasize, "We have to consider systemic interactions within and between ecosystems rather than isolated effects and look at emergent, self-organizing processes of change rather than linear mechanical cause-and-effect. These transitions can be grouped under the headings of 'ecological systems thinking.'" (p15).

This paper uses 'ecological systems thinking' as a departure point and asks, what pre-design and planning tools can help us reverse this lifestyle impasse, while augmenting resilience, creating affordability and synergies, and ultimately leading to quantum change? And second, how can infrastructure projects be catalysts for positive change and for building sustainable and inclusive communities? Holistic tools and assessment methods such as *Ecological Urbanism* are significantly more effective than conventional green building tools. Conventional tools, such as the US Green Building Council's *Leadership in Environmental and Energy Design (LEED®),* may help in forging a "common language" (Cole & Pearl 2007, p6), they nonetheless fail to adequately address context specificities and social cohesion (Mertenat & Cucuzzella, 2011). Generic performance tools encourage reducing resource use and adverse environmental impacts and improving the health and comfort conditions for building occupants and aim for at least a net zero impact. However achieving net zero for carbon will not solve all of the problems described above. A much more holistic design model is required; one that includes net positive development[i] and that profoundly integrates the dimensions of resilience, affordability[ii], their synergies, and humanity's "health and happiness." (One Planet Living, 2008)

The danger of relying wholly on quantitative assessment methods, including carbon accounting, is that we may lose sight of vital qualitative aspects of design[iii]. If we want more than incremental change, then we need the tools for applying quantum change. This is the fundamental goal of the paper: to elaborate on the tools and processes that can bring about quantum change in our aging cities. Borrowing from the Ecological Urbanism model developed by the Urban Ecology Agency of Barcelona (and Salvador Rueda), and Joe Ravetz's synergistic framework, among others, this paper will primarily address the following first step: MINING: *How can we effectively evaluate the dormant, inherent synergistic potential within an existing context*? The MINING PHASE is emphasized this is the phase most often under-valued in current frameworks, and in the design process in general. Here, the MINING phase is defined as the pre-design phase, in which the multi-disciplinary design team is charged with the task of uncovering a context's latent and synergistic potentials. The themes of socio-economics, complexity, socio-ecology, governance and culture are assessed, investigated and challenged. Before any visioning can commence, the core values underpinning the current context are probed. Current practice conventional assessment tools are not designed for this re-questioning, so brainstorming and imagination must be given ample space and importance. *The example of the infrastructural hub is used throughout this paper to illustrate how proper mining can lead to quantum change.*

## 2. THE LIMITS OF CURRENT ASSESSMENT TOOLS + METHODS

While many green building assessment tools have come a long way in their development, having expanded in scope and in application, they remain inadequate in addressing the issues of affordability, governance, social engagement, multiple scales of inhabitation, and other softer, intangible, yet indispensable aspects of a successful design project. Green buildings usually aim to reduce social and environmental impacts relative to the status quo; they are rarely 'resource autonomous' and almost never have positive off-site impacts (Birkeland, 2007, p3). Systems thinking has yet to be incorporated into most mainstream assessment tools, which seem to disregard that "[s]olutions to complex environmental problems that involve a wide range of scales of influence and time frames requires systems thinking – the ability to appreciate and address linkages and inter-relationships between a broad range of often conflicting requirements." (Cole and Pearl, 2007, p8) In fact, the way that building environmental assessment methods identify discrete performance requirements often translates into design in isolation, rather than design that encourages and exploits creative synergies, closing loops and responding appropriately to the local ecological and social contexts (Cole, 2012, p41). Moreover, current green building tools are product-based and do not require that stakeholders or occupants be involved through the creation, implementation and operation of projects (Plaut *et al*., 2012), even though such involvement is what strengthens social resilience (Cutter, 2008).

These criticisms have been made before by Birkeland (2007), Cole (2012), and Ravetz (2000a), among others. The concern of primary importance to this paper, however, is that assessment tools under-value, if not ignore, the MINING phase. In fact, most evaluation tools do not even get introduced to a project until after the MINING phase, when a concrete project has already been established, and major re-questioning is difficult or even counter-productive.to team-building amongst the various stakeholder concerns. Moreover, green building assessment tools such as LEED may be criticized on the basis that:

- Individual performances are evaluated *relative* to a benchmark, rather than in their absolute consequence (Cole, 2012, p41)
- They are premised on creating gradual, incremental change, and not *quantum change*
- Overall success is measured through the simple addition of the weighted scores *(ibid)*
- Performance criteria fail to preserve resources through a conscious cyclical process of regeneration (Fisk, 2009).
- They are generic and fail to address local or regional qualities
- They exclude many measurable negative impacts as well as many potentially positive ones
- They have progressed much more rapidly at the scale of the individual building than the scale of the infrastructural hub or neighbourhood or even the scale of the building integrated into a larger context

Expanded to evaluate neighbourhood design, *LEED for Neighbourhood Development* is divided into four unequally weighted categories: smart location & linkage, neighbourhood pattern & design, green infrastructure & building, and innovation & design process. *LEED ND* can nevertheless be criticized on the basis that it has ill-defined limits; socio-economic aspects only represent a fraction of total points (Urban Ecology Agency of Barcelona, 2012, p52); it does not include local economy (*ibid.*, 76); it does not require social engagement or participation; and it does not contribute to solving the lifestyle crisis described at the beginning of this paper (Mertenat & Cucuzzella, 2011). Furthermore, there are too few prerequisites that are necessary to make sure that all projects are certified and are in fact holistic. While *LEED ND* represents a step in the right direction, it ultimately serves private sector interests through incremental change and cannot guarantee "Net Positive Development" or social cohesion at the community scale.

The Living Building Challenge 2.0 goes beyond *LEED ND* and offers some promise for creating net positive buildings. It addresses social justice, local food production, and accountability for community scale projects. It has also expanded its scope from the individual building to community projects and infrastructure. However, even this approach can be considered limited when considering affordability, high quality public space, and escalating biodiversity losses. As many have argued before, no green building assessment or performance tool can achieve true sustainable development without effective partnerships, participative processes and governance, co-learning, and transparency.

Unfortunately, *Life-Cycle Assessment* (LCA) cannot on its own lead to quantum change either. This approach has been generally received within the environmental research community, and increasingly in practice, as the only legitimate basis on which to compare the environmental attributes of alternative materials, components and services. It analyses and assesses the environmental impact of a building's materials, its components and assemblies throughout the entire life of the building (including throughout construction, use and decommissioning). By contrast, Social Life Cycle Assessment is a technique directed at helping stakeholders to improve social and socio-economic conditions of production and consumption (Benoît *et al.*, 2009, 5), though it uses the same four phases of LCA. Studies may be performed to provide a "holistic picture of the positive and negative impacts generated by the production activities." (Benoît Norris, 2012, p442). SLCA may help lead to more Sustainable Production and Consumption (SPC), and assist in clarifying why the "closing of loops" is paramount, since social aspects of the latter are rarely discussed (Parent *et al.,* 2012, p1). While SLCA can help identify "social hotspots," it nevertheless remains in its infancy, and beyond generating information on product supply chains' social impacts, *all* of its applications remain unclear (*ibid.,* p7). Furthermore, quantitative methods are used for assessing social or cultural impacts that are difficult or impossible to measure (Cucuzzella, 2011, p71). Neither LCA nor SLCA on their own, are sufficient tools for helping integrate a project into its neighbourhood, but nonetheless may still provide an important piece to the larger puzzle.

Some 'regenerative design' tools have begun to emerge in the past few years, which go beyond the quantitative metrics of conventional assessment tools. These regenerative tools may be promising in helping designers to achieve higher ecological and social resilience in their projects. The LENSES[iv] and REGEN[v] approaches, for instance, are 'process-based' tools with some metric evaluation components included (Cole, 2012, p49). These tools include social, cultural, economic and ecological systems issues and processes, but also emphasize their complex interrelationships (ibid). Consequently, they offer guidance to designers and other stakeholders in situating projects within a complex network and are able to strike a balance between quantitative, isolated indicators as well as the qualitative aspects of a specific context. These tools could potentially be very useful for a design team during the MINING phase; however, while they provide the design team with the appropriate questions and/or themes, they do not yet tie together MINING and FRAMING spatially (for example mapping tools) to ensure concrete, local change. This may be seen in contrast to the "Ecological Urbanism" mapping-based approach.

Improving, intensifying, and complexifying existing evaluation tools may not be the answer, however. Rather, we need to promote 'synergistic mapping and lateral approaches' and holistic, systems thinking tools during the MINING phase. This vision is most holistically created through an Integrated Design Process, with open and continuous lines of communication between the team, transparency, and redefined cultural boundaries (Cole and Pearl 2007, p6). In order to encourage quantum change, rather than incremental change, and in order to equip infrastructural projects with the capacity to evolve with resilience, we must look beyond conventional green building assessment tools, or at the very least, not rely on them solely. This paper, in line with leading eco-systemic thinkers (such as Salvador Rueda of the UEAB), argues that infrastructural hubs and masterplans must score well holistically, rather than in just a couple of categories. Furthermore, real 'net positive' design must look beyond micro-accounting for sustainability. It must also look at socio-economic, socio-ecological, cultural, metabolic factors, and have the courage to incorporate numerous qualitative measures in order to achieve resilience, affordability and synergies. By conducting qualitative analyses most critically during the initial *MINING* phase of a project, dramatically increases the potential for a robust resulting vision during the subsequent *FRAMING* phase. In order to approach 'net positive' in a project, it is most important to first mine the immediate context for its obvious and hidden potentials, apply a holistic model such as *Ecological Urbanism*, and be equipped with the site-appropriate tools to apply and deliver the holistic model to the site and eventual infrastructural project(s).

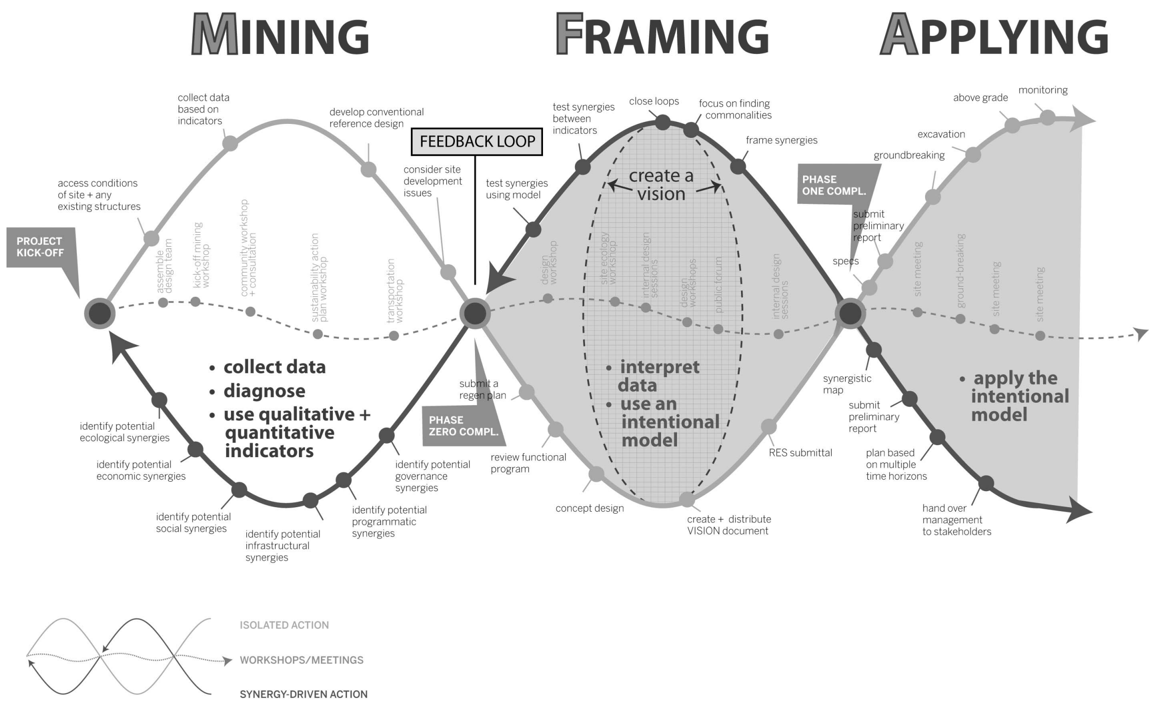


Figure 1. The three-step phase: Mining, framing, and applying. Source: authors.

Figure 1 illustrates the three-step process. The top line represents 'collecting data in isolation,' while the bottom line represents 'synergy-driven mining.' The amplitude of the curves represents the number of options available. The lines converge at key points in the pre-design process, representing the passing of one phase to the next. Feedback loops are incorporated into the design process, notably during the 'framing phase,' whereupon the design team may go back to revisit the raw data collected in the 'mining phase' and allow the programming to emerge. The middle line represents community activities and tasks – mainly workshops – that are integral to the participatory and/or Integrated Design Process (IDP). During the framing phase, the 'collecting data in isolation' and 'synergy-driven mining' come together to help form a collective vision. And in the applying phase, the options are left wide open in order to ensure multiple future horizons and scenarios.

## 3. MINING: EVALUATING THE DORMANT, INHERENT POTENTIAL WITHIN AN EXISTING CONTEXT

One of the most challenging tasks facing us in Canada is how to re-frame the revitalization of the aged inner city fragments and infrastructure built beyond our planet's ecological footprint limitations. The scale of an 'infrastructural hub' is the bridge between public and private (management and economics), local and regional (biodiversity and transport), and short-term and long-term visions. More specifically, and in contrast to the master plan, public and private partnerships are part of an infrastructural hub's core definition; its initial phase includes multiple programming elements; it reaches across a myriad of scales and benefits from atypical synergies; and its positive, potential outcomes are numerous. These infrastructural hubs offer prime opportunities for promoting quantum and net positive change. In these primed contexts, such as the revival of the Sagrera neighborhood in the heart of Barcelona, can foster the re-tooling of an entire neighborhood's past while projecting it's future potential. While at the scale of the individual building, it is difficult to capture far-reaching synergies, 'infrastructural hubs' operate at scale(s) where many converging dimensions can come together: transit, increasing biodiversity, connecting people, experimenting with new infrastructure, and so on. For this reason, this paper does not touch on individual buildings.

One of the most primed opportunities for renewing our built fabric – both in terms of infrastructure and quality of life - is by uncovering both latent synergies and suitable degrees of resilience within our inner city neighborhoods and their neighboring fringe industrial belts. For instance, Montreal's long-standing strength has been it's rich, diverse cultural roots, it's undulating topology, and it's eclectic neighbourhoods, often within close proximity of one to another. *Threshold**s*** between distinct biological ecotones are the most biodiversely enriched z*ones,* where the overlapping of two divergent contexts propagate both rare growths and a healthy degree of resilience to withstand shocks. Our most promising, inexpensive, underutilized sites are those where industry has left behind toxicity, inaccessibility and fragmentation, especially when those sites border lively neighbourhoods and/or green spaces that are already vibrant and culturally alive, since it is easier to renew the physically run-down structures compared to removing stains of stigmatization. At these "magical thresholds" lie the endless potential for affordable rebirth, social diversity, much needed resilience and cultural tolerance – a fertile setting for the less conventional work, live and play, where the young urban agriculturalist can live side by side with artists, and families and in walking distance to a transformed industrial incubator.

These dormant sites can be found all over the island of Montreal; similar abandoned sites exist in many North American post-industrial cities. What these thresholds longingly require are the following:

i) Cities that have the courage and vision to prioritize these opportunities and see them as opportunities;
ii) All levels of government putting aside their individual aspirations to co-invest into a series of collective pilot projects;
iii) The process and visioning exercise in the MINING phase being holistic and inclusive with a clear governance and where a long-term 'vision carrier' can ensure the continuity of a drawn out process.

In order to fully exploit the full potential of these "magic thresholds," it is first important to diagnose a site. Phase zero in the design process hence involves evaluating the dormant, inherent potential within an existing context. This phase may also be referred to as a *MINING* or *DIAGNOSIS* phase and aims at understanding the genetic code, or DNA, of a site in order to mine for potential synergies and adequate resilience. Important to the mining phase is diagnosing a context's low-lying fruit (such as transient vacant land – even if only for transitional purposes, interstitial spaces that are currently collective but grossly under-developed or under-utilized, etc) on the one hand, and its most dire needs (such as sufficient affordability, clean energy and water demands, etc), on the other. If the low-lying fruit are not readily available within the confines of a site, it becomes important to enlarge the site context under scrutiny and look at regional metabolic flows, as we will later illustrate in the Ecological Urbanism model. Conventionally, the pre-design phase for architecture is very short, and it is undervalued. However, by investing more time and money into the pre-design phase, financial, social, and ecological benefits may be magnified. This paper argues, that the pre-design phase's importance is imperative to setting up the "winning conditions" (Pearl, 2013) for a successful and sustainable project. This pre-design phase may be highly creative and dynamic, and in the end, will expose the most promising renascence scenario.

The diagnosis can occur along various axes, one example being Dr. Joe Ravetz's five categories: urban, economic, ecological, social-cultural, and governance (2011, pp32-33) and may take form either as isolated data-collection activities or synergy-driven mining activities. An example is by frontloading design – a term championed by the Rocky Mountain Institute in the 1990s – that signifies soliciting input from the design team early on in order to insure a truly integrated design (Hootman, 2013). The isolated data-collection and synergy-driven activities allow the most suitable programming to emerge, based both on current needs and the synergistic opportunities that the context permits. Transparent governance and an Integrated Design Process are critical exploration tools right from the outset, and stakeholders[vi] must collectively be able to mine both the hidden and the obvious potentials of a project's context. The specifics of the *mining* itself is done by an enlarged design team, where the breadth of the team is dependent on the context. Once the isolated and paired qualities are uncovered, workshops involving various stakeholder interests are then undertaken.

Understanding the DNA of a site can be done in several ways. Several holistic pre-design and planning tools exist, for example, beyond the conventional disciplines of architecture and urban planning. These tools are but a few examples of ones that can be used to understand the dormant inherent potential of a context – whether its urban complexity, socio-ecological interdependencies, or inherent resilience. These approaches use a mixture of quantitative and qualitative indicators, and can aid stakeholders in creating a robust vision to carry forward. They also provide unique ways of mapping and understanding sets of spatial relationships.

3.1 *Mining for Complexity*

Salvador Rueda's Ecological Urbanism model from the Urban Ecology Agency of Barcelona is an example of a model that can be used to mine the inherent urban complexity of a context. Salvador Rueda describes Ecological Urbanism as a tool that "seeks to adapt urban design to a site's natural conditions in order to maximize what nature has to offer." (Rueda, 2012, p17) Rueda outlines two constraints on urban interventions: *efficiency* (defined by the equation E/nH or resources/urban organization) and *livability*, which he defines as the quality of life of people, quality of public space, infrastructure and public services, biodiversity, and social cohesion.

One of the most compelling elements of Salvador Rueda's Ecological Urbanism approach is the way in which it deals with scale: his approach looks at multiple scales *simultaneously.* In several of his works, he uses the metaphor of Russian dolls, "where the size of each figurine depends on the peculiarities of the variable it holds inside and also on the one that contains it." (Rueda 2012, p8) For example, as Rueda points out, contamination can impact the local scale, regional scale, and also global scale *(ibid);* and issues such as contamination may become units as well as multiples in a polynuclear network. By extension, in Rueda's model, the indicators and investigative analysis may determine the scale of intervention. That is to say that the scale of intervention may not be pre-determined. The analysis may result in regional scale metabolic analyses, but also in smaller scale interventions such as green walls, urban furniture, and so on.

Salvador Rueda's approach is both a process and a product. The Urban Ecology Agency of Barcelona uses approximately fifty indicators that fit under the general categories of compacity, complexity, efficiency, and social cohesion. Under the umbrella of these four main categories, eight other categories are explored (Urban Ecology Agency of Barcelona 2012, p633): efficient land use; quality of public space; sustainable mobility; management and governance; urban biodiversity; maximum self-sufficiency of metabolic fluxes; social cohesion; diversity of uses and urban functions/urban complexity. In addition to outlining baseline and desired outcomes, Rueda also indicates which phase of development the indicators can be applied to: Planning (P), Development/ Construction (C), or Use (U). Depending on the scale and location of a project, the indicators can be selected and studied in synergistic sub-sets, in order to maximize the potential resilience of a project. The Ecological Urbanism model is a flexible and adaptable model, and maps can be overlayed in order to capture these synergies. It can be used during the

MINING phase to better understand a context's DNA, and thereby set up the winning conditions for reinvigoration.

### 3.2 *Mining for Socio-Ecological Interdependencies*

Cadenasso, Pickett & Grove (2006) from the biological sciences have developed a biocomplexity model that can also be used to mine the dormant inherent potentials of a site. This model uses patch array dynamics to overlay social and ecological patches in order to understand their interdependencies. The authors propose three axes in their biocomplexity framework, which are explored through these patch dynamics: heterogeneity, connectedness, and contingency (1).

The biocomplexity framework is relevant because it highlights several interrelationships, though these interrelationships are not always synergistic. For example, this model may permit investigating the relationship between parcel size and ownership type of forested areas (8). A single lot would have one landowner and would be managed very differently than a larger parcel with multiple landowners. Another relationship outlined in Cadenasso, Pickett & Grove's study has to do with the health of riparian zones. High nitrate levels are measured in areas adjacent to houses that use fertilizer. Middle to high-income households tend to use fertilizer, while lower income households do not. Hence there is a relationship between ecology and socio-economic status (2006, p9). Interrelationships, like synergies, are not necessarily what is set out to be proved at the outset. On the contrary, they sometimes prove to be the antithesis, or a tangential outcome, of what may have been originally hypothesized. The approach could potentially evolve to include research into synergies. For instance, Cadenasso *et al.,* recognize that vacant lots in Baltimore present an opportunity to design new storm water infiltration schemes, site trees, and target other aspects of revitalization to integrate storm water management. Such integration of human and ecological features can be important in underserved neighbourhoods to engage community members and to promote their involvement and support in managing local initiatives (2006, p11). This would be equally true in the case of infrastructural hubs. It is such synergies between human and ecological dimensions of the built environment that have the strongest potential for promoting positive change.

The biocomplexity framework can be used to describe the complexity of an urban ecosystem. It is not an end in itself, but rather a tool to help create models, generate hypotheses and explore new, dynamic forms of mapping synergies. The framework is inclusive of various systems, processes and scales and provides a roster of components, suggesting how these components may relate to one another (Cadenasso, Pickett & Grove, 2006, p4). One of the key strengths of the model is that it is flexible and adaptable, and the components in the model are selected "on characteristics of the precise situation the model applies to, or on the research question guiding model development." *(ibid)* Beyond highlighting socio-ecological dependencies, the socio-ecological patches created from the framework generate new spatial identities and entities that can help architects and planners look beyond property lines and at capturing synergies and enhancing resilience.

### 3.3 *Mining for a Context's Resilience*

Susan L. Cutter *et al.*'s resilience model based on composite indicators (2008) is another pre-design/planning tool that is useful for mining the inherent dormant potential of a context. These authors specifically elaborate on a conceptual model for measuring and mapping resilience. The model works for comparing resilience between regions or sub-regions, and for comparing types of resilience. Their work includes a comprehensive set of quantitative indicators: *social resilience*, *economic resilience, infrastructure resilience* (which includes the physical systems (pipelines, roads etc.,) as well as their dependence and interdependence on other infrastructure), *ecological resilience,* and *community competence* or *institutional resilience* (which measures how well a community functions before and after a disaster) (Cutter, 2008, pp603-604). Once the raw data is collected, these indicators are then mapped. These indicators are not only scalable, but can also be used by multiple actors for a variety of functions.

Although the model is not adjusted for a local context, it nonetheless effectively demonstrates regional differences in resilience in the study region of the Southeastern United States, and moreover in the various types of resilience. The strength of the approach lies in the comparative resilience between regions/municipalities, and the identification of comparatively high and low types of resilience (for instance, it is useful for a region to understand which municipalities have the most comparatively low social resilience, and so on). If we were to use the South-West borough of Montreal as a hypothetical design site, it might be useful to understand that it has comparatively lower social resilience than neighbouring boroughs, but comparatively high ecological resilience and the potential for exploiting biodiverse connectivity with other boroughs. This may help local residents, local experts, and regional experts to decide where to spend their energies and resources, and a promising programmatic outcome would be a well-developed urban agriculture revitalization strategy. By mapping and tracking resilience indicators, leadership officials can have a better understanding of what type of actions are necessary (preventative actions, mitigative actions, or proactive, 'regenerative' measures). Within infrastructural hub projects, local and regional governments must play a pre-emptive role in anchoring various cultural dimensions before cost of implementing these strategies becomes too expensive. Understanding a context's resilience is key to accomplishing this task proficiently and affordably. Hence, this tool is useful in the MINING phase in order to better understand baseline resilience levels and how resilience in different sub-regions may be connected. It could also aid the design team in understanding how intervening in one sub-region may improve the resilience in neighbouring sub-regions, thus having positive off-site impacts.

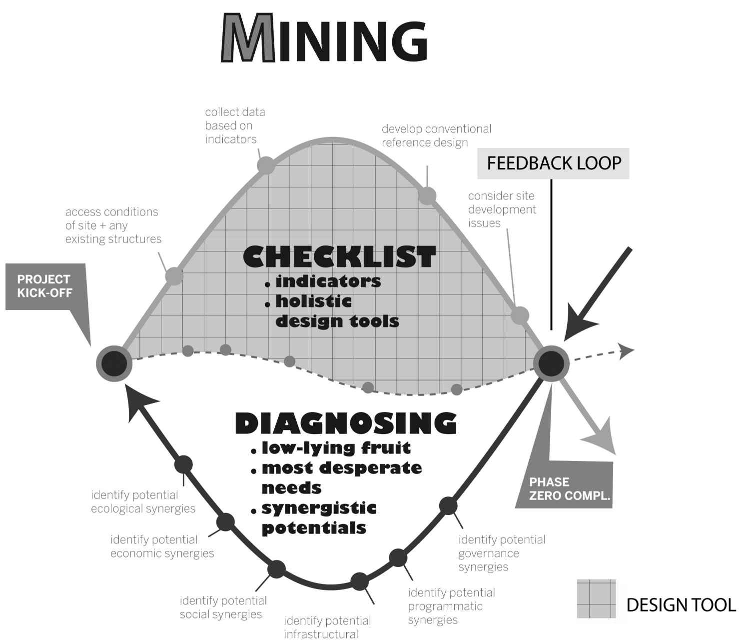


Figure 2. The MINING phase: isolated and synergy-driven actions. Source: authors.

## 4. FRAMING THE TRANSFORMATIVE POTENTIAL AN URBAN INFRASTRUCTURE PROJECT CAN PROVIDE: FRAMING

Section 3 of this paper outlined several pre-design/planning tools that are useful for phase zero of a project. After mining for the inherent dormant potential of a context and understanding its genetic code, we enter phase one of the design process: framing. The framing phase includes the formulation of a vision, which includes synergies between the various and diverse elements studied during the mining phase. If "mining" is gathering the raw data in its isolated, objective state, then "framing" is transforming the raw, isolated data into favorable or 'winning' design conditions. This phase may dip back into the mining phase for further diagnosis once the visioning direction has been sufficiently evaluation and developed. An analogy can be made with medical diagnostics, and the process of how doctors diagnose their patients' predicament before proposing (framing) the appropriate treatment. Some professionals rely on their experience instead of truly starting afresh, and while this may not prove problematic in most cases, certain situations could significantly benefit from a more rigorous and novel diagnosis. Phase one or the 'framing' phase may also involve the use of an intentional model, such as the Urban Ecology Agency of Barcelona's 'Ecological Urbanism' model. This model needs to be adaptable, agile and dynamic, such as Cadenasso *et al.*'s bio-complexity model, which has built in flexibility and adaptability in order to address different regions and different scales, and the Ecological Urbanism model, which also can also be tailored for a specific context. The Urban Ecological and Bio-complexity models can both be used as pre-design tools as well as framing tools, each with their own strengths for helping designers and stakeholders to discover the transformational potential of a project's context. These frameworks to not lead the team on a straightforward path towards creating a vision; rather, they serve as tools to nurture and inspire one. A third intentional model that can help in this framing phase is Dr. Joe Ravetz's *synergistic framework.*

Ravetz's 'heuristic mapping approach' or *synergistic framework*, looks for creative opportunities that are at once "*relational* (involving different actors, worldviews, activities)" and "*emergent* (looking for innovative, creative, collaborative, and co-evolutionary)." (Ravetz 2012, p1). In particular, this approach is useful in diagnosing the inherent dormant *synergistic* potentials of a site. The framework as a whole provides a method and toolkit for synergistic thinking, which can use both information technology (IT) and also simple visual methods for deliberation and decision-making. Ravetz asks, how do we help cities move towards more creative and sustainable pathways (*ibid,* p4)? His approach emphasizes above all, creative connections of people and organizations (Ravetz, 2011, p32). Ravetz defines several types of synergies that may be useful during the framing phase *(ibid):* Urban synergy, Economic synergy; Ecological synergy; Social-cultural synergy; and Governance synergy. This tool, in combination with some of the other tools described above, may help the design team set up the most favourable design conditions for a project.

In summary, the 'framing' phase involves the intelligence, creativity, and co-learning of designers and other stakeholders to interpret the raw data collected and the various diagnoses put forward in phase zero. There is no "ultimate" framing tool, but rather a myriad of framing tools that may tailor themselves better (or not) to the context at hand. The use of an intentional model may help the design team to set up the framing of the vision. The intentional models are efficient in different contexts and different scales, however, the "Ecological Urbanism" model operates at multiple scales simultaneously and helps to frame synergies between indicators, as well as define what is high-quality social space. The biocomplexity model works best from the scale of an individual city block to the larger district, and in the context of testing socio-ecological interrelationships. The synergy framework works best at the largest scale, and frames the synergies of the project and helps to close metabolic, social, and economic loops. It also involves scavenging for untapped potential and may do so by using an intentional model such as the ones outlined above. By bringing broader social and economic considerations into the mix, a more comprehensive and varied range of consideration and negotiation emerges, that more fairly consider a wider range of stakeholder interests.

## 5. APPLYING: EXTRAPOLATING THE REGENERATIVE POTENTIAL TO THE IMMEDIATE NEIGHBOURHOOD

If phase zero in the design process involves mining for the genetic code of a context, and phase one involves interpreting the data and transforming it into the most favorable design conditions, then phase two is 'applying' the model. This phase involves the prioritization, orchestration and synchronization of the framing phase, leading to transformative action (i.e., vision into action). First, this phase involves using the appropriate tools for the appropriate context (zoning, infrastructure investment, taxation, maintenance, and so on). It equally involves context-specific practical challenges, such as governance and management, legislative limitations, political conundrums, and simultaneous and multiple timelines (planting the seeds of a project, versus reaping the harvest). Unlike a master plan, which can be very challenging to modify, the proposed three-step process of this paper leaves the application phase wide open with the potential for multiple future, successful possibilities that may unfold along multiple timelines. So how can an applied framework anchor a vision without predetermining its final shape? The answer, and also the topic of future research, is that the "infrastructural hub" must always remember its mining roots, while projecting forward its most promising synergies, with the agility to respond to the ever-changing context and the resilience to handle unexpected challenges.

## 6. CONCLUSIONS

This paper investigated *how to more profoundly nurture a transformative change in "lifestyle,"* and through a three-step design process that is holistic and comprehensive, it put forward more indicators than conventional green building performance & assessment tools such as *LEED, LEED ND*, and *BREEAM*. It has above all, stressed the importance of the 'MINING PHASE,' which is often undermined in conventional frameworks, and not only relies on the proper holistic tools, but the design team's intelligence, creativity, will, and courage. By mining for the dormant, inherent potential within an existing context, framing the transformative potential an urban infrastructure project can provide, and applying the model by taking into account local challenges using a holistic intentional model, *one can go beyond incremental change towards more meaningful, quantum change*. While phase zero can enable the anchoring of a vision inclusive of as much promising contextual potential as possible, phase one synthesizes the mining and stakeholder interests to frame the vision, and phase two empowers the 'guardians of the vision' to carry the vision forward. All three phases involve transparent governance, and an Integrated Design Process, as well as a synergistic understanding of the socio-economic, socio-ecological, cultural, and complexity factors of a context. This design process goes beyond quantitative assessment methods to include the qualitative factors necessary to achieve quantum change. Indeed, as Krausman et al. remark, what we need 'is a worldwide effort to invent, to design, and to experiment with infrastructures, renewable resources, and new technologies for a novel industrial transformation, a transformation that does not build human communication, creativity, and happiness upon gigatonnes and megajoules.' (Krausmann *et al.,* p652). Currently we are stuck waiting for affordable high-tech solutions to enable quantum change. Although embracing "systems thinking" is currently within reach, unfortunately we will probably require a powerful environmental menace in order to re-define our global and local sharing of our decision-making processes (Wright, 2012; Homer Dixon, 2009).

The acknowledgement of the importance of systems thinking shifts the emphasis from quantitative accounting methods to the links and synergies between constituent elements of systems, as much as the elements themselves (Cole & Pearl, 2007, p11). The process still holds significant influence (IDP as one approach) and its importance must somehow be encouraged and accommodated *(ibid).* This paper has also outlined several holistic design tools that when used in tandem with an Integrated Design Process with an emphasis on MINING may present the key meaningful net positive change for our inner-city infrastructural hubs. Nonetheless, further research must address the following questions: How can uncovering the dormant inherent potential and synergies of a context early on in the process concretely lead to quantum change? How can it do so while remaining "affordable," so that its lessons learned may be applied and transferred to a wider range of contexts? And finally, will assessment tools ever be able to meaningfully incorporate the qualitative indicators necessary for quantum change?

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ENDNOTES

[1] Here, we define positive development as design that "achieves net positive impacts during its life cycle over pre-development conditions by increasing economic, social *and* ecological capital." (Birkeland, 2008, xv). According to Birkeland (2007), net positive design can be achieved by 'design for ecosystem services' - design that creates robust supplies of food, air, water, energy and biota and "*increases* the ecological base." (2) She explains, "[I]f we do not turn our urban areas into ecologically productive systems, we cannot achieve global sustainability, let alone save our remnant wilderness areas." (1) The

central goal in net positive design, therefore, becomes to augment the ecological base, as well as the public estate.

[ii] Here, we define affordability as including the following: a mix of social housing, affordable housing defined as rents that are at least 10% below the neigbourhood average rental, and the ability for first-time homebuyers to enter the market at a subsidized rate. Affordability also entails lower capital costs through synergistic opportunities, the use of less expensive materials, low operating/maintenance costs, and the encouragement of small start-ups and self-sufficient initiatives.

[iii] If assessment tools themselves do not adequately incorporate qualitative indicators, they may not lead to quantum change. Other tools outlined in this paper are part of a more holistic series of tools required to fully anchor the most appropriate vision for the context. As Lovins outlines in "Tunnelling Through Cost Barriers," an integrated process may lead to greater savings since any desing improvement looked at in isolation may not be considered affordable. A dialogue at an early stage will allow for one system to support another system and for synergies to be captured (Zimmerman, 2006, p10).

[iv] See Plaut, J.M., Dunbar, B., Wackerman, A. and Hodgin, S. (2012). Regenerative design: the LENSES framework for buildings and communities *Building Research & Information* 40 (1): 112-122.

[v] See Svec, P., Berkebile, R., and Todd, J.A. (2012). REGEN: Toward a Tool for Regenerative Thinking. *Building Research & Information* 40 (1); 81-94.

[vi] For instance, a Community Land Trust (LCT) - a private non-profit corporation set up to acquire lands in a community and hold them in trust in perpetuity for the use and benefit of local and future residents-- may involve local residents, local experts, and a regional expert, all with equal decision-making power. Beyond giving access to affordable housing, CLTs are also effective at building a community (Nozick, 1992).

# Lessons from Net Positive Energy to be applied in Net Positive Material flows

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ABSTRACT: The emerging notion of regenerative design promotes a co-evolutionary, partnered relationship between humans and natural systems. Implicit in regenerative design the act of building over time buildings can give more than they require – that is, they are net positive. In the recent years the notion of net positive has garnered interest in the context of energy and water flows. However, due to the complexity and longer timeframe of material flows, the notion of net positive in relation to materials use has not yet been explored or developed. The work presented in this paper explores the lessons that can be gained from the current definitions and characteristics of net zero and net energy positive buildings to possibly form a basis for understanding net positive materials flows.

## 1. INTRODUCTION

The extraction, manufacture, and transportation of building materials have considerable environmental, economic and social impacts. In general, green buildings have the objective of doing less harm in their construction and operation by reducing local and global resource depletion and environmental degradation (McDonough & Braungart, 2002; Reed, 2007). In the context of this paper, green buildings strive to reduce the negative environmental effects of materials use by using more local materials, recycled and recyclable materials instead of new materials, or by minimizing the amount of materials or eliminating certain materials completely. By contrast, as presented by Cole (2012), the emerging notion of regenerative design and development 'promotes a co-evolutionary, partnered relationship between humans and natural systems and, in doing so, build rather than diminish social and natural capital' (p.40). A key idea in regenerative design is the potential of some buildings to give more than they require – that is, they can be net positive. Although the notion of net-positive has been acknowledged in the context of energy and water flows, due to the greater complexity and longer timeframe of material flows associated with buildings, it has been given little attention in relation to materials use.

In the context of energy flows, the design of net zero/positive-energy buildings as necessary performance aspirations is now widely considered and, indeed, are increasingly embedded in national energy policies as many countries have declared that all new buildings must conform to net zero-energy and/or carbon neutral emission standards by a certain date (Kolokotsa, Rovas, Kosmatopoulos, & Kalaitzakis, 2011; Dyrbøl, Thomsen, Albæk, & Danfoss, 2010). This paper raises the possibility that the notion of net zero and net-positive may equally be applied to materials flows. In order to develop an understanding of "net-positive material flows" as it relates to buildings, a number of specific questions emerge related to the baseline against which net positive is defined, the most appropriate timeframes, and relevant boundaries to frame a definition. The study presented in this paper explores the potential lessons that can be drawn from the key features and literature that has attempted to provide a definition of Net Zero Energy and Net Positive Energy buildings and its applicability for developing the concept of Net Positive Material flows. Torcellini et al., (2006), Kolokotsa et al., (2011) and Marszal et al., (2011) and others have presented and critiqued the currently accepted criteria associated with the definition and technical aspects of zero/positive energy buildings. These studies have formed the main reference sources of this paper as the basis for understanding the major features of the notion of net positive energy buildings and their appplicability to materials use.

## 2. NET ZERO AND NET POSITIVE: ENERGY

### 2.1 *Definitions*

Kolokotsa *et al.,* (2011) describe a net zero energy building as one in which the 'energy demand for heating and electrical power is reduced to an extent that it can be met on an annual basis from a renewable-energy supply' (p.3067). Torcellini *et al*., (2006) raise a number of issues underpinning the current definition of net-zero energy, such as:

- Whether the renewable-energy supply sources are located on the building, on the site or can be purchased off-site.
- The grid is used to supply electrical power when there is no renewable power available, and the building will export power back to the grid when it has excess power generation.
- Distinctions are necessary between whether the evaluation is based on primary energy, site energy, carbon emissions, or cost.
- Distinctions are necessary between all-electric buildings and those with a combination of electricity and natural gas.

With the notion of a net-positive building as Kolokotsa *et al.,* (2011) state, 'the 'two-way' flow should result in a net-positive export of power from the building to the grid' or to neighboring buildings. However, since different types of energy resources such as fossil fuels, solar, and wind have different environmental impacts, Kilkis, (2007) emphasizes that in order to understand the real environmental impacts of buildings it is important to consider the quality of energy – i.e., exergy[1] – in addition to its quantity. Therefore, she proposes a new definition for the term NZEB – 'a net zero exergy building that has a total annual sum of zero exergy transfer across the building-district boundary in a district energy system, during all electric and any other transfer that is taking place in a certain period of time' (Kilkis, 2007). Of significance to this paper, the definitions of both net zero energy and net positive energy buildings are currently premised primarily on environmental (energy) and economic (energy costs) criteria.

### 2.2 *Declaring the Baseline*

The baseline condition against which net-positive is assessed can be simply defined as the state in which generated and consumed energy are equal in a building in a yearly basis - that a net zero energy building. Therefore, a NPEB could conceivably be a building wherein the supplied renewable energy exceeds the required amount of energy, but little had been done to reduce energy demand. However, as the ultimate goal of NZE/PEB is to reduce energy, it is important to apply energy efficiency strategies in such buildings in order to reduce energy demand before supplying renewable energy (Iqbal, 2004; Torcellini et al., 2006; Marszal *et al.,* 2011). In this sense, NZE/PEB design concept can be considered, as Kolokotsa *et al.,* (2011, p.3068) stated, 'a progression from passive design'.

### 2.3 *Declaring the Time-frame*

As the energy demands of buildings vary through time to a great extent, different time-frames have been identified for defining/measuring the energy production/consumption balance of buildings. It can differ from monthly, yearly, operating time of the building, or whole life cycle of the building. Most of the definitions for NZEB consider energy exchange of buildings in a yearly basis (Marszal, *et al.,* 2011) since this offers several benefits:

- Consistency with most of the building energy simulation programs (Marszal, *et al.,* 2011);
- Reducing the complexity and uncertainty of dealing with energy consumption during production, construction, and deconstruction stages.
- Addressing the seasonal changes in the weather and energy demands.

However, a yearly balance fails to consider unexpected weather changes from year to year, e.g., severe or mild winters. Moreover, as operational energy is reduced through energy efficiency strategies, the initial embodied and decommissioning energy become more significant (Sartori, Napolitano, Marszal, Pless, Torcellini, & Voss, 2010). Hence, as Hernandez & Kenny, (2010) suggest, despite all the complexities, complete life cycle of a building is the most accurate and comprehensive time-frame for assessing the balance between energy consumption and production in a building.

2.4 *Declaring the Boundary*

Physical boundaries can be defined for both supply and excess of renewable energies. In terms of renewable energy supply, sources can be located on the building site such as solar panels or they can be transported to the site e.g. biomass (Marszal, *et al.,* 2011). Torcellini, *et al.,* (2006) provided a general categorization and also a ranking for preferred renewable energy sources which is represented in the Figure 1. in which the lightest is the most favorable type of energy supply.

In terms of the excess of renewable energy, for the off-grid Zero Energy Buildings – those not connected to the grid – it can be stored in batteries for future consumption of the building itself. For the on-grid Zero Energy Buildings – those that have connection with the grid –it can be sold to the grid (Marszal *et al.,* 2011; Pless & Torcellini, 2010) or it can also be sold to the neighbor buildings. Considering the interaction of neighborhoods in terms of transferring the excess energy opens up a new forms of partnerships and challenges to current notions of ownership. As off-grid ZEB requires large amount of storage and also they are incapable of interaction with the community in terms of trading the energy, they are less favored in current practice (Torcellini, Pless & Crawley, 2006).

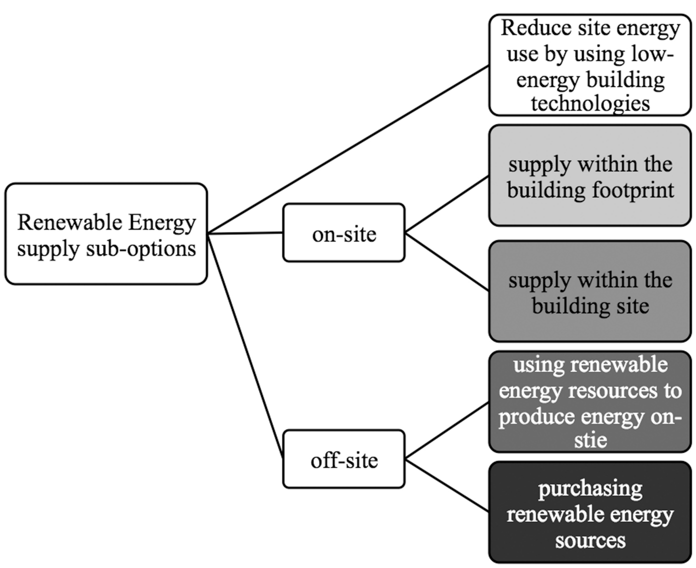


Figure 1. NZ/PEB Renewable Energy Supply Option Hierarchy . Based on Torcellini, (2006)

### 2.5 *Uncertainties*

Kolokotsa, *et al.,* (2011) provided a definition for the Estimated Net Energy Produced (ENEP) as an indicator for NZ/PEB studies. ENEP, they suggest is 'the energy available from renewable sources over a period of time after subtraction of the energy required for the building operation over the same period.' (p.3068). They further point out that the actual figures for this indicator can vary widely from the estimated computation in the design phase. They relate these uncertainties and variations to a number of factors: unpredictable user-behavior, changing weather conditions, generation–consumption matching, operation of active and passive climate-control systems; and, atypical availability of energy on a "weather-basis" rather than a "need-basis" (p.3068). Kolokotsa, *et al.,* (2011) conclude that neglecting of these variables in the assessment of ENEP asserts the 'static and simplified' nature of this indicator, which result in catastrophic differences between estimated and actual building energy performance. It accentuates the requirement for a more adaptable and dynamic view toward NZ/PEB.

## 3. NET POSITIVE: MATERIALS

This section explores the parallels between Net Positive Material Flow (NPMF) and the characteristics of Net Zero Energy/Net Positive Energy identified above.

### 3.1 *A Quantitative Definition of NPMF*

Similar to the definition of net positive energy buildings, a metric is required for defining NPMF. By contrast, in the context of construction materials, since the "production" of materials throughout the life of a building is not an option, the notion of net-positive material flow cannot be defined as producing more material than used in a building through its lifetime.

One possible quantitative definition for NPMF could relate to the number of times which a material is recovered and reused, with the material flow considered to be net zero if materials are recovered just one time. Here, by using a material more than once the necessity of reproducing the same material is eliminated the same number of times as it is recovered. This would lead to a net positive material flow. The metrics for assessing the amount of recovered materials can be based on mass, volume, cost, etc. However, this definition remains problematic for a number of reasons:

- As the time frame is much larger than energy flows, a considerable uncertainty exists about how the future will unfold. Thormark, (2001) and Saghafi and Hosseini Teshnizi, (2011) emphasize that despite an anticipated greater future need for the recovery of materials, whether or not a material or component will actually be recycled depends on many factors such as: the time required for its recovery, the risk of working in the area for building disassembly, variety of possible uses of the material, changes in the construction techniques in future, etc. The uncertainty increases when it comes to the understanding the potential number of times that a building material or component will be recovered in a relatively distant future.
- The quality of material recovery should be considered in any definition. For instance, some materials can be reused without requiring too much additional processing, while some others can only be used to produce recycled content materials.
- There are also different qualities of reusing materials, i.e., some materials can be reused in the same function and with the same quality, while the quality of others will decrease in their lifetime and thereby reducing their potential to be used in the same function.
- The benefit of considering cost as the metric for assessment is that the quality of recovered material can be reflected in its economic value. Nonetheless, similar to NPEBs, fluctuations in material market affect the credibility of cost as a measure.

### 3.2 *A Definition of NPMF Based on Regenerative Design*

The definition for NPMF could possibly be derived from one of the core ideas of regenerative design: the notion that buildings can be designed to provide positive impacts rather than simply reducing negative impacts. Here, NPMF can be defined based on increasing or shifting of value associated with material flows through their usage in the built environment. Currently, despite many technical and economic improvements in the use of reclaimed materials, the overall value of building materials[2] decreases at the end of a building lifetime. Hence, few building materials are considered sufficiently valuable to be reused or recycled at the end of buildings' lifetime. This reflects an imbalance between different types of value attributed to material flows and hence the primary purpose of research on NPMF introduced in this paper is to recognize the various values ascribed to materials, the interconnections between them and the possibility of increasing the overall value during materials' life-time. Understanding and assessing the interaction between quantitative values (e.g., environmental impacts) and qualitative values (e.g. social/cultural value for new material) is a major consideration within this work. A key notion is to understand how the current linear use of materials can be turned into a closed loop as a result of the added overall value. This definition addresses the problems of the quantitative definition in dealing with the number of times that materials are recovered and also quality assessment of material recovery.

### 3.3 *What are Types of Value ascribed to NPMF?*

Published literature on building materials selection tools acknowledges that the criteria that affect materials selection can be grouped under various categories covering both technical and non-technical criteria. However, current building material assessment tools mostly concentrate on the technical performance criteria. Although materials should be considered in terms of fulfilling physical, economic, socio-cultural, and environmental requirements, the physical, environmental and economic requirements are typically given greater emphasis in current material selection tools. Many qualitative factors such as aesthetic or cultural values are ignored in these tools (Akadiri & Olomolaiye, 2012). Furthermore, current studies and tools do not consider the interrelation between different criteria primarily because of the discipline specific nature of the research that generative the performance criteria.

The current literature on the environmental assessment tools provides some understanding of the values related to material flows in the building industry. The UK's Building Research Establishment Environmental Assessment Method (BREEAM), Japan's Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), and the US Leadership in Energy and Environmental Design (LEED) all emphasize the need reduce the environmental impact of materials use by encouraging the use of local materials and also encourage the use of recyclable, recycled content, rapidly renewable, and low-emitting contaminant materials (Castro-Lacouture, Sefair, Flórez, & Medaglia, 2009). By contrast, the South African Sustainable Building Assessment Tool (SBAT) highlights the importance of social aspects in sustainable building assessments (Gibberd, 2005). (See Table 1)

Over the past few years some specific material assessment tools are developed to assist design teams in choosing materials that meet the specific requirements of building assessment tool (Ogunkah & Yang, 2012). Life Cycle Assessment (LCA) is the most comprehensive method for evaluating the environmental (E-LCA), economic (LCC), and recently social impacts (S-LCA) of materials and products through their life cycle. Most of the building assessment tools are more or less based on LCA. Table 2 illustrates the focus area of some building and material assessment tools.

Table 1 Literature Review Domains

| | Literature area | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Green Building Assessment Systems | | | | Material Assessment Tools | | | Regenerative Design |
| Values | LEED | CASBEE | SBAT | BREEAM | LCA | LCC | S-LCA | |
| Socio-cultural | | | ● | | | | ● | ● |
| Economic | ○ | ○ | ● | ○ | | ● | | ● |
| Environmental | ● | ● | ● | ● | ● | ● | | ● |
| Physical | ○ | ○ | ○ | ○ | | ○ | | ○ |
| Scale | | | | | | | | |
| Component | ◐ | ◐ | ◐ | ◐ | ● | ● | ● | ○ |
| Building | ● | ● | ● | ● | | | ◐ | ◐ |
| Neighborhood | ◐ | ◐ | ◐ | ◐ | | | | ● |

The inventory of environmental impacts that are associated with material consumption is well developed in LCA tools and typically contain criteria such as global warming, ozone depletion, eutrophication, and acidification, waste generation, etc. (Ramesh, Prakash, & Shukla, 2010). The costs associated with a material usage in its whole life-time are studied in LCC analysis tools. The physical value of a materials relate to the functional/performance requirements such as durability, weathering resistance, strength, etc., and have a primary impact on a design team's decision about material choice.

Socio-cultural value can be considered in two aspects:

1. Those that are attributed to the surrounding environment and can be improved by using a material, such as employment, human health, and equity;
2. Those that are attributed to materials and affect people's preference for choosing materials, e.g., aesthetic values, valuing new rather than old materials, etc.

Although this latter aspect has profound affects regarding the success of using reclaimed materials, it has been less studied in the existing literature. Arkes and Hutzel (1997) discuss a psychological paradox between people's typical dislike of wastefulness and yet have preference of new items. In their paper, they juxtapose these two inherent tendencies and recommend that when the natural features of a product is cued, people choose to preserve rather than replace. It is due to a common perception about limitation of natural resource supply.

The different values assume different importance or weight in different design contexts such as: building geographical location, building function (e.g., residential, commercial, and academic); function of materials in buildings (e.g., structure, finishing, etc.); visibility of materials in the building – materials which are visible in building are aesthetically more important in comparison to hidden materials; and stakeholders point of view – different stakeholders have different priorities in their decisions (See Table 2). A balance between the often competing values in the initial choice of a material is typically reached from having input from different stakeholders. Such decisions invariably become more complex when considering the potential impact of different values on each other and also their change through time.

Table 2 Impact of Variables on the Importance of Different Values

| **Variables** | Building Function | | | | Material Function | | | Material Visibility | | Stakeholders | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Single Family Residential | Multi-unit Residential | Commercial | Academic | Structure | Outdoor Finishing | Indoor Finishing | Visible | Hidden | Investor | Design Team | Resident |
| **Values** | | | | | | | | | | | | |
| Socio-cultural | ● | ● | ● | ○ | ○ | ● | ● | ● | | ◑ | ◑ | ● |
| Economic | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ◑ |
| Environmental | ○ | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ | ● | ◑ | ◑ | ◑ | ◑ |

| | Single Family Residential | Multi-unit Residential | Commercial | Academic | Structure | Outdoor Finishing | Indoor Finishing | Visible | Hidden | Investor | Design Team | Resident |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Values** | | | | | | | | | | | | |
| Socio-cultural | ● | ● | ● | ○ | ○ | ● | ● | ● | | ◑ | ◑ | ● |
| Economic | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ◑ |
| Environmental | ○ | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ | ● | ◑ | ◑ | ◑ | ◑ |

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inition becomes explicit when quality of recovery, e.g., reusing in the same function, reusing in different function, recycling, etc., recovery percentage, and also the frequency of recovery are considered in comparison to the baseline condition.

Another alternative for baseline condition can be developed for the regenerative definition of NPMF, which is based on value assessment. A key premise of the work presented in this paper is that reclaimed materials should be chosen over new materials, if so, one possibility is that the base line for describing NPMF could be new materials. This baseline conveys that if the overall values – physical, ecological, socio-cultural and economic – of reclaimed materials reaches or exceeds new materials they will be preferred in the construction industry. The latter definition highlights the importance of the quality of resource recovery. Reclaimed materials can be divided into two major categories: recycled content materials and reused materials. As such, the different values that are discussed in Section 2.1 should be compared between new, recycled, and reused materials. A recycled content material might have higher physical and economic value, but lower ecological and economic value compared to a reused alternative. The percentage of recycled content in recycled materials should be considered in this analysis as it affects the values, e.g., the physical value of a material might decrease when its recycled content percentage is increased.

### 3.5 *Declaring the Timeframe*

In the material flows, due to its longer timeframe, an annual balance cannot be achieved. Hence, considering at least one building lifetime seems to be necessary both in quantitative and regenerative definition of NPMF. In quantitative definition, net zero can be achieved after finishing the first building's lifetime. However, as discussed before, achieving quantitative NPMF is highly unpredictable as it deals complex factors in a long timeframe.

Regenerative NPMF, on the other hand, deals with fluctuation of different values through material flows over time. These values may either remain stable, increase/decrease or shift. Socio-cultural values can shift based on the changing human mindset and society's collective priorities. These changes, many of which are unpredictable, result in an uncertainty about the future. Direct and indirect socio-cultural, ecological, economic, and physical values and their change in a declared/anticipated timeframe should be considered within the regenerative definition of NPMF. The aim of this research on NPMF is to identify the critical values which have the potential to be increased/shifted in order to increase the potential use reclaimed material.

### 3.6 *Declaring the Boundary*

Although individual materials or components can be studied in order to define NPMF, the definition will be considerably different if materials are considered within a larger system, e.g., building, neighborhood, city, or watershed. Considering materials within the scale of a neighborhood opens up the discussion of the possibility of developing local economies and markets for reclaimed materials. An established local market for reclaimed materials facilitates the access of the design team to reclaimed materials with expected quality and quantity. Here it becomes necessary to clarify who are the beneficiaries of improving local markets of reclaimed materials. In other words, from which stakeholders' point of view are local reclaimed materials considered to be valuable?

### 3.7 *Dealing with Uncertainty*

Owing to the large timeframe of building material flows, uncertainty is major issue in development of the concept of NPMF. Despite the recycling potential of a material, it is not clear whether it will be reclaimed at the end of buildings lifetime or how many times it will be recovered in its lifetime or how long it will remain in the materials cycle. Recovery of building material at the end of a building lifetime may be affected by budget, time, having a place for storage, demand for reclaimed material at the time of deconstruction, risks that are associated with the deconstruction process, and etc. On the other hand, whether reclaimed materials are considered as a major resource for new construction will be affected by presence of reliable reclaimed material with the desired quality and quantity, access to the database of reclaimed materials, relative cost of new and reclaimed materials, users' willingness and trust for using reclaimed materials, and etc.

The complex systems thinking embedded in notion of regenerative design highlights the idea that change and uncertainty are the only certainty we have. As such, it is clearly necessary to make this much more explicit in making strategic decisions and the tools deployed to assess their success. The future frameworks and assessment tools would, by necessity, have to accept uncertainty and therefore move toward promoting and assessing resilience and adaptive capacity of a system and its potential contribution to maintain and ideally improve the social, ecological and economic health (Du Plessis & Cole, 2011).

## 4. CONCLUSION

Although the idea of being net positive – which is a key notion in regenerative design – has been acknowledged in the context of energy and water flows, it has been given little attention in relation to materials use, mainly due to the complexity and longer timeframe of material flows associated with buildings. This paper suggested a new approach toward construction materials that is an effort for having positive impacts rather than reducing negative impacts. To investigate the possibility and main obstacles of applying this idea to building material flows, major aspects of Net Positive Energy Buildings (NPEB) are explored in the paper, in order to find out the lessons that can be learnt from them in developing the concept of Net Positive Material Flows (NPMF) (See Table 3).

Table 3 Comparison of Key Issues in Net-Zero and Net-Positive Definitions

| | **Net-Zero** | | | **Net-Positive** | | |
|---|---|---|---|---|---|---|
| | Energy | Material | | Energy | Material | |
| | | Quant* | Regen** | | Quant* | Regen** |
| Metrics | - Primary Energy ●◆<br>- Site Energy ●<br>- $CO_2$ Emissions ●<br>- Cost ▲<br>- Exergy ●◆ | Number of Recovery Times | **Values:**<br>- Socio-cultural<br>- Economic<br>- Environmental<br>- Physical<br>■▲●◆ | *The same as NZ* | *The same as NZ* | |
| Baseline | Consumption=Production<br>Consumption Reduction | Reused Once in the same Function | Value of New = Value of Reclaimed | Consumption ∧ Production | Reused more than Once in the same Function | Value of New ∧ Value of Reclaimed |
| Time-frame | - Annual<br>- Building Operating Time<br>- Whole Life Cycle | One life Cycle | One life Cycle | *The same as NZ* | More than One life Cycle | At least One life Cycle |
| Boundary | **Demand:**<br>- Building<br>- Site<br>- Off-site<br>- Grid<br>**Excess:**<br>- Grid<br>- Storage | - Materials<br>- Building<br>- Neighborhood<br>- City<br>-Watershed<br>- Country<br>- World | *The same as Quant* | **Demand:**<br>- Building<br>- Site<br>- Off-site<br>- Grid<br>- Neighborhood<br>**Excess:**<br>- Grid<br>- Storage<br>- Neighborhood | **Demand:**<br>- Neighborhood<br>- Local Sources<br>**Excess:**<br>- Neighborhood<br>- Local Sources | *The same as Quant* |

Focus Area: ■ Social ▲ Economic ● Environmental ◆ Physical Quality
* Quantitative Definition
** Regenerative Definition

Currently there is an existing gap between the awareness of benefits of using reclaimed materials and their use, especially for reusing building materials. An explanation for this issue can be the failure of current studies to incorporate a holistic view toward material flows. Despite a current awareness regarding the wide range of factors affecting building material selection, the majority of green material assessment tools still take into consideration only a limited range of factors (Ogunkah & Yang, 2012). These factors are mainly quantifiable technical, economic, and environmental factors. Most green building material assessment tools are, as Ogunkah & Yang (2012) suggest yet to 'incorporate social or cultural criteria directly into the decision making process, but instead incorporate them indirectly into technical or economic decision making criteria. (p.6) As a result of analyzing current practices in defining NPEB and comparing it with NPMF following major questions arise regarding NPMF, which require further investigation:

- How net-positive material flows can be defined? What is the appropriate metric for assessing NPMF?
- What are the values that can be changed through material flows? Is it possible to increase these values in material flows? Is it possible to shift social and cultural values, toward valuing reclaimed material more than new materials? How can the interrelation between social,

economic, environmental, and physical values be considered in assessing the overall value of materials?

- How can we go beyond the building boundaries and consider a material's value in a larger system rather than in an individual building?
- What is an appropriate timeframe for NPMF framework?
- What are the strategies for dealing with uncertainty about the future?

These questions form the basis of the primary ongoing research work introduced in this paper.

## ENDNOTES

1. The concept of exergy quantifies the potential of an energy source to be dispersed. Exergy can therefore also be described as the "valuable part of energy" (Thesseling & Schlueter, 2009). After the system and surroundings reach equilibrium, the exergy is zero.
2. The overall value of materials is defined as the overall interactions between different values which are socio-cultural, economic, ecologic and physical values.

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# Shifting the ownership paradigm in the built environment

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ABSTRACT: Net positive design often involves sharing or exchange of some form of resource – energy, information, water, etc. – beyond the single building scale. Therefore, this paper considers the implications regarding changing notions of ownership. In general understandings common in many Western contexts, ownership is often defined as the sum of total rights held by various persons or groups of persons over things. This definition, however, may limit the potential to advance net positive design in building design frameworks. Shifting from a private to a social ownership paradigm could potentially influence the future of building design. This paper queries the potential shift, also considering what changes may occur in spatial and temporal boundaries of a building project when shifting towards a social ownership paradigm.

## 1. INTRODUCTION

The future of building design may need to go beyond the efforts of green or 'eco-efficient' design in order to overturn the negative environmental effects of human presence on earth (Pedersen Zari, 2012; Mang & Reed, 2012). This implies the development of net positive building projects that can contribute to the regeneration of greater social-ecological systems – redefining current human-natural relationships. As an approach to the development of net positive design, regenerative design and development promotes a 'coevolutionary, partnered relationship between sociocultural and ecological systems that builds, rather than diminishes, social and natural capitals' (Cole, 2012; Cole & Oliver, 2012). As a key tenet of a regenerative paradigm, understanding the world as a set of complex, interactive, interdependent and evolving social and ecological systems implies resource exchange – e.g., material, energy, information – between systems, and with it a rethinking of the notion of ownership.

There are many who question what role the contemporary concepts of private ownership or market principles have in today's world – with clear implications for social inequality, economic instability and ecological unsustainability (Heynen *et al.,* 2007). The concept of 'ownership' influences and shapes social interactions and the ways humans relate to the natural world. How and what things are regarded as 'property', how do various forms of appropriation take place, through what legal-institutional mechanisms, and how do concepts of ownership influence day-to-day relationships and human understandings of their social-ecological environment. These conceptualizations, and the property relations that derive from them, also influence the dynamics of how we understand, design, and develop our built environment. In all these senses, understanding the legal institutional frameworks and social-cultural aspects of 'ownership' holds important intellectual value in developing better relationships between human and natural systems. Indeed, property is a key, yet under studied, component of human-environment relations that has significant consequences for equity, sustainability and other considerations (Jacobs, 2010).

Many issues demand attention when questioning the role of contemporary concepts of private ownership: what set of cultural values, practices and concepts define a private property paradigm? What limitations do current private property-regimes impose on building design, the built environment or other broader sustainability goals? What are the dynamics of resource flow and capital accumulation in more social and collaborative ownership models? How do stakeholder roles, rights and liabilities change with shifts towards cooperative and collaborative ownership? Answering these and other questions directs attention to other pressing issues such as social equity, power relations, fair resource distribution, natural resource management, ecological sustainability, economic and political stability, policy development and social capital accumulation. A key premise of this paper is that a shift from a private to a social paradigm can help facilitate the notion of net positive building design.

The ambition of the paper is, therefore, to explore broader conceptualizations about ownership that regard it as an evolving dynamic system of social-ecological relations around property – instead of static structure of rights – and examine the potential to facilitate net positive design create social and natural capital. Central to the general purpose of this investigation is the consequences for a building's temporal and spatial boundaries under different ownership paradigms. The paper begins by defining the concepts of ownership paradigm and property-regimes. It then contrasts two opposite perspectives in respect to the concepts of ownership, property and appropriation and then highlights the inherent difficulty involved when defining a 'changing and purposeful concept such as property' (Macpherson, 1978; Hann, 1998). The paper then discusses the inadequacies of dominant property-regimes aligned with a private ownership paradigm by contrasting it with 'shadow' means of collaborative ownership based on dynamic property relations and concludes with a summary of the most relevant findings.

## 2. DEFINING OWNERSHIP

### 2.1 *Ownership paradigms and property-regimes*

An ownership paradigm can be defined as the set of practices, values and concepts held by a particular community in regards to property and property relations. In this paper, a distinction is made between two different ownership paradigms: private and social. By thinking through the implications of either paradigm with respect to net positive building design, this paper argues that a shift towards a social ownership paradigm potentially holds social-ecological benefits at various temporal and spatial scales, and particularly meaningful for fostering net positive building design and community development.

A property-regime can be defined as 'the structure of rights and responsibilities characterizing the relationships between individuals or groups of individuals with respect to things' (Bromley, 1991; Hanna & Jentoft, 1996; Vatn, 2001). It includes both the structure of rights and duties and the rules under which those rights and duties operate (Bromley, 1991; Hanna & Jentoft, 1996). Although common in the property literature, this paper does not regard the four standard property-regime types (private, common, state and open-access property) as diametrically distinct and mutually exclusive. Instead, this paper focuses on the values and implications that define these regimes, highlighting a private-social ownership spectrum.

### 2.2 *Brief historic overview*

Although concern about private and common property has been present since very early theoretical discussions of ownership (see Yates, 1992; Long, 2006), the discussion here is particularly concerned with the rise of the marketization and privatization of property previously regarded as non-proprietary, and linked to ownership trends in an era of 'neoliberal environmental governance' (Heynen *et al.,* 2007).

For centuries, the concepts of ownership and appropriation in many Western civilizations were considered as absolute rights of human dominance over nature, endowed by divine authority (Hanna & Jentoft, 1996; Hann, 1998). From late seventeenth-century on, the appropriation of land in Europe became increasingly contested. It was then that John Locke proposed the right of unlimited appropriation as a natural right based on labour (Macpherson, 1978; Strang & Busse, 2011), only to be opposed by David Hume, Jean-Jacques Rousseau and Immanuel Kant, who argued that there cannot be labour without preexisting occupation or possession (Strang & Busse, 2011). The natural environment was increasingly seen in reference to its utilitarian attributes as means to accumulate wealth. Land and other natural resources were quickly becoming privatized and commodified, and property rights were becoming a freely negotiable 'absolute' individual right, separated from any form of social function, much like it remains until today. This model was particularly important in the context of European eighteenth and nineteenth-century growing capitalist markets, and over time the concept of property was reduced to a notion of individual private property: 'an exclusive, alienable, 'absolute' individual or corporate right to things' (Macpherson, 1978).

### 2.3 *Ownership, property and appropriation*

The concepts of ownership, property and appropriation are closely linked and are often confused and used interchangeably. Notes and Queries on Anthropology (1967), in its sixth edition, makes a clear distinction between ownership and property: 'Ownership is best defined as the sum of total rights which various persons or groups of persons have over things; the things thus owned are property.' Appropriation relates to the communication and upholding of ownership of either previously un-owned property or the claim of title through means of exchange or inheritance and it can be best defined as the act of making something one's own. In current ordinary use of the word, property means "things." When we 'buy a property' or 'lease a property' what is advertised to us might be a house or office space, but what is really offered is not the thing itself, but a legal right. As property rights became increasingly 'absolute' saleable rights over things, the difference between legal rights over things and things themselves was blurred (Macpherson, 1978).

These understandings about ownership, property and appropriation – in terms of 'rights over an object' – although common in Western usage, seem narrow and ineffective for broader understanding of how we relate to each other and our physical environment. A more contemporary anthropological conception of ownership and appropriation regards them as processes of social interaction rather than attributes awarded to owned objects (Hoebel, 1966; Macpherson, 1978; Hann, 1998). Concepts regarding ownership reflect how people see themselves both as individuals and part of a community, their 'perceptions of interdependence', and what they expect about the control they exert over a particular place or object (Hanna & Jentoft, 1996). In describing property relations, Strang and Busse (2011) suggest that 'ownership is a culturally and historically specific system of symbolic communication through which people act and through which they negotiate social and political relations'.

Three key issues emerge from examining Strang and Busse's (2011) conception of ownership:

1. Ownership is regarded above as a social dynamic system rather than a 'static bundle or structure of rights'. This highlights a human-made purposeful system, presumably informed and motivated by the cultural value system of the society in which it is conceived (Macpherson, 1978).
2. The idea of ownership as culturally and historically specific points out its evolving nature. This is, not only does the meaning of ownership and property vary widely across cultures, but it also changes within a single community through time.

3. As acts of communicating and contesting rights, ownership not only influences 'social relations between people' (Hann, 1998), but also shapes and is shaped by how people relate to things in the environment they inhabit (Strang & Busse, 2011). Ownership, therefore, is connected to the creation of identity.

This last point places both social and ecological embeddedness at the core understanding of the concept of ownership.

## 3. PRIVATE-SOCIAL OWNERSHIP SPECTRUM

### 3.1 *Private ownership models*

With increasing neoliberalization across a range of contexts and governance realms, there has been unparalleled push towards a focus on exclusive private property rights (Harvey, 2005). The private ownership paradigm is firmly based on 'misleading ideas of separability' and individuality (Hann, 1998), where owning property is thought to have somewhat of a 'natural and absolute right to it' (Meyer, 2009).

Private property-regimes sit at the core of contemporary neoliberal agendas, with an insistence on engagement with markets, even as free-market capitalism has proven to be inadequate for a range of issues from poverty and hunger, financial crisis, to climate change and overall ecosystem degradation (Hawken *et al.,* 1999; Harvey, 2005). Commentators have suggested that private property models and consumerist values that inhere in them are fundamentally incompatible with the natural world in which societies live and depend on (Homer-Dixon, 2007). In a private property-regime, the value given to property is almost entirely determined by individual economic wealth accumulation – a primary function of free markets. In this sense, any ownership paradigm that fosters the idea of unrestricted material growth as the fundamental source of economic stability and human well-being, is inconsistent with any sustainability logic, and therefore, destined to collapse (Homer-Dixon, 2007). While some of these notions may appear over-stated, it is clear that there are fundamental tensions and inconsistencies between private property-regimes, free-market orientation, and sustainability principles and goals.

In one exploration of the limits of private property-regimes, Meyer (2009) exposes its utopian character. He argues that, in order to achieve absolute rights over property, everything within the human and natural environment would have to be commodified (a commodity is defined as 'a thing that is produced for sale or exchange' within a market-system, ibid). But to isolate and form a market out of non-commodified natural resources – such as air, light, water, people or parts of people – is a 'fictitious commodification' (Polanyi, 1975) since such things can never be entirely detached from social and ecological relations (Meyer, 2009). All of these lines of inquiry open up questions related to the suitability of private property-regimes and marketization schema, particularly in an era of increasing population, and worsened ecological degradation. This paper takes on this line of inquiry with respect to recent goals and paradigms related to design and the built environment, and considers as well what alternative property-regimes might afford, including social ownership models.

### *3.2 Social ownership models*

The predominance of private property-regimes today has not undermined the engendering of more social means of organization in reference to property. Alternative understandings of what ownership means have endured in less-prominent forms, particularly when diverse cultural and geographic contexts are considered (Hann, 1998). In a social ownership model, ownership has a different meaning, referring more to shared identity, allegiance, a sense of belonging, social obligation, sharing and reciprocity, instead of resource commodification and control (Pálsson, 1991; Hanna & Jentoft, 1996). In particular, some have suggested that the harsh conditions of some habitats, where the survival of humans depends on a fragile balance in human-nature relations, has transformed the way some cultures understand ownership, reflecting interconnectedness, interdependence and accentuating a 'oneness with nature' (Hanna & Jentoft, 1996). Strathern (2011) explains that alternative concepts emerge when other concepts, such as the private concept of ownership, reach their limits. A cross-cultural exploration of these ideas about ownership as a social relation can serve to open up exploration of limits and opportunities of particular property models.

Property models can be understood in a spectrum with private property on one end, and social ownership on the other. A progression towards the social end of the spectrum potentially holds more collaborative, cooperative, and collective means of human organization around property – including notions such as belonging, identification, self-realization, giving, sharing or borrowing (Hirsh and Strathern, 2004; Strathern, 2011). This progression implies a shift towards a less bounded and dynamic understanding of the concept of ownership where social and ecological relations, and not free-market and individualistic values, are key to informing ownership concepts (Figure 1).

It is important to make a distinction between state property-regime and social means of ownership. Although they might share and overlap in values, practices, and perspectives – because of their social nature, they are fundamentally different. In a state property-regime, property is owned, managed, regulated and distributed by the governing institutions, sometimes in representation of the group of people that elected them. In the past, this has lead to individualistic behavior depleting open-access resources. In social ownership models, property rights are held by a group of people with common interests where decision-making over their property is motivated by 'social behavior' (Hanna and Jentoft, 1996), and where collective goals are favored over individual desires avoiding a 'tragedy of the commons'.

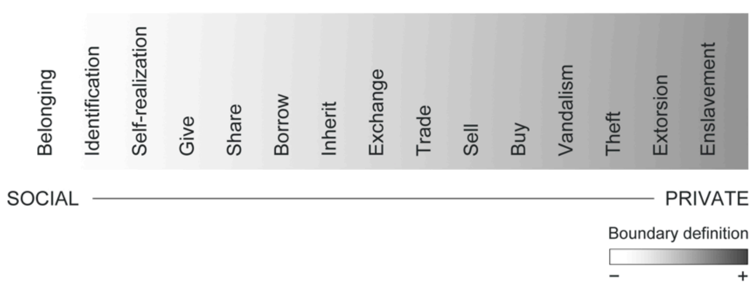


Figure 1. Boundary definition and values related to ownership models within a private-social ownership spectrum.

Co-operative enterprises are exemplary, yet surprisingly unknown, social models of organization around property (Skurnik, 2002). At its Manchester Congress in 1995, the International Co-operative Alliance defined a co-operative as 'an autonomous association of persons united voluntary to meet their common economic, social and cultural needs and aspirations through a jointly-owned and democratically-controlled enterprise' (MacPherson, 1996). Co-operatives are business enterprises owned and controlled by its members, open to all and with unlimited number of members, in which benefits are accounted for in terms of services for its owners – instead of economic profit based on capital invested (Skurnik, 2002). These member-driven enterprises are founded on social values of self-help, self-responsibility, democracy, equality, equity, and solidarity, and guided by seven principles by which these organizations put their values into practice: voluntary and open membership; democratic control; member economic participation; autonomy and independence; education, training and information sharing; cooperation amongst co-operatives; and concern for the sustainable development of communities are the central guidelines by which these organizations put their values into practice (ILO, 2002).

All of these notions highlight co-operatives as social ownership models of economic development motivated by social behavior with a strong commitment to sustainability principles and goals.

## 4. PARADIGM SHIFT

Generally, the work reported herein explores the consequences of an ownership paradigm shift in reference to the built environment and more particularly it expands on potential consequences for the future of building design. Creating a truly sustainable building practice may prove difficult if approached from an individual, independent, autonomous building's perspective, and according to Mang and Reed (2012), the future of building design may need to go beyond individual 'eco-efficient' building efforts in order to improve the environmental conditions associated with a human dominated planet. Orr (2002) adds that 'collective intelligence' instead of 'individual brilliance' is required to create a built environment that can support sustainable patterns of living.

Considering the spectrum above, this research advances that a shift towards a social ownership paradigm is facilitated by (Table 1):

1. A shift from principles based on misleading ideas of separability, autonomy and control to those centered on ideas of collaboration, cooperation, and shared responsibility;
2. An understanding of ownership as social and ecological relations rather than a set of abstract norms with no social function;
3. Dynamic, flexible, evolving social structures and institutions that foster the development of policies and regulations that support social ownership models;
4. A re-alignment of current market-type societal values (Lazlo, 2009) those centered on ideas of collaboration, cooperation, and shared responsibility; and,
5. A shift from a 'mechanistic' to an 'ecological' worldview that regards the world, as a network of multiple complex social-ecological systems interconnected and interdependent at different temporal and spatial scales (Capra, 1997; Mang & Reed, 2012).

Table 1. Transitions in a private to social ownership paradigm

| | | Private paradigm | Social Paradigm |
|---|---|---|---|
| 1 | Principles | Separability, autonomy, control | Wholeness, interdependence, uncertainty |
| 2 | Conceptualization | Set of abstract norms | Social and ecological relations |
| 3 | Social structure | Rigid, static | Dynamic, flexible, evolving |
| 4 | Values | Individual, market-type | Collaboration, cooperation, shared responsibility |
| 5 | Worldview | Anthropocentric, mechanistic | Ecological, biocentric |

## 5. CONSEQUENCES FOR BUILDING DESIGN

### 5.1 *Boundary definition*

In a property-regime, the understanding of ownership as a structure of rights and responsibilities over an object implies the notion of boundary. Property-regimes shape the built environment. They influence how buildings are designed, define a building's boundaries in space and time, and shape the building's role within the larger social-ecological systems it is connected to.

A private property-regime conceptualizes a building project as the commodification of space and defines its boundaries in reference to institutional legal codes and regulations. Spatially, this conceptualization generally limits a building project to its property lines. Temporally, current building design practice generally covers from conception until commissioning or occupation.

Current green building assessment tools, such as LEED and Living Building Challenge, also operate within a private ownership paradigm. They are rooted in a 'mechanistic' worldview, informed by principles of separability, control and self-sufficiency, and they focus mainly on increasing energy and material efficiency and minimizing the negative environmental effects of buildings (Mang & Reed, 2012).

In a private ownership paradigm, legal policies and regulations define buildings as isolated and independent closed systems. These social institutional structures restrict a building's capacity to establish connections with neighboring buildings, limiting the potential to open channels for the exchange, sharing, or trading of resources in order to work collaboratively to enhance the environmental performance of the whole. Moreover, particular sociocultural, natural and intellectual impacts related to the built environment may not be apparent within the temporal boundaries of a private property-regime. The long-term feedbacks resulting from a building project, and the positive or negative consequences they might conceal, are almost always ignored.

A key premise of a regenerative sustainability perspective is to recognize a building project in relation to the larger social-ecological systems it is 'nested' in (Mang & Reed, 2012). It conceptualizes a building in terms of its relations to other social-ecological systems, not in isolation, acknowledging shared interests at various levels 'based on the energies that are exchanged up and down the different [spatial and temporal] scales' (Capra, 1996; Sanford, 2011; Mang & Reed, 2012; Pedersen Zari, 2012). Regenerative discourse acknowledges the importance of community building when the temporal boundaries of a project are extended, and recognizes the key role of collective action in the formation of identity. When 'deliberate collaborative action' is engaged, communities may be developed and through social interaction over time, they may generate a similar story or share similar expectations for the future (Hanna & Jentoft, 1996).

Social means of organizing around property also serve as long-term positive sociocultural feedbacks by reinforcing social values over individual ones, since 'members [of a community] adhere to norms and values not only because it pays, or from fear of sanctions, but also because they are involved and morally committed' (Hanna & Jentoft, 1996). By sharing rights and responsibility over 'things' through time a sense of belonging may be developed.

When expanding a building project's spatial boundary to include neighboring systems, opportunities for resource exchange, sharing and generation are increased, and financial requirements for the maintenance of shared infrastructure are reduced. Partnering and sharing resources, technologies, along with social, natural, cultural, and financial capital, can potentially allow several building projects to engage in complex collective tasks that require investments unviable and previously unimaginable by individual buildings. Neighboring buildings might 'surrender' excess – otherwise unused – land property to, with the support and partnership of multiple stakeholders at various scales, collectively engage in the construction of a waste-water treatment plant that would provide the local system with treated water and would reduce their water intake, potentially eliminating storm water runoff. Its effects would cascade through multiple social-ecological systems and across multiple scales. Similarly, a group of neighboring buildings might use collective 'excess' land to build a community garden for its inhabitants along with a workshop where communal gardening tools and equipment are kept, shared and maintained. This would reduce the number of tools required and could potentially foster a culture of shared responsibility.

### 5.2 *Connectivity*

Besides shaping and establishing a building project's spatial and temporal boundaries, property-regimes define how a building is conceived in relation to its surrounding social-ecological systems. Private property-regimes encourage the performance of buildings as individual units, isolated from their social-ecological context, encouraging self-sufficiency at the building scale.

A regenerative discourse embraces values of interconnectedness, interdependency and whole/living systems (du Plessis, 2009; du Plessis & Cole, 2011; Mang & Reed, 2012). By expanding a building's spatial and temporal boundaries and recognizing a building's inherent connections to other social-ecological systems, regenerative design and development works to 'generate a cascade of capacity development up and down system scales' (Mang & Reed, 2012).

Collaborative ownership strategies foster the idea of collective actions. For this, it is useful to think of all complex systems –including buildings– as a system or a purposeful network. A system can be defined as 'a set of things interconnected in such a way that they produce their own pattern or behavior over time' (Meadows, 2008). Within a network, the links than connect the various nodes can be anything that transports any kind of resource – material, energy, or information – between the nodes. Understanding buildings as part of larger interconnected systems or networks allows them to work together towards a common environmental goal rather than as individual autonomous buildings.

Greater connectivity in a system often means the various subsystems in a network can more efficiently use, share and combine their ideas, resources, services, and infrastructure (Homer-Dixon, 2007). By removing the constraints imposed by a private property-regime, a group of buildings could potentially work together as a system, uncovering potential resource exchange possibilities that could all together enhance the environmental performance of the whole while maintaining or improving economic viability. Such is the case of the Center for Interactive Research on Sustainability (CIRS) building at the University of British Columbia. Without the standard limitations imposed by private property on neighboring buildings with different owners, the CIRS building is able use 'waste' heat from a neighboring building to supply its heating demands (Robinson *et al.,* 2013). These results are only possible through a re-definition of a building project's stakeholders, their roles and their effective commitment and participation (du Plessis & Cole, 2011). Increasing connectivity in a system might also result in increased vulnerability. Establishing new connections and relations could harbor unexpected patterns that could eventually turn into hazardous feedback loops, resulting in partial or entire system break down. If the connections had not been established, the internal hazards would otherwise remain isolated and its negative cascading effects not suffered by the rest of the system.

### 5.3 *Resource flows and capital accumulation*

Resource flows – i.e., energy, material, information, etc. – within and across building projects, their storage and transformation, are also defined by the concept of ownership. Moreover, how any social structure conceptualizes ownership determines the potential of 'property' to build financial, social, cultural or intellectual capital.

In a private property-regime, 'incorporeal rights' of property – that is, the rights to sale, trade, transfer, share, or dispose of – determine the allocation and flow of resources within a system, often disregarding any form of social function (Hann, 1998). Codes and regulations that were developed mainly to guarantee exclusive property rights of buildings restrict resource exchange between neighboring buildings. Multiple stakeholder liabilities and poor institutional support also contribute to discourage collective efforts towards greater environmental goals.

Aligned with a social ownership paradigm, regenerative design and development promotes a coevolutionary, partnered relationship between sociocultural and ecological systems that builds, rather than diminishes, social and natural capitals (Cole, 2012; Cole & Oliver, 2012). Partnerships and other collaborative efforts are means of social organization that often result in greater capital generation, they allow the integration of capital and resources and increase a system's potential to pursue ventures not possible at the individual building scale. As part of their Climate Action Plan (2010), the University of British Columbia in partnership with Nexterra Systems Corporation, are working together on the Bioenergy Research & Demonstration Facility, a community-scale biomass-fueled energy plant that is expected to provide heat and electricity to the Vancouver Campus. This project would be financially unfeasible at an individual building scale and certainly technologically impossible without a partnership structure that allows the sharing and exchange of information resources.

When transitioning towards a social ownership paradigm, the way we understand the concept of a net positive building also becomes increasingly important. It is highly improbable that an individual building can achieve complete resource net positive status, and if it does, its physical, financial and social conditions might prove it impossible to replicate elsewhere. Such a notion often disregards social and cultural capital in its accountability and may only be applicable at a greater social-ecological systems level. By adopting a whole/living systems perspective, the regenerative discourse recognizes that many important factors that determine the potential of a project to become 'net positive' do not always reside within scale of an individual building, and are only achievable by expanding the temporal and spatial scales to include the 'larger [social-ecological] systems in which a building is nested' (Moffat & Kohler, 2008; Mang & Reed, 2012). The importance of a building then resides in its role within a greater social-ecological system. A building project might be individually 'water positive' and not net positive in terms of energy resource, but it might contribute to the overall energy effectiveness of the greater social-ecological system. Creating a loop where resources can be exchanged, traded, or shared can help discover opportunities within systems. A building might be individually net positive in terms of heat resource, but if that resource is not used within a greater resource loop, the resource is considered as 'waste'. Herein, the concept of collective effort is implicit in the development of regenerative social-ecological systems.

At present, the focus of net positive buildings is mostly given to energy, water, heat, carbon, and other accountable resources. This is not surprising since 'non-commodified' flows and resources tend to be ignored in a private property-regime (Moffat & Kohler, 2008). Such resources are just a type of resource in which a building project can be regarded as net positive, but when assessing how projects contribute to greater social-ecological systems, other resources become relevant. The unique social structure of a university allows for great volumes of information resource flow and intellectual capital accumulation. Universities are highly connected – mainly through virtual means and often across great spatial dispersion – systems of collective knowledge creation, where information is deliberately shared and where collaborative work is increasingly being regarded as of high-value. In a private property-regime, the value of intellectual property is mainly linked to its economic value. In highly competitive free markets, sharing information is across corporations is uncommon and sometimes highly undesirable. Until we conceptualize intellectual property in terms of its social function, information capital and flows similar to those in the social structure of a university seem hard to achieve.

### 5.4 *Institutional support and stakeholder engagement*

A paradigm shift will not be possible without the effective engagement of different stakeholders, governance institutions and policy developers at various scales (du Plessis & Cole, 2011). Understanding stakeholder needs, priorities, and limitations is central to an adequate transition towards more collaborative means of social organization. Effective community participation in decision-making processes is also fundamental, especially in the later stages of a building project in order to ensure an 'ongoing regenerative capacity' (Mang & Reed, 2012). It requires that designers, owners, developers and building inhabitants work together in synergistic manner in order to achieve the goals set by social ownership models.

Institutional support will play a fundamental role in enabling a shift away from the current dominant private property-regime. According to Hanna and Jentoft (1996), the role of government institutions is 'instrumental in the design, implementation, and enforcement of resources regulations'. Emerging social ownership models must be nurtured if they are to prosper. It is important to develop new policies and regulations with clear collective goals that enable and foster cooperative and collective relationships at scales larger than a single building, where resource exchange between legal boundaries is possible, well regulated, and encouraged

(Pedersen Zari, 2012). And this must be accomplished while avoiding regulatory schemes that result in unwanted negative feedbacks such as unfair distribution, ecosystem degradation and economic instability. Unless these recommendations are implemented, regenerative development might be restricted to seldom and isolated cases. Furthermore, because many university campuses are not bounded by private ownership limitations and conditions, this type of institutions could potentially play a relevant role as laboratories where alternative ideas about cooperative organization can be developed, nurtured, studied and promoted.

## 3. CONCLUSIONS

A primary goal of this paper has been to identify and explore the dynamics of alternate conceptualizations of 'ownership' and the potential implications for net positive building design. Aligned with a necessary shifting towards a social ownership paradigm, regenerative design and development asserts that collaborative effort is crucial for the development of buildings with net positive performance.

Recognizing the social and ecological embeddedness in the act of building, regenerative design and development highlights the necessity to broaden the temporal and spatial boundaries of building design. By increasing connectivity between neighboring buildings, it potentially allows the emergence of new connections and potentially allows for greater human and natural capital building. This will require a new definition of the role of stakeholders, increased community participation well after a building is completed, and development of supporting policies and regulations. However, such claims need to be verified by more in-depth studies. This paper also has implications for a broader set of issues such as how people relate to each other and to their environment.

Removing regulatory obstacles that a private property-regime imposes over building boundaries would have important consequences in terms of legal liabilities not covered in this paper. Understanding these and other restrictions and barriers that hinder the transition towards a social paradigm in many Western societies is particularly important, and represent an important area for further research. The observations gathered in this preliminary analysis would also be furthered by in-depth research of collaborative ownership strategies at smaller scales, such as sharing spaces within a single building.

Although moving towards more social means of organizing around property constitute an important step towards a social ownership paradigm, it remains important to question the role of political economic practices and institutional social frameworks that allow private property-regimes to remain as the most idealized means of ownership and appropriation.

Even if collaborative means of ownership are not a final solution to a broader sustainability discussion within net positive building design, their study holds important intellectual value and they serve as powerful explorations towards a broader conceptualization of ownership as means of shaping social relationships and our relationship to the natural world. And most importantly, alternative socially-oriented values that underlie a social ownership paradigm may serve as an important feedback into a much-needed shift towards a truly sustainable building practice.

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# Thermal Autonomy as Metric and Design Process

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ABSTRACT: Metrics for quantifying thermal comfort and energy consumption focus on the role of mechanical systems, not architecture. This paper proposes a new metric, "Thermal Autonomy," that links occupant comfort to climate, building fabric, and building operation. Thermal Autonomy measures how much of the available ambient energy resources a building can harness rather than how much fuel heating and cooling systems will consume. The change in mental framework can inform a change in process. This paper illustrates how Thermal Autonomy analysis gives rich visual feedback as to the diurnal and seasonal patterns of thermal comfort that an architectural proposition is expected to deliver. Thermal Autonomy has far-reaching utility as a comparative metric for envelope design, identifying mechanical strategies, and mixed-mode operation decisions. Foremost, it is a generative metric to quantify ways that the building filters the ambient environment. The use of Thermal Autonomy is illustrated through parametric building thermal simulation and analysis.

## 1. INTRODUCTION

There is a need for the fundamental re-alignment of how we measure and think about thermal comfort in buildings. Most existing metrics were developed to inform the design of mechanical systems. Occasionally, metrics are proposed that define when people are likely to be comfortable without heating or cooling systems, but these metrics are framed to avoid energy use rather than embrace the opportunities of climate. No existing comfort metric relates the building fabric and the occupant to the climate. As a result, existing metrics tell us little about how a building design might perform independent from mechanical systems.

This paper introduces the concept of Thermal Autonomy as both a metric and a design process. Thermal Autonomy is the ability for a space to provide acceptable thermal comfort through passive means only. More broadly, the process of designing for Thermal Autonomy represents a fundamental shift in understanding building performance - one that prioritizes the building fabric as a selective filter for the ambient environment to provide occupant comfort.

Building thermal performance is a complex phenomenon involving thousands of physical interactions at any given moment. To compound the complexity, occupant thermal comfort is spacio-temporal - neither a snapshot, a summary, nor an average can tell the whole story. Diurnal, weekly, and seasonal patterns must be understood. To accomplish this for the 8,760 hours in a year, sophisticated graphical representations of the data are required.

The concepts and techniques presented here were born of practical necessity as well as theoretical discourse. As a firm located in the San Francisco Bay Area, many of our projects are in California coastal climates that should not require building heating or cooling much of the year. In spite of this, most buildings are extensively conditioned even in these climates. Thermal Autonomy is a concept developed to show our clients - architects, engineers, and building owners - the patterns, degree, and quantity of thermal comfort for a given design. Even in our work in more extreme climates, such as New York or India, we have found that Thermal Autonomy, in concept and practice, is applicable and potent.

We often liken Thermal Autonomy to sailing. While modern sailboats are equipped with motors for days without wind, design of the boat is optimized for sail-driven locomotion. So too should buildings be able to "sail" using the "free" energy of wind, air, sun, and internal heat sources to temper the indoor environment. The resultant autonomy is not just a building that is self-reliant but one that is calibrated to the climatic context, connecting occupants to the changing weather.

## 2. BACKGROUND

As the building industry has slowly come to understand the connections among thermal comfort, heating and cooling systems, energy consumption, and greenhouse gas emissions, there has been increased urgency for sophisticated comfort definitions. There are currently two branches of thermal comfort indices: those for conditioned and those for naturally ventilated buildings.

Modern comfort metrics for conditioned buildings derive from Ole Fanger's 1967 comfort model. Based on physiological research of subjects in mechanically conditioned environments, this model has been used to better understand the range of environmental conditions that building mechanical systems must provide to minimize the number of occupant complaints. The Fanger comfort model predicts how dissatisfied an occupant is likely to say they are on a 7-point scale between "hot" (+3) and "cold" (-3). This scale has been statistically correlated to the percentage of people likely to be dissatisfied in a space (Rohles et al., 1975). Standards such as ASHRAE-55 and EN 15251 recommend that environmental systems be engineered to ensure less than a given percentage of occupants are likely to be dissatisfied. Thus we arrived at a situation wherein a statistical probability of comfort can be correlated to a range of temperatures and humidities for a given air speed, metabolism, and clothing level. Rather than being used to explore occupant comfort, these metrics are more typically used to define thermostat setpoints. This represents a profound shift in focus from occupant comfort to HVAC system performance.

Research has shown that occupants in naturally ventilated buildings experience an expanded sense of thermal comfort when they have access to operable windows. This is due to adaptation to, as well as perceived control of, their thermal environment (deDear & Brager, 1998). With the publication of the adaptive comfort model and the formal incorporation of this thinking into standards and codes, the industry is beginning to re-accept the possibility of unconditioned buildings for the first time since the widespread introduction of air-conditioning in the 20th century.

Like the Fanger comfort model, the adaptive comfort model has been statistically correlated to a percentage of occupants likely to be dissatisfied. This allows for the quantification of hours beyond an acceptable limit as a single number. The contingencies and subtleties of both comfort models are thereby lost as single-number metrics become the principle method of describing performance requirements. While this can be useful for benchmarking, this paper shows how single-number metrics have limited utility as design informants.

## 3. METHODS

Thermal Autonomy as a metric and design process is explained here through the lens of a schematic design for a classroom in Oakland, California. For this study, Thermal Autonomy is defined as:

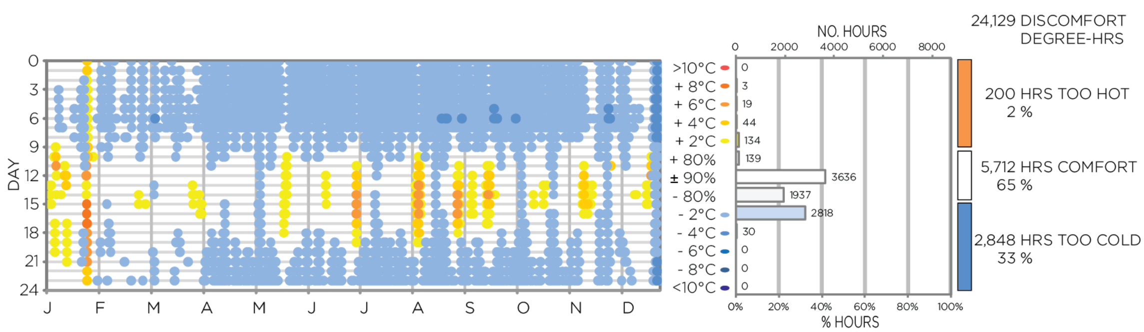
> *the percent of occupied time over a year where a thermal zone meets or exceeds a given set of thermal comfort acceptability criteria through passive means only.*

In this example it is more narrowly defined as the percent of occupied hours during a Typical Meteorological Year when a Mixed Air Thermal Zone meets or exceeds 80% acceptability criteria for adaptive thermal comfort.[vii] The thermal zone includes no heating or cooling systems, and it is assumed that fresh air demands are met with trickle vents (modeled as a constant supply of ventilation air during occupied hours).

Thermal Autonomy, as a concept, posits all buildings as initially unconditioned and naturally ventilated. Even spaces without any practical ability to open windows can be understood in terms of Thermal Autonomy, or lack thereof. Stripping a building of its mechanical systems, if only as a thought exercise, can shine a brighter light on the deficiencies or limits of a building envelope or operational strategy.

Graphs are used to visualize and interpret the simulation results (Figure 1). The heat map on the left charts the days of the year on the X-axis against hours of the day on the Y-axis. Each circle is an hour of discomfort and the hue indicates degree of discomfort. The chart facilitates the reading of diurnal, weekly, and seasonal patterns. Coupled with an understanding of the climate and building being modeled, the visualization helps us to identify appropriate architectural and operational responses, such as increased shading or shifting occupancy schedules.

Figure 1. Sample visualizations of Thermal Autonomy. In tandem, the heat map (left) and histogram (right) present the complexity of a space's thermal autonomy.




The histogram on the right groups all hours of the year according to degree from the 80% acceptability range. While the heat map reveals the patterns of comfort, the histogram reveals the extent. It gives a meaningful summary of conditions outside the comfort zone and helps quantify the effects of parametric changes to the building.

On the extreme right, three types of single-number metrics are reported relative to comfort critera: (A) weighted degree-hours, (B) number of occupied hours, and (C) percentage of occupied hours. These are the metrics defined by EN 15251, the European standard for thermal comfort performance. The following study reports these aggregated numbers along with data visualizations, and the utility of these metrics are explored in the Discussion section.

### 3.1 *A classroom design in Oakland, California*

The Oakland Unified School District started to develop a masterplan for a new high school and asked how they could make it more sustainable. We used the concept of Thermal Autonomy to show how a typical classroom in the masterplan would perform without heating or cooling systems. The masterplan was well-designed to meet a functional program, typical wood-frame construction methods, and address a challenging urban and social context. Different operational and building envelope scenarios were tested on the masterplan and select results are presented here.

In order to design a thermally autonomous building, it is important to consider the climatic context. Work on the classroom began with a detailed analysis of the climate based on first-hand observation and close readings of the Typical Meteorological Year (TMY) data. Oakland's climate is characterized by mild temperatures modulated by the large masses of the Pacific Ocean and the Central Valley of California (Figure 2).

There are two distinct seasons: a rainy winter extending from December to April and a dry summer from April to November. Most of Oakland's rainfall occurs during the winter months with an annual accumulation of about 50 cm. During winter rain events the wind is variable and gusty. Even with all the rain, about 30-50% of the winter days are clear or partly cloudy. Regardless, the temperature usually stays between 10 and 15°C during the day and 5 to 10°C during the night.

Less than 2 cm of rain typically falls between April and November. In these dry summer months morning fog is common and it burns off by late morning. These mornings are brisk with temperatures between 10 and 15°C. By afternoon temperatures rise into the 20's with a consistent breeze from the west-northwest. Nights are often clear and cool with temperatures dropping back into the teens.

As early as May, but more often in late August, September, and early October, Oakland experiences a series of 3-4 day events called "heat storms." These days are marked by high temperatures around 30°C, clear skies, and little wind. During these events temperatures drop about 10°C at night.

In spite of Oakland's cool climate, the building bioclimatic chart (Figure 3) shows that buildings can help keep people comfortable without significant heating or cooling. Highlighted regions of the psychrometric chart show that a well-insulated building with properly-oriented glass and mass for passive solar heating can keep people warm most of the year, though supplementary heating is required at times. In addition, natural ventilation can keep people cool enough except during heat storm events. During these periods shaded thermal mass that is purged of heat at night can provide comfort.

Four classroom scenarios were analyzed for a variety of orientations and building proportions: (1) a baseline building, (2) a baseline building with natural ventilation, (3) a climate-responsive building, and (4) a climate-responsive building with school year occupancy. For the example presented here, the process is illustrated by a 7.3 m deep by 12.2 m long by 3.66 m high classroom with a large 2.75 m by 12 m window wall facing due south. The initial thermal simulation assumed a code-compliant building envelope with no overhangs and little thermal mass.[viii]

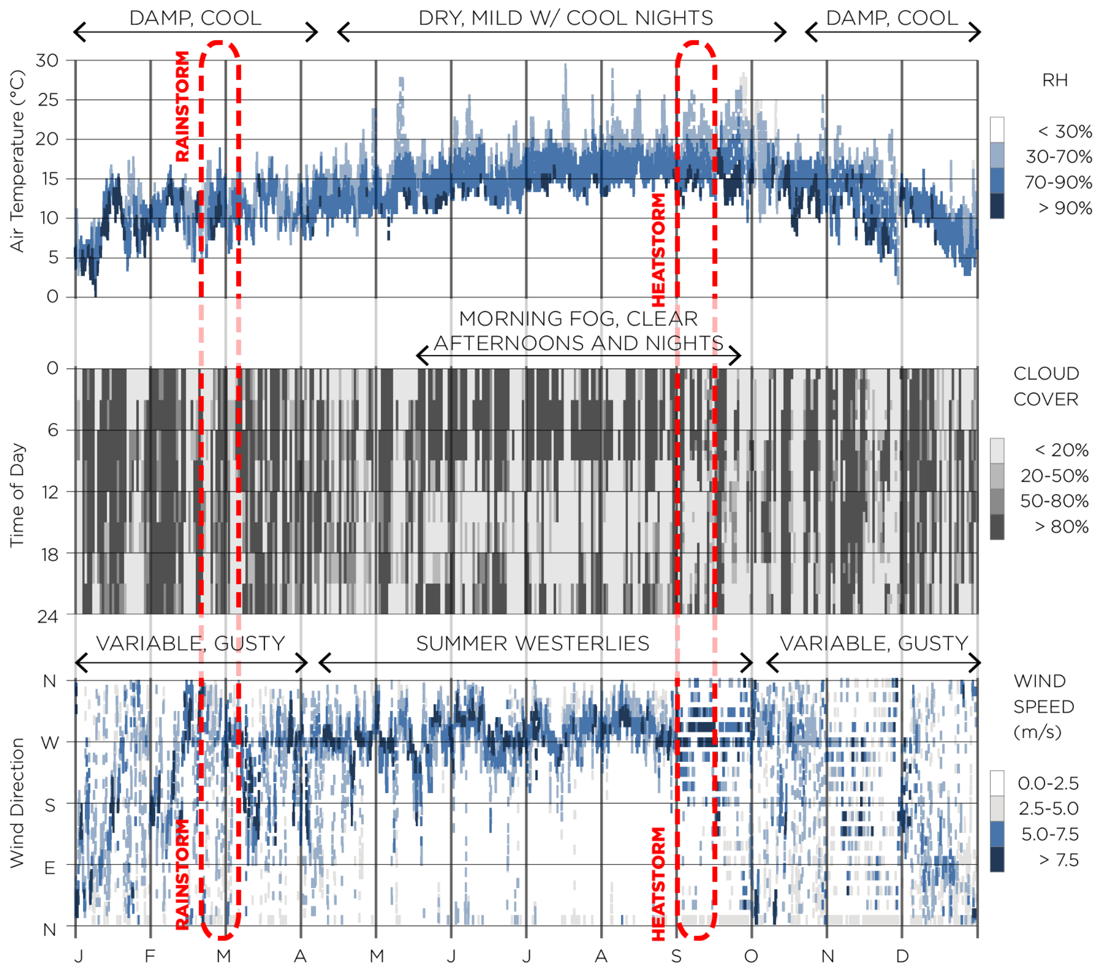



Figure 2. Analysis of Oakland Typical Meteorological Year (TMY). The analysis illuminates weather patterns and events that are likely to affect building performance strategies. Emphasis is placed on diurnal and seasonal patterns of air temperature, humidity, cloud cover, and wind. Analysis focuses on two events that define the Oakland climate - cold winter rain storms and early fall heat

Thermal simulations were calculated using EnergyPlus, a subhourly heat and mass balance simulation engine. Results were compiled and post-processed using custom scripts to calculate $\Delta T$ of the indoor operative temperature compared to comfort temperature as defined by the ASHRAE -55 Adaptive Comfort Standard. Thermal Autonomy Discomfort Degree Hours were defined as degrees from $T_{comf}$ (17.8°C + 0.31 x $T_m$, where $T_m$ is the monthly average of the daily average outdoor dry bulb temperatures).

In the case of this public school classroom, it was clear that the occupants would have the ability to adapt their clothing to the climate as well as operate windows. Based on this the 80% acceptability limits were used to define the comfort zone (±3.5°C from $T_{comf}$). When occupant expectations and adaptability are not as clear cut, one of the strengths of this process is that it requires dialogue among the designers, owners and/or occupants to set appropriate occupant thermal expectations from an early design stage.

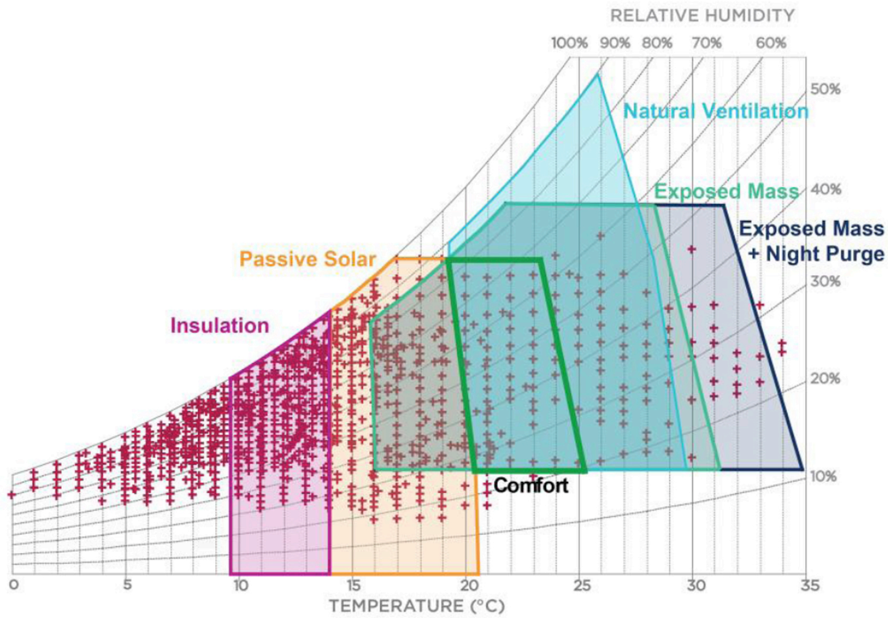



Figure 3. Building Bioclimatic Chart. Hourly TMY data with passive strategy overlays

Figure 4 shows the results of the first simulation. The indoor operative temperature is consistently over 35°C - more than 10°C above the upper limits of the comfort zone. The color-coded heat map in Figure 5 is saturated with red, indicating gross overheating for most of the year. The histogram reveals that there are only 905 hours of comfort conditions, or just 10% of the year.

Why so much overheating in such a benign climate? The classroom that is modeled does not have a heating or cooling system and ventilation air is only supplied to code minimum levels for fresh air.[ix] By adding natural ventilation in the second run, hot air is effectively exhausted for much of the year. 81% of the annual hours are now comfortable, but 17% of the year is still overheating. The yellow and orange colors in the heat map in Figure 6 reveal the patterns. At a glance, it is obvious that discrete afternoons throughout the year are too hot with the worst overheating from September through November. By comparing the results with the climate data in Figure 2, one can see that afternoons of overheating correspond to outside temperatures above 21°C and clear skies.

Using this information, effective building strategies for achieving thermal comfort can be prioritized. In this case, a sensitivity analysis helped identify appropriate climate responses within the general parameters of the baseline building's dimensions and materials. The glass performance was improved, a 1.2 m horizontal overhang was added, insulation was added to the walls and roof, and the carpet was removed to expose the 10 cm-thick slab.

Different operating protocols for natural ventilation were explored in concert with the material changes. Night time ventilation coupled with increased thermal mass drives down the periods of overheating. This is apparent in Figure 7 where the bulk of uncomfortable hours lies in the evenings when windows are opened to purge the mass of excess heat. With this ventilation regime, periods of overheating occur on only 14 days in the afternoon. By accounting for a 2.2°C cooling effect due to air motion[x], the yellow dots would represent times of thermal comfort. This results in only 66 hours of overheating. Overlaying the occupancy schedule (8am-4pm during the spring and fall semesters) in Figure 8 reveals that only 57 hours of the year (during 6 days) overheat when the building is occupied.

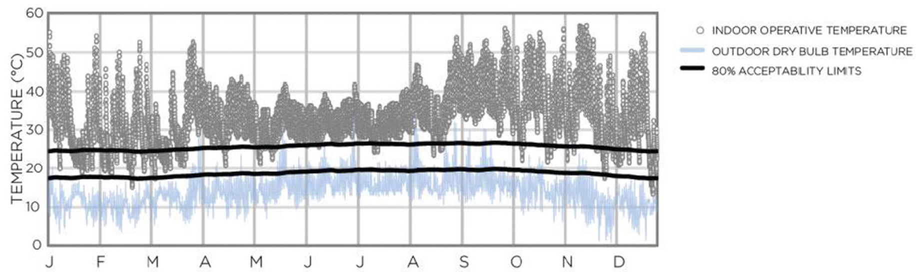



Figure 4. Baseline building, annual operative temperature and comfort zone

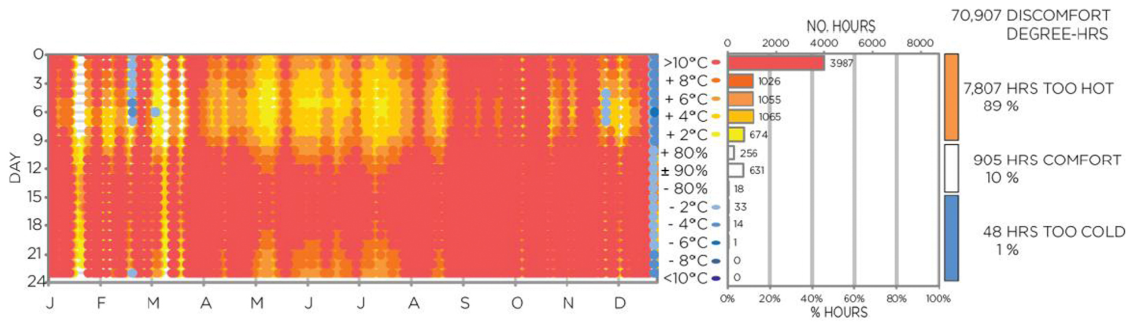



Figure 5. Scenario 1: Baseline Building

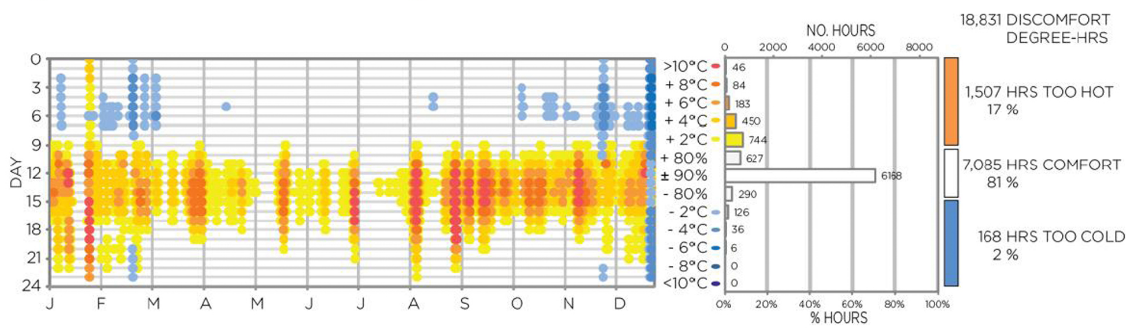



Figure 6. Scenario 2: Baseline building with natural ventilation

4. DISCUSSION

The use of Thermal Autonomy as a design approach underlines the deficiencies of standard industry practice. Typical engineers would model the classroom with a complete heating, cooling, and ventilation system. This would mask the poor performance of the building envelope and lack of passive operation present in the initial run. The results would be presented as a bar chart of monthly energy use, abstracting the performance into a large amount of energy use dominated by cooling. If subsequent climate-responsive designs were modeled, the cooling loads would decline, but the specific patterns of afternoon overheating would not be apparent. Standard practice would dictate that a cooling plant be installed to meet whatever demand is present, not questioning the underlying assumptions of occupant comfort or building operation.

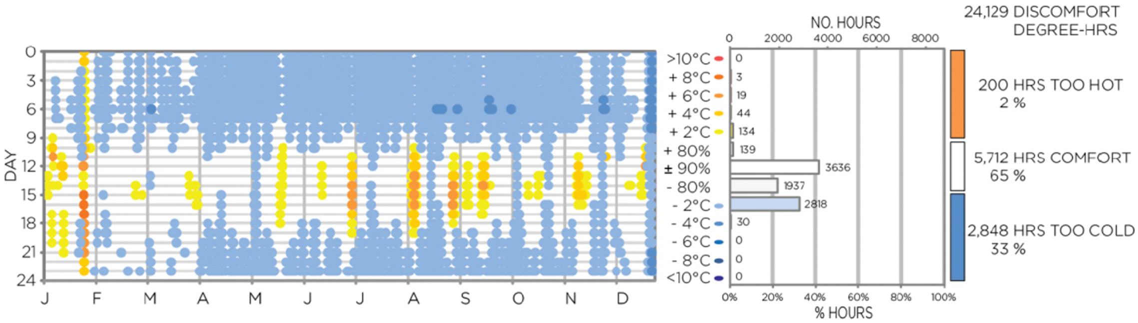



Figure 7. Scenario 3: Climate-responsive building with night ventilation

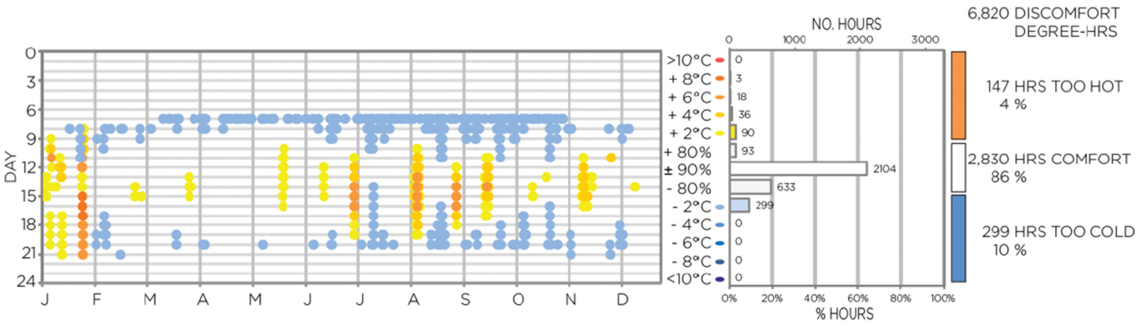



Figure 8. Scenario 4: Climate-responsive building with night ventilation, occupied hours only

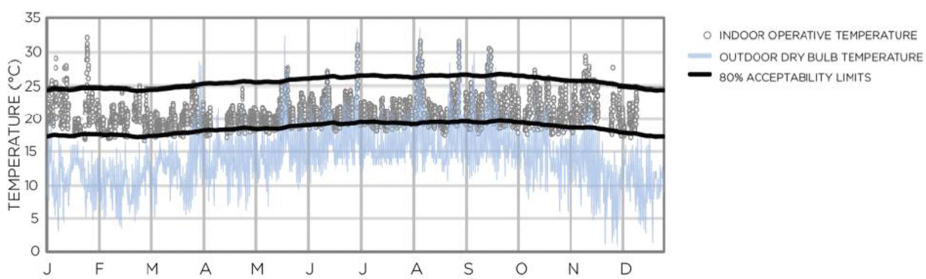



Figure 9. Climate-responsive building, annual operative temperature and comfort zone

The Thermal Autonomy analysis presents a fine-grained picture of building performance that is tangible and synchronous with common intuition, allowing informed decisions about the need for cooling. Given the results above, the school district has three options: install a cooling system for the six overheated days, adjust their occupancy schedule (i.e. hold classes outside during heat storm events), or adjust their thermal comfort criteria for these times of the year. Since the simulation showed that indoor operative temperatures peak at 32°C (Fig. 9), the client could make an informed and common sense decision about the classroom thermal environment. If similar thermal models had been run with full HVAC systems, the client would be forced to make a decision based on energy demand or capital cost. The analysis of Thermal Autonomy significantly changed the design and decision-making process.

Intrinsic to the Thermal Autonomy approach is the ability to see critical patterns in the simulation results. This is a two-part problem: first, the data must be graphically processed so that it can be clearly visualized, and secondly, the visualization must be correctly interpreted. Neither is a trivial task. By graphing hour, day, and degrees-from-comfort, the designer is able to see diurnal as well as seasonal effects. The scale of the representation also makes a difference: thumbnail images tell one story, while close, hour-by-hour reading can tell a more nuanced one. Further data manipulation through histograms tell a complimentary story, summarizing the finer grain information that our eyes and brains may not be able to discern. This summary information, when seen in tandem with the heat map, fills out a picture of the Thermal Autonomy.

It is important to note that the histogram in isolation does not supply enough information to be useful for design. By the same token a single number such as percent time comfortable or degree-hours from comfort may have utility as a standard or benchmark but is practically useless for informing a design approach. The results of the four scenarios are as follows:

Table 1. Summary of Thermal Autonomy results for 4 scenarios

| Scenario | Thermal Autonomy (TA) | Degree Hours ($TA_{ddh}$) |
|---|---|---|
| 1 | 10% | 70,905 |
| 2 | 81% | 18,843 |
| 3 | 65% | 24,183 |
| 4 | 86% | 5,435 |

There is only a 5% increase in Thermal Autonomy between Scenarios 2 and 4, but a 3-fold decrease in Thermal Autonomy Discomfort Degree Hours. However, neither of these metrics tells us that Scenarios 3 and 4 would not require a cooling plant.

Understanding and/or creating client expectations is a critical part of the process. Some spaces might have strict requirements because of occupant clothing requirements, atypical metabolism levels, or increased thermal sensitivity due to age or health condition. The vast majority of building types can operate in a wider band of comfort expectations.

Furthermore, the potential for a program to adapt to a climate is an underexplored avenue. If the school day were moved two hours later, from 10am-6pm, the need for heating could be significantly reduced. Although this might be impractical for a school district, they might consider relaxing their comfort standards on hot days or holding classes outside. This underlines the role, not only of the designer, but also of the client and occupant in operating a sustainable building.

The classroom example underscores how sensitive Thermal Autonomy can be to operational schedules. As evidenced by Figures 7 and 8, comfort patterns differ depending on use. While the building might be designed for one type of operation, it likely will be adaptively reused at least once in its lifetime. That is not to say that operational patterns should be completely ignored - in the classroom example given, night ventilation would not have been a viable strategy had full annual operation been exclusively considered. Dynamic strategies that can change according to occupancy patterns enable a building to be more readily reused. We would therefore propose two distinct definitions of Thermal Autonomy: $TA_{total}$ is the percent of time over a complete year, whereas $TA_{occupied}$ is the percent of time during occupied hours only.

Although this paper proposes Thermal Autonomy as an alternative metric to energy use, Thermal Autonomy as a concept is closely related to energy consumption. Every hour that is not thermally autonomous requires an energy input in order to achieve thermal comfort. The further from comfort, the more energy. By understanding degree and pattern, Thermal Autonomy provides clues for how to strategically deliver energy in an effective manner. For instance, the climate-responsive classroom is 2°C below comfort for an hour or two on most mornings. A short burst of heat to take the chill off is all that is required. More, and the classroom might overheat later in the day.

## 5. CONCLUSIONS

The primary purpose and utility of Thermal Autonomy is to provide an alternative approach to design by understanding performance in terms of occupant comfort, climate, building construction, and operation. Thermal Autonomy is not just a metric for quantifying performance, but a method for identifying the patterns of daily life that inform a design.

Rather than defining performance in terms of energy consumption or greenhouse gas emissions, this approach shifts the focus from energy systems to building construction and operation. The primary benefits include:

1. Envelope as environmental filter: By foregrounding the building envelope, insulation, shade, glass, ventilation, and thermal mass become the primary parameters for tuning a building to its climate.
2. Greater understanding of the impact of internal loads: Thermal Autonomy facilitates understanding of when the heat generated by people, lights, and equipment should be reduced, stored, or used for greater comfort.
3. Ease of interpretation: Even if "comfort" is notoriously difficult to define, it is an intuitive concept. Energy use, on the other hand, is an intrinsic abstraction that is once-removed from comfort and focuses on cost or emissions rather than occupants.
4. Rethinking assumptions: This process places an emphasis on occupant comfort and expectations, enabling designers and owners to rethink conventional defaults.
5. Gentle failure: In the event of an interruption in power or fuel, a thermally autonomous building will still provide comfort conditions.
6. Fewer active thermal systems: This process prioritizes envelope performance such that buildings require fewer (or no) active thermal systems.
7. Strategic use of active systems: Because these analysis techniques reveal the patterns of discomfort, mechanical systems can be strategically designed for the specific types of discomfort an occupant is likely to experience.
8. Extended free-running periods: Even in extreme climates there are usually swing seasons and/or parts of days when thermal comfort can be provided without mechanical systems. The Thermal Autonomy process can help extend free-running periods in Mixed Mode buildings.

Using Thermal Autonomy as a design metric and performance goal can change the conversation from limiting energy use to improving the quality of the environmental experience. Rather than an emphasis on mechanical systems, Thermal Autonomy privileges the occupant and the architecture. In a conventional design process the architect proposes a building fabric and the engineer designs a prosthetic mechanical system that remedially manufactures thermal comfort. Thermal Autonomy as a process posits the building fabric as the primary creator of comfort. This also shifts the conversation from one of problem-solution to generative design alternatives, engaging the design team as an integrated whole rather than an architect/creator and engineer/problem-solver.

## 6. FURTHER RESEARCH

This study has not attempted to benchmark Thermal Autonomy for different climates or building types. While we are wary of single-number building metrics, Thermal Autonomy might be a useful way of defining building performance for a given climate and program. It remains to be seen if Thermal Autonomy benchmarks could be used as minimum performance standards, but it would be interesting to see the patterns and degree of Thermal Autonomy for different buildings in different climates over a large sample size. Comparing these Thermal Autonomy numbers to Energy Use Intensity would, in turn, result in a greater understanding of both metrics.

The method and metrics outlined here were explained for a single thermal zone. It is possible to expand this logic to multi-zone buildings through the use of zone weighting. Although the patterns of Thermal Autonomy are still important to understand for each zone, one could distill a whole-building Thermal Autonomy metric by area-weighting and/or occupant-weighting each zone. The question of how to weight the zones is an important one that could potentially produce misleading results. Some comfort metrics, such as "Exceedance" (Borgeson & Brager, 2011), advocate for occupant-weighting. However, this method biases existing occupancy patterns over long-term whole-building performance. Further research using different building types, occupancy assumptions, and adaptive reuse scenarios is needed to validate a specific zone-weighting approach.

Another application for Thermal Autonomy is to better understand and classify Mixed Mode operation - buildings that operate as conditioned buildings for only part of the year. The heat map reveals what portions of the year are likely to require mechanical heating and cooling. Thermal Autonomy can help designers characterize the frequency and role that mechanical systems play.

It is with these questions in mind that we propose Thermal Autonomy as a metric and design process. The metric is a simple and intuitive measure that relates building performance, occupant thermal comfort, and climate. Though there are sophisticated and nuanced applications for the metric, we feel that its broad definition is a strength. As thermal comfort research continues to advance, Thermal Autonomy can reflect these changes along with simulation software and ultimately, the building design process.

## ENDNOTES

[1]ASHRAE Standard 55 adaptive comfort model states that "the 80% acceptability limits are for typical applications and shall be used when other information is not available. It is acceptable to use the 90% acceptability limits when a higher standard of thermal comfort is desired."

[2]California's Title 24 Energy Code is among the most restrictive in the United States but its performance approach allows latitude in how tradeoffs are achieved. For reference, requirements are similar to Ashrae Standard 90.1. The base building used these recommended assemblies.

[3]ASHRAE Standard 62.1. Ventilation for Indoor Air Quality.

[4]ASHRAE Standard 55 adaptive comfort model assumes up to 0.3 m/s air motion. Air speeds higher than that, but no higher than 1.2 m/s, will extend the upper limits of the comfort zone according to the SET Method graphically represented in Figure 5.2.3.2. The 0.9 m/s difference between 0.3 and 1.2 m/s corresponds to 2.2°C of cooling.

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# How can certification systems support positive design and development?

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ABSTRACT: LEED and other assessment systems evolved out of recognition that built environments present opportunities to reduce negative impacts of human activity on the planet. Using metrics based on greenhouse gas emissions and other criteria, these systems encourage activity that minimizes negative impacts associated with buildings. As understanding of the concept of regeneration has grown, USGBC is evolving LEED, despite limitations that may be inherent in a "points" based certification system. In LEED v4, goals were developed, "what we want LEED projects to be good at," including human health, community, and environment. This approach seeks to reorient project teams toward delivery of projects focused on positive engagement with local and global ecosystems rather than just reduction of negative impacts.

## 1. INTRODUCTION

Green building certification systems were created in response to recognition that the built environment presents a critical opportunity to reduce the negative impacts of human activity on surrounding ecosystems and the planet. Over the past two decades, LEED, BREEAM, and others have demonstrated an ability to significantly affect the way buildings and communities are designed and operated. LEED alone has and is driving uptake of green building concepts and technology in roughly a billion square meters of building in over 50,000 projects in more than 135 countries in the commercial market sector as of January 2013. Using metrics based on greenhouse gas emissions, ozone depletion, acidification, and other criteria, certification systems encourage activity that minimizes negative impacts associated with buildings. As technology and market forces have evolved to allow a broader segment of the buildings industry to conceptualize and deliver "net zero" impact buildings, industry thought leaders have increasingly explored the opportunity to develop "net positive" projects and the practice of regenerative design and development has grown. Increasingly, these innovative practitioners are engaging with certification system developers to explore the ability of certification systems to evolve so that they encourage and reward not just the reduction or avoidance of negative impacts, but also inspire the use of processes which result in positive impacts and regenerative projects. Put another way, could these systems catalyze a regenerative/net-positive industry transformation the way they have catalyzed a more general "green" transformation? Issues related to the potential for certification systems to support sustainability were raised in 2005 in Cole (2005) and have been discussed more recently in terms of the potential for these systems to encourage "regenerative" outcomes (Cole 2012). The purpose of this paper is to explore this question, with a focus on LEED.

## 2. GOING "BEYOND GREEN"

An increasing number of thought leaders now describe their work as "beyond LEED" or, more generally, "beyond green." The approaches taken by these paradigm busting innovators take different shapes, but most have in common a focus that leads to strategies that transcend minimization of environmental damage. For example, they can include a broadening of focus to include social and economic issues; they can move from "less damage" to a net-zero status; they can seek to restore damaged systems; through biomimicry, they can emulate nature; and they can take a regenerative approach to design and development. In some cases, the change in focus is less on strategies and more on process – using a process that involves a broader range of stakeholders working in a significantly more integrated way.

The terms "net zero," "net positive" and "regenerative" are used with widely differing definitions and this creates problems for any effort to develop certification system criteria to measure and verify compliance. For example, some use "restorative" and "regenerative" or "net positive" and "regenerative" synonymously, but most of the growing literature on regeneration contradicts this (Cole 2012, duPlessis 2012, Mang and Reed 2012). Regenerative design and development thought leaders propose definitions that are based on whole systems thinking, rooted in place, view humans as part of nature, and support the co-evolution of human and other natural systems.

Net zero and net positive approaches are sometimes posited as steps on a path from "doing less damage" approaches to regenerative approaches. But, it is important to note the mindset shift that must occur to move from a fragmented system of discrete elements to a holistic, regenerative approach.

The definitions of "net zero" and "net positive" do not propose such a change in approach, but rather a change in the definition of criteria and metrics. Projects can have a narrow focus on net zero or net positive energy or can look more broadly to include water, materials, and other aspects of a building project. Often, in recognition that buildings do not exist in isolation, the scale considered necessarily expands well beyond individual buildings to collections of buildings in communities, cities, watersheds, airsheds, jobsheds, etc.

## 3. CONSTRAINTS AND OPPORTUNITIES FOR RATING SYSTEMS

The underlying philosophies, structures, metrics, and processes associated with current certification systems pose significant challenges as developers consider the ability to transition these systems from green to regenerative approaches to design, development, and operation of buildings and communities. These obstacles and changes that would be needed are discussed thoroughly in Cole 2012 and are summarized in the following:

> "…reframing of building performance within regenerative design, there is the need to understand and reconcile a number of issues, including: the relationship between systems thinking and reductive approaches; the relationship between the performance of individual buildings and the larger context in which they are located; and the relationship between place-regional-specific approaches and globalized systems…what is perhaps the most significant and necessary shift does not reside at the strategic level, but in the mindset among design team and client participants. And this, in turn, will be dependent on a shift in our worldview from one that sees us as separate from and dominant over nature, to one that considers us integral to, and interdependent with, natural systems." (p 51)

Cole also suggests that

> "development of design frameworks and tools that spur innovative design solutions is a priority … to move beyond 'green design' into the realm of 'regenerative design' thinking" and notes three potential implications for practice of this shift: re-establishing regional design practices, establishing common ground with diverse stakeholders, and changing responsibilities and skills of designers. (p 51-52)

The obstacles to shifting to net-zero or net-positive criteria within an existing rating system framework exist but are less significant than obstacles to a shift to a regenerative framework since net zero and net positive approaches still use discrete technical criteria and quantitative metrics. The constraints and opportunities we have identified over 15 years of designing and implementing the LEED rating system, as well as some discussed by Cole, are presented in this section.

### 3.1 *Constraints*

In exploring the potential for LEED to transition to a system that supports net-positive or regenerative design and development, we have identified several key constraints; in most cases, these constraints apply to other certification systems as well.

- *Certification systems necessarily favor quantitative and discreet technical criteria rather than whole systems level analysis.* For the vast majority of the buildings industry, this is probably the key obstacle to transitioning LEED or any other current certification system to a regenerative framework; it is less of an issue for a net-positive approach. Most green building certification systems serve two masters. They function in the market as both environmental assessment frameworks and market transformation tools. When used as verification/assessment mechanisms rather than design guides, integrative projects with regenerative aspirations generally achieve the highest levels of certification. In these instances, the certification criteria do not directly drive design decisions – the decisions are a reflection of the outcomes of integrative process and thus, the certification serves as validation of successful execution of a "regenerative" inspired concept. Far more often than not, however, the certification itself is the objective of the project team. When used as a design guide, the additive nature of a "checklist" composed of discrete criteria summed to derive a final score yields outcomes sometimes significantly divergent from whole systems thinking. To achieve the highest levels of performance at the most reasonable cost requires project teams to use integrative processes and to look at systems and synergies among strategies, but few certification systems contain requirements to directly or explicitly encourage this behavior. Therefore, they can produce outcomes compliant with the strict requirements of the system but substantially less than what the system goals intend. LEED was intended to be used as a tool in an integrative process, and the LEED Accredited Professional was intended to facilitate that process. However, this has not occurred in projects that use LEED as a design guide/checklist, considering each credit in isolation from the others.
- *Certification systems tend to focus on performance of the projects as discrete entities, not how their design, construction, and use relate to the social, economic, and ecological health of places they inhabit.* There are credits in LEED and other systems that relate to specific impacts of the project on its immediate surroundings and on the larger ecosystem it inhabits. These are discrete criteria, however, that do not *require* project teams to consider how they should respond to the ecological, social, and economic context and how they might contribute to the overall health of the place. They do not currently directly involve feedback loops and evolution over time as the context changes.
- *The need for simplicity, clarity and the ability of a project team to act on the requirements, necessary for voluntary uptake, is complicated by the inherent complexities of whole systems thinking and pattern analysis.* The checklist approach is one of LEED's features that have led to its success. It is organized in a way that conforms to design practice – credits are in

categories that are familiar to project team members. Requirements and metrics are stated in quantitative, unambiguous ways where possible to reduce confusion and enable verification. Although there is increasing flexibility in LEED to accommodate its use around the world in different contexts, credits are kept as consistent as possible to maintain an overall definition of LEED certification and to avoid confusion among owners and designers that work in many different countries. This is in sharp contrast to an approach that is based entirely on the patterns in a particular place. Additionally, hyper specialization in modern professional practice has resulted in a marked lack of knowledgeable professionals capable of determining, without assistance, the unique attributes of "place" that should be addressed during project development.

- *We do not have metrics that apply to regenerative work.* Regenerative projects often depend on the "story of place" as described by the Regenesis Group (Regenesis Group 2013) to document the project's goals, strategies, and accomplishments. Indicators of success must be developed for each project, based on its goals and analysis of its place. Narrative documentation adds to the difficulty of reviewing the project's achievements for certification purposes. In addition, developers of certification systems generally do not have the expertise in social and economic concerns needed to develop metrics to reflect the broader spectrum of issues. There are metrics that have been developed in other fields to measure social and health of communities, but their applicability to individual buildings is not always clear.

### 3.2 *Opportunities*

Although the constraints are daunting, it is important to explore the opportunities for helping to move practice toward more positive, regenerative approaches.

- *The potential market is huge.* In the earliest days of the green building movement, few people imagined that it would reach as many people and changed practice as it has. While we might look at a shift to net-positive or regenerative approaches with skepticism, it is not impossible – 1+ billion square meters of green building globally was "impossible" 15 years ago.

- *Momentum exists.* Leaders are doing this work now. To many, it is viewed as the way of the future, even if they are not currently engaged in it. There is enthusiasm among many in the field to expand into areas of human health, social equity, community health, truly sustainable economic prosperity and development. To deliver on the outcomes certification systems were created to deliver, we must engage in this dialog.

- *Resources exist.* Case studies of successful regenerative projects and training programs from experienced experts are now available.

- *Certification systems have been very effective in defining "green building" and opening dialog among stakeholders.* Can this be expanded to encompass discussion of regenerative design and development?

## 4. WHERE ARE WE GOING WITH LEED (AND BEYOND LEED)?

In 2008 USGBC began thinking about a "roadmap" for the future of LEED. This concept envisioned that LEED would expand from its current focus on doing less environmental damage to a net zero or sustainable approach, and then would evolve to support restorative and regenerative work. This roadmap is illustrated in Figure 1.

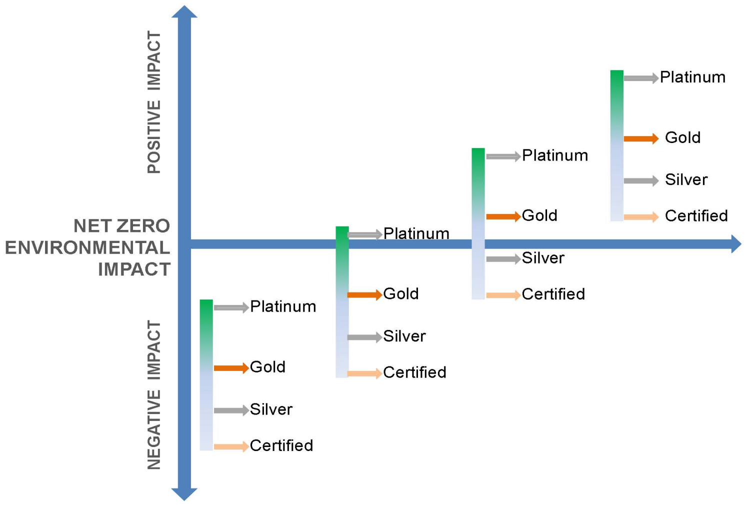


Figure 1: Roadmap to 2030, version 1

As we worked to figure out how to implement the concept idealized in this graphic, it became apparent that, while useful as a developmental heuristic, it was far from the most accurate or descriptive representation. First, the graphic implies a linear process of evolution, in which the rating system moves in a stepwise fashion from below the line to above the line. Second, the complexities in the evolution of individual credits are hidden. Third, it implies that everything must go through a net-zero point which is far from the most efficient path for some issues. Fourth, it does not provide much guidance on what “above the line” should look like. Finally, it implies that LEED could, in fact, become “regenerative” although, as stated above, no conclusive understanding of what this would entail has been formed.

In the process of developing LEED version 4, we revised and evolved this paradigm and have begun to create a clear and focused vision for going “beyond LEED” as it currently exists. This includes:

- An expansion of the scope of LEED to include social, human health, economic, and other factors not currently addressed adequately in the rating system.
- Adoption of a set of seven underpinning/overarching system goals for LEED, stated aspirationally, as things we want LEED projects to be good at rather than negative impacts we seek LEED projects to avoid.
- A renewed focus on the use of integrative processes in design, construction, and operation as a step toward whole systems thinking.
- An expansion of the process of stakeholder involvement to encourage longer-term commitment to the project.
- An ability to incorporate place-based information and priorities.
- Consideration of the implications of scale and linkages among scales from individual office interiors to larger scale communities.
- Recognition that education, case examples, tools, and experiential learning will all be important in changing mindsets as well as behavior.

These steps will not, by themselves, make LEED a tool for regenerative design and development but we hope that they will enhance the way the rating system encourages and rewards positive actions and systems thinking. Our goals are to expose a significantly larger market to new ideas and encourage new audiences to explore and learn about them. One of the things LEED has historically done well is to focus attention on ideas and strategies that might be new to some users and encourage these users to learn about them and adopt them in their practices.

Figure 2 illustrates our initial concept for a new way to think about the future of LEED. The outer circle represents the whole system in which we are working. The next ring segments the whole system into the seven system goals for LEED projects. The highlighted portion of each goal segment represents one interpretation of LEED's current effectiveness in addressing specific sub-goals established to make the broader system goals actionable.

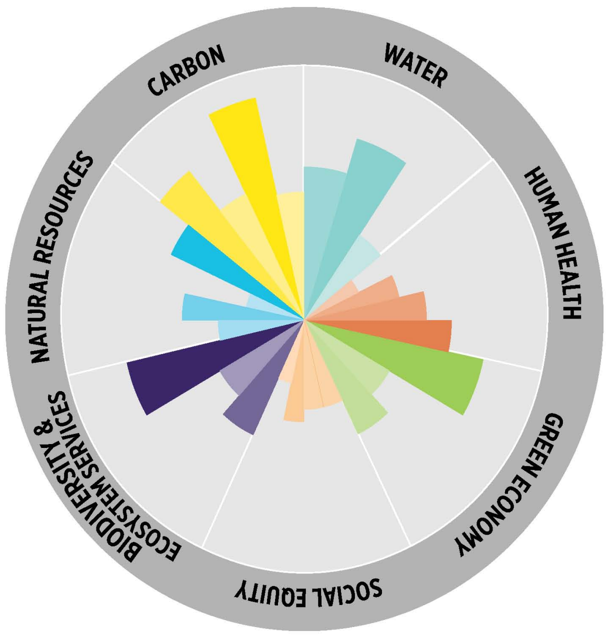


Figure 2: Envisioning the Future of LEED

This new vision is still being developed. In the remainder of this paper, we suggest some specific ideas for what LEED (and most other certification systems) can do to evolve toward a more systems-based, integrative, inclusive, place-based approach.

*Focusing attention on integrative design, a move toward systems thinking*, Since its inception in the 1990s, LEED was designed to be used as a tool in an integrative process. Many project teams employ LEED as intended but market evolution, general green building knowledge and the emergence of process management tools which have their origins in current non-integrative practice have enabled a large user base to use the rating system as a checklist for many projects. To counter this trend and to take advantage of the high market visibility LEED enjoys, LEED version 4 introduces a new credit which encourages and rewards the use of integrative process. While limited in its scope, this credit is intended to encourage every project team to think about the integration and synergies among credits as they proceed through the design, construction, operation, and renovation processes. It is anticipated that, over time, the credit will be expanded to encourage greater degrees of project team integration and to move from being a credit that rewards integrative process less and demonstrably integrative outcomes more. How this credit evolves relative to outcomes is still somewhat unclear.

In addition to the credit requirements and the expected direct impact they will have on LEED projects, including a credit for integrative process leverages LEED's bully pulpit in a unique way. Links to existing formal and informal education and tools are being established to support credit implementation and it is likely that additional tools will emerge over time as well. Education programs aimed not just at the specific requirements of integrative process credit achievement but also at the use of a system-based integrative approach for entire projects. The LEED version 4 Reference Guide will serve as an important jumping off point for projects exploring integrative process for the first time and explain the credit goals and requirements as well as highlight synergies for all credits to encourage teams to maximize opportunities for integration.

As market experience with integrative process grows, consideration of a synergistic credits achievement structure will be evaluated as a mechanism to reward outcomes of integrative process rather than process itself. This structure could be a key way to ensure project teams recognize the greater benefit of each strategy when all are done together.

*LEED can help teams envision positive results, positive interactions.* The new goals for LEED projects, stated as positives, change how we frame credits and the way teams think about project seeking LEED certification. As USGBC revised credits for LEED version 4, we recognized that the impact categories (greenhouse gas emissions, ozone depletion, acidification, etc.) we had used in LEED 2009 for assigning point value and thus relative importance of credits did not allow for "positively" stated credits. It was also difficult to prioritize the importance of these impact categories since they all reflected parts of a whole system in which all parts are important.

For LEED version 4, new goals for LEED projects, which serve as the basis for credit point allocation, have been developed:

- Reverse contribution to climate change
- Enhance human health and well being
- Protect and restore water resources
- Protect biodiversity and ecosystem services
- Promote sustainable and regenerative resource cycles
- Enhance community, social equity, environmental justice, and quality of life
- Build a greener economy

Projects cannot reach these goals by only doing less damage – they must be encouraged to take steps that have positive outcomes. LEED credits are being reviewed to explore whether intents could be recast to state positive objectives and outcomes. These positive statements of goals and intents will help project teams envision different purpose and strategies.

Credit metrics will also be examined. Reformulating credits to reward positive processes and behavior is not just a case of changing a number or requirement from negative to positive. The concept of "positive" for many credits likely will involve different sets of goals, strategies and technologies.

A detailed explanation of the process and mechanics used to develop the credit and point structure of LEED is available at www.usgbc.org (Owens and Macken 2011).

*Broaden scope to include social, economic, human health in meaningful ways – another move toward systems approach.* The new LEED goals require us to broaden our scope and to address issues such as social equity, economy, and human health more thoroughly. These issues are included in LEED now, but often they are addressed as indirect benefit of an environmental intent; for example, it has been postulated that the use of local materials has a greater socioeconomic (supporting local economies and providing jobs) than environmental benefit. While not the initial intent of this LEED credit, the social outcome of credit achievement is no doubt directly in line with LEED's overall system goals. Additionally, LEED's heavy emphasis on energy efficiency addresses human health and wellbeing impacts of climate change.

There is not a thorough understanding of the impacts of the built environment on social equity, community well-being, economic development, and human health. Specific examples are known but we have not examined systematically how the built environment affects these areas, how important these impacts are on the overall problems, what the opportunities are for changing the impacts from negative to positive, and how LEED could encourage that behavior. As a first step in understanding what the priorities should be in addressing these new areas, USGBC convened a summit of public health experts in January 2013. This summit acknowledges a broader need to expand the dialogue beyond the people and institutions currently involved. This will help us focus on the most important problems and identify the opportunities for buildings and communities to address these problems. Not all problems are things that buildings can affect; we should focus on those in which the built environment is a significant part of the problem and the potential solutions.

As we review each of the goals and the credits that contribute to those goals, we will identify gaps in each area. What issues are not currently addressed? Do we need new credits or slight refocusing of existing credits? Are there obstacles in the market and practice that will make it difficult to implement these new credits? The Community and Economy goals are clearly underdeveloped and the Human Health goal also needs to be filled out; it is likely we will identify gaps in other goals as well. As we identify new topics to be addressed by credits, we will need to depend on our expanded partnerships to provide the new expertise demanded to answer these questions.

Incorporation of these new goals will require greater focus on integration and interaction among credits – including social and economic credits with rest of system. As Cole (2005) notes:

> "while the three domains of environmental, social and economic are typically used to frame sustainability, it is their points if intersection that are equally critical, i.e. the ways and extent to which they influence each other positively or negatively. Simply adding social criteria to the current mix of environmental performance measures may not necessarily expose the way that one influences and is influenced by others. It can only do so if the method or tool is used as part of the deliberations between various stakeholders, i.e., synergies are achieved through active, cross-disciplinary use of the tool, rather than by simply the structure of the tool itself." (p. 461)

*Incorporating "place" and local, regional, context considerations – and role of project in place.* "Place" can be defined by a watershed, an airshed, a geopolitical boundary, a cultural context, and other elements of the nested systems in which a project is located. Certification systems need to find a balance between consistency and adaptation to local context. To continue to harness existing momentum and impact, maintenance of a recognizable structure may be advisable. Additionally mechanisms that reduce burdens on users who certify multiple projects and a focus on consistency among requirements from project to project present challenges for local adaptation. On the other hand, place and context are crucial elements of regenerative work, with the project team exploring and getting to know the place in all of its aspects before the design process begins. Cole (2012) notes:

> "the framing of the discussion of building design as inseparable from place carries the implication that it is equally, if not more important, to understand how building design, construction and use positively influence the social, ecological and economic health of the places they exist within. This is clearly different from green building practice that focuses on the performance of the building as a separate entity." (p. 47)
>
> and,
>
> "…rather than striving solely for an understanding of an individual building's performance, the potential contribution it makes to the social, ecological and economic health of the place it functions will perhaps be of equal, of not more, significance." (p. 43)

A few certification systems are designed for specific places or are designed to be adapted to the place in which they are used. LEED has incorporated Alternative Compliance Paths to begin to adapt credits to different places, conditions, and contexts. LEED also has the capability to provide project teams with a regional overlay of conditions that are relevant to the project, such as climate, and a place-based weighting of credit importance based on that information. Tools, such as the REGEN tool developed in concept by BNIM for the USGBC, could offer a more detailed source of place-based information for project teams. While neither of these tools replaces the "on the ground" exploration and learning that occurs in the place, they can provide useful background.

*Focus on process.* Regenerative processes include a deeper involvement of stakeholders, with the aim of developing relationships that will continue into the future and enable the project and its community to co-evolve. It broadens the conversation, gets all perspectives represented, and explores what is important? What are strongly held values? How can this contribute to shaping the project?

As certification systems move toward a focus on performance and outcomes, we should not ignore our role in encouraging better processes through training, resources and case examples, and, perhaps, through credits. The introduction of the Integrative Process credit in LEED Version 4 is intended to focus attention on the benefit of an integrative approach, and encourage project team members to learn about it and incorporate it into their practices. It is possible that other process-related credits will be useful in moving project teams toward more inclusive stakeholder involvement. In addition, examples of projects that have used deeper stakeholder involvement would introduce teams to the possibilities.

## 5. CONCLUSION

As with many market transformations, the evolution of the understandably risk-averse and historically slow-to-change buildings industry seems to be following a typical Rogers curve for diffusion of innovation (Rogers 1995). While the rate and pervasiveness of change are the subject of much debate, there is general recognition of trends toward incorporation of a broader set of criteria that more directly address human health, social and environmental issues in the design, construction, operations and maintenance of the built environment. As these trends evolve, segments of the buildings industry that were either unaware or actively resistant to change become increasingly capable of engaging in the types of action and multi-attribute decision making necessary to produce higher performance buildings.

The role of green building certification systems in this evolution is still unclear. Certification systems have been instrumental in defining the scope and reach of green building concepts over the past two decades and could have an important role in what may become a third generation of transformation which moves practice from "less bad" activities to "regenerative" practice. For all of their limitations, green building certification systems are an unprecedented but nevertheless established and proven conduit to the market. Harnessing this infrastructure to deliver content that activates this transformation should be considered as a significant opportunity. In spite of the acknowledged limitations both on the technical as well as market side of the equation, green building certification systems are fertile ground to promote regenerative concepts as well as unique feedback loops to measure and analyze success. The concepts presented in this paper are intended to contribute to this dialogue by exploring this potential and presenting some initial ideas for moving forward.

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# Regenerative Neighbourhoods – scaling up from net positive buildings

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ABSTRACT: Emerging approaches support regenerative design and development at the building scale. Buildings such as the Centre for Interactive Research on Sustainability at the University of British Columbia (UBC) are attempting to demonstrate that net-zero and even net-positive performance with respect to energy, water and carbon, health, happiness and productivity is technically, financially and institutionally possible. Building-scale applications also demonstrate the limitations of applying regenerative sustainability principles at the building level (e.g., missed opportunities for integration of energy and transport infrastructure, water and wastewater, urban form, community engagement). This paper presents the early findings of the UBC Regenerative Neighbourhoods Project. This includes a scan of the urban sustainability context, a rationale for neighbourhood scale application, and insights on process and potential performance standards.

## 1. INTRODUCTION

### 1.1 *Sustainability and the Built Environment*

Predominant sustainability and environmental responses have typically encouraged incremental ‘less harm’, or possibly ‘net zero’ solutions. Such efforts are important but inadequate in two ways: they are insufficient because the magnitude of change required to achieve global sustainability demands transformational change that goes beyond net zero to net positive outcomes, and they are demotivating because an invitation to sacrifice, or to minimize harmful human activities, is inherently uninspiring (Gifford and Comeau, 2011).

‘Green’ building approaches such as LEED illustrate this inadequacy. While they have increased the awareness of green buildings and helped reduce the adverse environmental impacts associated with the construction and operation of buildings, rapid global urbanization and an unprecedented building boom worldwide have contributed to increasing environmental impacts associated with buildings worldwide. This is, in part, because most new (and existing) building stock worldwide is still not being designed to comply with green building standards and, currently, most ‘green’ building rating systems reward building performance that is based on ‘less harm’ solutions with respect to energy, emissions, water, indoor environmental quality, and so on. Presently, about 40% of all energy and material resources are used to build and operate buildings globally. Even with the growth in the green building industry, aggregate $CO_2$ emissions from buildings are projected to grow faster than any other sector through 2030 (UNEP, 2007; 2009).

The insufficiency of the less harm approach can also be explained by looking at the city scale. The world's urban population is expected to increase by more than two billion people in the next 30 years (UNDP, 2012). If current trends continue, this will lead to dramatically increasing demands for urban infrastructure and resources. Fortunately, new approaches to sustainability are emerging.

### 1.2 *Regenerative Sustainability*

There are a wide range of views on the meaning of 'sustainability' and 'sustainable development'. One view argued for by Robinson (2004) is the view of 'procedural sustainability':

> *"where sustainability can usefully be thought of as the emergent property of a conversation about desired futures that is informed by some understanding of the ecological, social and economic consequences of different courses of action ... This view acknowledges the inherently normative and political nature of sustainability, the need for integration of different perspectives, and the recognition that sustainability is a process, not an end-state"* (Robinson, 2004, p. 381).

Following on this view, 'regenerative sustainability' can be thought of as a net positive approach to sustainability leading to a mutually beneficial co-evolution of socio-cultural ('human') and ecological ('natural') systems. It is explicitly distinguished from a 'less harm' approach. It can be expressed in the form of a question: To what degree can human activities lead to improvement of both ecological integrity and human quality of life as emergent properties?

The aspirations and key principles of regenerative sustainability are emerging from several converging historical threads including architecture and design, community engagement and respect for people and place, systems thinking, sustainability assessment, human well-being assessment and others. Regenerative sustainability embraces such qualities as whole, integrated and closed loop systems; supports the potential for self-organization of living systems; encourages shared responsibility and ownership; and catalyzes the capability for 'net positive' outcomes in human well-being and ecological integrity (Cole 2012; du Plessis 2012; Svec et al. 2012, Reed 2007). While the aspirations and key principles of regenerative sustainability are becoming clearer, the operations and practices as they relate to the built environment are not yet well developed (Cole, 2012).

### 1.3 *Regenerative Design and Development*

The term 'regenerative design' was first introduced by John T. Lyle as a design process that takes into account the people and environment in which it is situated to create a project that is in harmony with the local community and ecosystem (Lyle, 1994). Lyle drew from the ideas of permaculture, bioregionalism, and ecological design and applied them to buildings and a small campus.

The Cradle-to-Cradle (C2C) concept applied this thinking to the way we build and design, including applications to industrial processes and product development (McDonough & Braungart, 2002). C2C suggests that products and developments can be designed so that, after their useful lives, they can provide nourishment for something new through technological and biological cycles. Inherent in the C2C concept is the idea of 'net positivity' or 'upcycling.' Today, C2C principles are being applied in a range of contexts, including the built environment (Mulhall & Braungart, 2010).

Some insights about the emerging field of 'regenerative design and development' related to the built environment are provided below. Importantly, they represent not only an intention to restore and regenerate socio-cultural and ecological systems but also a shift in perspective about the role of buildings, and the built environment itself, from being the primary subjects of interest to being seen for their potential to catalyze mutually beneficial co-evolution of human and natural systems in a partnered relationship with place (Cole, 2012). According to Reed (2007), the regenerative process begins by:

*"attempting to understand how the systems of life work in each unique place. Our role, as designers and stakeholders is to shift our relationship to one that creates a whole system of mutually beneficial relationships. By doing so, the potential for green design moves us beyond sustaining the environment to one that can regenerate its health – as well as our own"* (Reed, 2007, p. 1).

Mang and Reed (2012) differentiate between regenerative *design* and regenerative *development*, suggesting that the former builds the regenerative and self-renewing capabilities of designed and natural systems (i.e., the designed interventions) while the latter creates the conditions necessary for its sustained, positive evolution (i.e., the benefits accrued from regenerative designs). DuPlessis (2012) broadens the narrative, making the case for a 'regenerative sustainability paradigm' that aims to "…restore and regenerate the global social–ecological system through a set of localized ecological design and engineering practices …" (p. 15).

Some early attempts of regenerative design and development frameworks have been suggested, including: the Regenesis Framework (Mang & Reed 2012), the REGEN tool (Svec et al. 2012); the LENSES framework (Plaut et al. 2012) and the Perkins+Will framework (Cole et al. 2012). More information on all of these can be found in the special issue of *Building Research and Information 40(1).* See Cole (2012) for an overview.

Other frameworks, with potential relevance to regenerative sustainability and neighbourhoods include: the Living Building Challenge 2.1 (International Living Buildings Institute, 2011), the Portland Sustainability Initiative's EcoDistricts framework (PoSI, 2012), Arup's ASPIRE tool (Arup ASPIRE information sheet, n.d.) and Cradle to Cradle Criteria for the Built Environment (Mulhall & Braungart, 2010). All of these frameworks offer some insights about encouraging a shift towards a regenerative approach to design or development, with potential application to the neighbourhood scale. However, most of these approaches – at this stage of their development – remain early efforts with most focused on single building or project design (an exception being the EcoDistricts framework). Furthermore, early thinking on regenerative design and development has been criticized in general as lacking concrete evidence of its efficacy (Cooper 2012), its applicability in an urban context (Clegg 2012), and its applicability at different scales (Tainter 2012).

### 1.4 *Why Neighbourhoods?*

To date, regenerative sustainability (including regenerative design and development) has mainly been applied at the building scale. As part of the exploration of scaling up, this paper focuses on informing the potential for net positive neighbourhoods through an understanding of its broader urban context (see Section 3). We expect urban neighbourhoods to be an important context for further exploration of regenerative sustainability because:

- Cities, including their neighbourhoods, have a large influence on global sustainability. They are major centers of human population resource use, waste and emission creation and habitat damage (UN-HABITAT, 2011; UNEP 2007, 2009; Pimm & Raven, 2000) as well as centers of human, social and financial capital with significant potential for creativity and innovation (Glaeser, 2003)
- There is growing empirical evidence and recognition that cities shape themselves 'organically' from the bottom-up through the millions of self-organizing socio-economic and policy-shaping transactions at the building and neighbourhood scales (in addition to top-down 'master plans') (Batty 2008; Batty 2012a; Salat & Bourdic, 2012)

- There are limitations of single-building innovation on overall urban form and function (e.g. doesn't cover connecting infrastructure and services, mobility, public spaces) (Clegg 2012; Tainter 2012) and,
- There is good potential for more meaningful community engagement at the neighbourhood scale than at the metro and building scales. The neighbourhood scale allows smaller, more informed engagement and sense of ownership (compared with the urban, or metro, scale) and more diverse interests to engage in decisions shaping socio-cultural and environmental considerations (compared with the building scale). More meaningful engagement may also offer the potential for enhanced social learning through a reciprocal 'mindset-built form' relationship (i.e. where changing worldviews re-shape neighbourhood built form and neighbourhood built form, in turn, re-shapes worldviews).

This suggests that communities of people engaged in the conceptualization, design, development and on-going life of buildings, neighbourhoods and districts hold considerable potential for contributing to urban sustainability. The premise that urban neighbourhoods are an important context for further exploration is supported by a number of recent efforts focused on sustainability at the neighbourhood scale, including Falk & Carley's (2012) identification of the characteristics of a sustainable urban neighbourhood, The Freiburg Charter for Sustainable Urbanism (2012) 'lessons from Vauban', CABE's (2008) and URBED's (2008) exploration of what makes an 'eco-town' and how the concept has been applied across Europe, and Woodcraft et al.'s (2011) exploration of 'social design' and the creation of thriving communities.

## 2. RESEARCH PROGRAM

### 2.1 *UBC Campus as a Living Laboratory*

To respond to the need for better integration of operational and academic sustainability efforts, partnership interests and research, The University of British Columbia (UBC) has developed a formal Campus as a Living Laboratory for Sustainability (CLL) initiative. The intention is to develop interdisciplinary research projects that leverage operational requirements to create substantive partnership opportunities with industry and other community partners, and to leverage teaching, learning and research opportunities for students, faculty and staff. The entire 400-hectare, 400-building campus (containing about 1.5 million square metres of floor-space) is seen as a test-bed in which to demonstrate operational innovations that catalyze the development of new knowledge and new applications, systems and technologies.

Many universities have characteristics similar to UBC that make them uniquely qualified to serve society in this role: (a) they are single decision-makers (and often owner-occupiers) of significant capital stock, consisting of multiple buildings and energy, water and waste systems; (b) they are public institutions, or have a public mandate, that can be more forgiving on pay-backs, and long-sighted on returns; (c) they educate; and (d) they conduct research.

### 2.2 *The Centre for Interactive Research on Sustainability (CIRS)*

The Centre for Interactive Research on Sustainability (CIRS) is a 5,800m$^2$ living lab flagship building on The University of British Columbia (UBC) Vancouver campus designed to operate at the frontier of sustainable performance in environmental and human terms, and to serve as a living laboratory of sustainable practice over its lifetime (Robinson et al., 2013). In this sense, CIRS seeks to become an example of building-as-catalyst for the net positive co-evolution of human and natural systems. Embedded in the UBC campus, its ability to fulfill this role will continue to be researched and developed further. CIRS seeks to demonstrate that it is technically, financially and organizationally possible to plan, design, construct and operate buildings that deliver net positive environmental (biophysical) and human well-being benefits to their communities.

CIRS seeks to become net positive in seven ways; 4 environmental (net positive in structural carbon, operational carbon, energy, and water) and 3 human (human health, happiness and productivity). Details of these approaches to net positive performance involving advanced, integrated systems and including a high degree of connectivity to its surroundings can be found at www.cirs.ubc.ca. CIRS is beginning to demonstrate that human and environmental net benefits can spill over from the building into its surroundings. Some observations from CIRS include:

- The sub-system (e.g., building) can only be 'net positive' in relationship to its contribution to the broader system (e.g., its surroundings, or neighbourhood);
- There is a complex, integrated combination of biophysical stocks and flows within and across the building boundary (e.g. heat, power, carbon, water, wastewater, materials);
- There are biophysical constraints (e.g., space, distance, thermodynamics, etc.) to the building's net positive reach (with respect to flows of energy, water);
- Quantifying 'net positive' is based in part on delineation of building 'system boundary' as part of a lifecycle assessment (LCA);
- The ability to make 'net positive' contributions to the building's surroundings depends, in part, on the unique characteristics of place (e.g. water self-sufficiency in Vancouver may not transfer to more arid climates);
- Social interactions (e.g., the CIRS community of inhabitants) and the communities it engages seem much less limited by these biophysical constraints;
- Early indications are that the influence of the CIRS community in re-framing the sustainability narrative through interactions with its surrounding communities (and supported by tangible building-scale examples), might be one of the more important 'net positive' contributions; and
- Some additional dimensions of 'net positive' are expected at the neighbourhood scale (e.g. transportation, community engagement, food systems, habitat) and warrant a review of the broader urban context) (see Section 3).

### 2.3 *Regenerative Neighbourhoods Research Project*

In the context of the CLL initiative, UBC is undertaking the Regenerative Neighbourhoods Project (RNP). The purpose of the RNP is to explore and catalyze the emergence of regenerative sustainability at the neighbourhood scale, firstly within the UBC campus and community, and secondly in communities beyond UBC. It has three main tracks: (1) research, (2) application at UBC and, (3), sharing lessons with partners and collaborators outside UBC.

The initial objectives of the Regenerative Neighbourhoods Project are to:

- Understand and explore the concept: What is regenerative sustainability as it applies to the neighbourhood scale? For example, what are the implications of scaling up regenerative sustainability from the building scale (e.g. CIRS)? What are some guidelines for engaging in regenerative sustainability processes?
- Understand assessment: How can regenerative sustainability performance be assessed?
- Understand obstacles/enablers and institutionalize continuous improvement at UBC.

Initial RNP activities include: reviewing relevant literature and best practices; hosting an exploratory summit; testing and refining an evaluative framework ('lens'); institutionalizing continuous improvement at UBC; and working with external partners in the private, public and not-for-profit sectors to test the efficacy of the concept in urban neighbourhoods and support broader knowledge diffusion. This approach is aligned with UBC's sustainability goal to *commit* the entire community to sustainability research, teaching and learning; to *integrate* by embracing interdisciplinary approaches to sustainability; to *demonstrate* by transforming its entire campus into a living laboratory, and; to *inspire* students, faculty, staff, alumni and partners beyond the campus gates.

## 3. THE URBAN SUSTAINABILITY CONTEXT FOR NEIGHBOURHOODS

The overarching question posed by the Regenerative Neighbourhoods Project is: how can human activity at the neighbourhood scale contribute in a net positive way to the co-evolution of socio-cultural and ecological systems? Neighbourhoods are set within a broader urban context, and as such, there is a reciprocal relationship: the development, on-going life, decline and redevelopment of neighbourhoods influences the patterns and dynamics of urban areas, and the overall urban context can exert considerable socio-economic, cultural, ecological and institutional influence on neighbourhoods. It is this latter context that is explored in this section through an examination of the issues facing cities and the practical and theoretical responses to those challenges.

### 3.1 *Urban Sustainability Context and Challenges*

Understanding the projected growth of cities and the expected consequences of intertwined current trends can inform urban sustainability approaches. Some biophysical implications of this growth, for example, include increasing habitat destruction, loss of biodiversity (Pimm & Raven, 2000), water shortages and nutrient cycling deficiencies (Kalmykova et al., 2012; Metson *et al.* 2012). Concurrently, cities face aging infrastructure, public sector debt as well as increasingly obsolete and resource-intensive buildings. Global urban infrastructure cost estimates for the next 20 years are $53 trillion, about $2.5 trillion per year (OECD, 2007).

Income inequality is growing in nearly all OECD countries (OECD, 2011a) with US and Canadian figures among the worst (Goldsmith & Blakely, 2010; Canadian Centre for Policy Alternatives, 2009; OECD, 2011b). At the same time, there is a reduced ability of citizens to articulate and organize requests for good government, a movement away from community life, and increased psychological alienation (Putnam, 2000). For example, in a poll of 3,841 people across Metro Vancouver, preliminary results found that residents considered their community to be a place where neighbourhood relationships are polite, but the connections are not particularly deep and one in four residents found Metro Vancouver to be a lonely place (Wightman, 2012).

Increasing empirical evidence argues strongly that current built form – and urban sprawl in particular – leads to a number of concerning health trends including less physical activity, increased obesity (leading to increased risks of cancer, heart disease, stroke, high blood pressure and depression), increased prevalence of diabetes and cardiovascular disease, increased injuries to pedestrians, less connectivity and social capital, and declines in subjective well-being and psychological health (Flegal et al., 2010; Frumkin et al., 2004). Many of these trends tend to be worse amongst lower income groups (Drewnowski, 2009; Akinbami et al., 2011), and poverty remains a massive issue in cities around the world (OECD, 2011a). In Canada, the urban poverty population is growing at faster rates than non-poor populations and cities are showing increasing spatial concentration of poor families (Canadian Centre for Policy Alternatives, 2009; Gertler, 2009).

Therefore, the urban sustainability context spans a complex, highly interdependent mix of socioeconomic, cultural, technological, public health, ecological and institutional considerations. This informs the context for considering regenerative sustainability at the neighbourhood scale: how can neighbourhoods maximize their net positive contribution to improved human well-being and ecological integrity, within this complex and dynamic urban fabric?

### 3.2 *Sustainable Community Planning*

There has been much written on the ways in which natural and human systems can be better integrated through the design of the built environment. Ian McHarg's *Design with Nature* (1969) and Christopher Alexander's *A Pattern Language* (1977) were early views on the adoption of an 'ecological worldview' in planning and an articulation of how regions should be planned according to natural processes and patterns. Natural patterns and processes can inform regenerative sustainability applied at the neighbourhood scale.

Since Local Agenda 21 emerged from the UN Conference on Environment and Development (Earth Summit) in 1992, a wide range of approaches have emerged for encouraging more sustainable communities. Some approaches (e.g. New Urbanism, Transition Towns) offer overall strategies for improving community sustainability, others focus mainly on improvements to the built environment (e.g., Smart Growth, Transit-Oriented Development) (Duany et al., 2009) and others (e.g., Roseland's Community Capital Tool and STAR Communities Rating System) provide comprehensive sets of indicators, or criteria, for what makes a sustainable community (Roseland 2012; STAR Communities Rating Guide 2012). In the UK, the HQE$^2$R index offers an assessment tool for both the renovation and development of sustainable neighbourhoods (Blum & Grant, 2006).

Some researchers even argue that, in many respects, the unsustainable nature of contemporary cities *is a consequence of* poor planning at the micro or neighborhood scale (Berg & Nycander, 1997; Churchill & Baetz, 1999). Sustainability planning at the neighbourhood scale can help to achieve sustainable urban form at the macro level (Kennedy *et al.*, 2005).

These initiatives provide overviews of issues to be addressed by any urban or neighbourhood sustainability approach and suggest generic, prescriptive – and sometimes 'less bad' – solutions. However, they are not explicitly designed to catalyze 'regenerative sustainability' or neighbourhood-scale 'net positive' solutions and are therefore subject to the limitations of 'less harm' approaches outlined in Section 1.1. Further, these approaches tend to promote 'one size fits all' solutions that are not shaped by the unique potential of each place for mutually beneficial co-evolution of human and natural systems.

### 3.3 *Complexity Science and Urban Morphology*

Cities can be characterized as entities that are sometimes growing, sometimes declining and continually changing shape and size. Cities can be looked at as a hierarchy of different sub-centers across many scales, from buildings, to neighbourhoods to entire cities. These different 'fractals' or 'systems within systems' tend to show self-similarity of patterns and shapes (Batty 2008; Salat & Bourdic 2012). Further, 'networks of neighbourhoods' connect with each other, and are shaped through transportation networks and flows of people, information, services, materials and energy (Batty, 2008).

While city planning approaches have often emphasized a top-down master planning approach, empirical studies show that as much as being influenced by top-down planning, cities tend to grow organically "from the bottom up as products of millions of individual and group decisions…" (Batty 2012a, p. S9). From Batty (2012a):

> *"In short, cities are more like biological than mechanical systems and the rise of the sciences of complexity which has changed the direction of systems theory from top down to bottom up is one that treats such systems as open, based more on the product of evolutionary processes than one of grand design. During the last half century, the image of a city as a 'machine' has been replaced by that of 'organism' but the origins of these ideas remain firmly embedded in past developments."* (Batty 2012a, p. S9).

Another key difference between buildings and neighbourhoods is the relative lack -- at the neighbourhood scale -- of discrete 'pre' and 'post' occupancy assessment opportunities:

> *"New growth or absolute decay tends to be a relatively small proportion of the total change. Cities are continually in flux as people and their activities respond incessantly to changed circumstances that involve shifts in movement patterns, locations, the use of buildings and in social preferences"* (Batty 2012b, p.54).

Regenerative sustainability strategies for neighbourhoods will, therefore, need to find key leverage points within this continuous flux, recognizing that while major events or discrete projects may take place in neighbourhoods (e.g. a (re)construction project, a new factory or public facility) cities, and the neighbourhoods within them, are constantly changing. A key part of this will be skills development, productivity and economic development as it will also play an important role in how cities shape themselves and grow (Glaeser, 2003). Therefore, an understanding of current and emerging economic models, with relevance to urban and neighbourhood settings, including their underlying assumptions, is likely to be an important practical consideration for regenerative sustainability principles applied at the neighbourhood scale.

### 3.4 *Urban Metabolism*

Whether explicitly or implicitly, regenerative sustainability invariably evokes an analogy with, or direct application of, ecological and biological sciences. Some researchers and practitioners point to the inability of existing planning theory to integrate the complex spatial, temporal and biophysical relationships present in cities, and have conceptualized the built environment as being a social-ecological system, where multiple-related metabolisms interact at different (physical and temporal) scales (Moffatt & Kohler, 2008). They argue that ecological models provide a useful basis for such an approach that integrates time scales and allows for an assessment of important factors related to resilience such as adaptive capacity.

With origins in 'industrial ecology', considerable applied research is also being undertaken in the area of 'urban metabolism' and 'neighbourhood metabolism.' Urban metabolism is the study of the stocks and flows of energy and materials in cities and their relationship with urban infrastructure (Kennedy et al., 2007; Wolman 1965). Proponents suggest an expanded and more widely integrated agenda in the field, and posit that "practical solutions to the development of sustainable cities can be achieved through studying urban metabolism, urban ecology, city carbon and water footprints, the dynamics of city growth, and the interdependency between social actors, institutions, and biophysical system flows" (Kennedy et al., 2012, p. 778). These recent perspectives represent a thread that is likely to be informative for regenerative sustainability at the neighbourhood scale.

## 4. SUMMARY: EMERGING CHARACTERISTICS OF REGENERATIVE SUSTAINABILITY AT THE NEIGHBOURHOOD SCALE

### 4.1 *Overview*

This paper started by articulating regenerative sustainability concepts including key aspirations, principles and frameworks mainly for the building or site scale, followed by a review of an actual application at the building scale (CIRS). The scale of analysis was then expanded to the neighbourhood and urban scale, including a scan of predominant urban sustainability approaches, urban morphology and metabolism to identify further insights relevant to neighbourhoods regarding both p*rocess* and *performance.* This section summarizes early insights as well as some propositions and emerging questions for further research.

### 4.2 *Process*

Applying regenerative sustainability principles at the neighbourhood scale means engaging *with,* as a part of, the mutually beneficial co-evolution of living systems and the technological support systems. Since neighbourhoods are dynamic and constantly changing, it also means engaging with neighbourhoods at key intervention points (e.g. major development projects, policies and bylaws, etc.) and with the on-going life of the neighbourhoods, including their constituents, relationships and surroundings (e.g. catalyzing the on-going capability for regeneration).

Recognizing the complexity of the urban fabric and unique qualities of each neighbourhood, an effective co-evolutionary process will also be unique to each neighbourhood. Therefore, pre-determining 'the' process for engagement, or planning, is not recommended. Notwithstanding this, generic project processes may be useful as a 'point of departure' for planning a specific intervention or project, for example, EcoDistricts' five phases (e.g. district organization, district assessment, project feasibility, project development, district monitoring (PoSI, 2012) or Plaut et. al's phases of a project's life cycle: discovery/conception, design/gestation, implement/birth, operate/life, decay/death and the beginning of a new cycle (Plaut et al., 2012). Other emergent, co-creative processes have been developed and applied (e.g. see Mang and Reed 2012, Hoxie et al, 2012). Further explorations of emergent, co-creative processes are warranted. For example, an exploration of Roger's diffusion of innovation theory (Rogers, 1962) may be informative in this context.

Based on this review of emerging regenerative and neighbourhood-scale sustainability theory and practice, the following process principles are proposed for further consideration and development:

*Place-based Narrative.* Sets an overarching net positive, motivational frame and connects with the unique story of place, or 'essence' of the neighbourhood and its surroundings. Recent related research as well as initial experience with the Regenerative Neighbourhood Project suggests that simply 'changing the story' from a sacrificial frame to a motivational frame can increase engagement in aspects of sustainability (Gifford and Comeau, 2011). Research and early applications also suggest that this guideline takes on more importance with scaling up as neighbourhoods can be more influenced by people and place than individual buildings.

*Highly Participatory, Relevant and Resonant.* Genuinely engages diverse people and place, and develops resonance with the unique expressed values, goals and needs. It utilizes dialogue and integrative multi-stakeholder processes to co-create integrated systems solutions (analogous to an integrative design process at the building level, but engaging the more diverse range of stakeholders that exist at the neighbourhood scale).

*Potential-seeking.* Aims for the unique 'net positive' potential of people and place, in part through provocative, inspiring questions and goal-setting. Creates clarity of meaning and purpose associated with the key aspirations and principles of regenerative sustainability at the neighbourhood scale (see Section 4.3).

*Capability enabling.* Relies not only on one-time restoration (e.g. a building that net sequesters carbon in its structure), but also on catalyzing the on-going 'capability' of self-organizing socio-cultural (including economic) and ecological systems towards net positive outcomes. This is analogous to a 'net positive social capital' directed towards the potential for net positive co-evolution of human and natural systems. The distinction is also significant in that it shifts the perspective from seeing the primary role of the built environment as one of product, to one of catalyst for co-evolution and net positive human and environmental outcomes.

*Adaptive and Transformational*. Processes for engaging with neighbourhoods will become more connected to the dynamic urban systems within which they reside, adapting to their unique context and transforming themselves (and their surroundings). For example, different infrastructure systems will need to respond to this co-evolution by optimizing at different scales (McGregor et. al, 2013) and be supported by further analysis, testing and adaptation.

Further practice and research is needed to test the appropriateness and efficacy of each of these suggested principles in the context of neighbourhoods. Other questions include, for example, what impact can 'changing the story' to a motivating 'net positive' aspirations and specific goals for neighbourhoods? How can these process principles enhance community engagement and project design processes? What are the barriers preventing regenerative sustainability aspirations and principles from taking root? Which systems optimize at which scales?

4.3 *Performance Assessment*

Regenerative sustainability performance assessment at the neighbourhood scale is still at the nascent stage. Early ideas support (a) an overall systems approach that integrates all biophysical, sociocultural, technological, institutional aspects and identifies relationships between these aspects (e.g. in a 'story of place') (e.g., Cole 2012; Mang & Reed 2012; Hoxie *et al.,* 2012) and (b) qualitative and, where possible, quantitative indicators as well as net positive targets. Given the systems-based approach inherent in regenerative sustainability, the emphasis is on the former. Overemphasis on metrics can result in fragmented and sub-optimal systems solutions.

There is, however, a discourse attempting to identify some measurable indicators and 'net positive' targets that are widely applicable and flexible enough to allow unique, integrated systems solutions, and help facilitate comparisons and learning across networks of neighbourhoods. An initial synthesis follows, based on the frameworks outlined above and the experience with CIRS (with examples of suggested shifts in emphasis associated with scaling up to neighbourhoods in brackets):

*Biophysical/environmental: Energy*, carbon and climate (e.g., emphasis on urban form/spatial pattern, transportation systems, mixed use and energy sharing, district energy systems); water (e.g. emphasis on stormwater management, regeneration of aquatic ecosystems; optimized scale for wastewater treatment); materials management (e.g., neighbourhood re-use and up-cycling opportunities), food & nutrients (e.g., emphasis on urban food systems and nutrient cycling (e.g., phosphorous); biodiversity (e.g. emphasis on habitat regeneration and a wider range of species) and air quality (e.g., indoor *and* outdoor air quality). Applying regenerative sustainability at the neighbourhood scale should also offer cost savings through elimination, downsizing, or delaying of redundant municipal infrastructure due to building and building-to-building solutions.

*Human/Social:* happiness (e.g., emphasis on inter-personal connections in private and public spaces); physical and mental health (e.g., emphasis on spatial patterns, active transportation, connectivity and community-building amongst diverse stakeholders); learning, education, arts and beauty (e.g., public art, art-based place-making); housing (e.g., accessible and affordable housing for all); diversity and social justice (e.g., emphasis on decreasing economic, institutional and behavioural barriers, attention to non-motorized public spaces); safety (e.g., attention to safety in public and private, indoor and outdoor spaces) and transportation (e.g. neighbourhood connectivity with sustainable urban transportation systems).

In line with the discussion, the following characteristics are suggested for an assessment tool:

- Whole systems: assesses integrated systems (including socio-economic, ecological/biophysical, technological, institutional) as opposed to only system-by-system; sector-by-sector; or department-by-department;
- Participatory/Diverse Stakeholders: engages diverse stakeholders in co-creating objectives, interactive feedback and evaluation;
- Embraces Ambitious Goals: able to track progress towards 'net-positive' goals including qualitative and, where possible, quantitative indicators;
- Comprehensive: addresses a representative wide range of interdependent human/social and environmental systems and including the capability for on-going regeneration;
- Generic enough to track progress over time and facilitate comparisons and learning between neighbourhoods, yet flexible enough to be tailored to the unique places; and

- Simple, elegant and intuitive (so the 'essence' of neighbourhood and regenerative sustainability is not obscured).

Further critique, development and testing of assessment tools represent a challenging and important field. How can performance assessment tools make use of already-developed sustainability assessment frameworks and tools? How can an assessment framework(s) be embedded within an appropriate regenerative sustainability process?

## 5. CONCLUSION

The exploration of regenerative, 'net positive' sustainability at the building scale has yielded some encouraging results (e.g., CIRS on UBC Campus) but has also uncovered some of its limitations. Early findings suggest that the neighbourhood scale is an appropriate scale, or 'niche,' within the broader urban fabric to further explore and apply regenerative sustainability principles.

This paper has expanded the range of interconnected issues involved by considering neighbourhoods in their dynamic urban context. Suggestions have been provided to inform process and performance considerations for engaging in regenerative sustainability at the neighbourhood scale.

Recognizing that millions of socio-economic transactions inevitably shape urban neighbourhoods, applying regenerative sustainability at the neighbourhood scale will require engaging a diverse citizenry in integrated, participatory and placed-based processes. In addition to exciting new opportunities for design professionals, successfully applying regenerative sustainability at the neighbourhood scale should engage a diverse array of expertise and interests (e.g. citizens, local, regional and senior governments, land developers, public health officials as well as finance, local business and civil society representatives). Exploring the potential and practicalities of new institutional, socio-economic and technological models should be considered.

With UBC's Regenerative Neighbourhoods Project, we envision a rich applied research space that builds on, synthesizes and advances these and related emerging ideas.

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# Positive Development:
# Design for Urban Climate Mitigation and Ecological Gains

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ABSTRACT: Positive Development (PD) theory reframes sustainable planning, design and decision making within an open systems and eco-positive framework. PD posits that buildings can go beyond regeneration and resilience over their life cycle to increase the net ecological base beyond pre-industrial conditions through, among other principles, building-generated eco-services. As architects and a biologist, as well as with substantial inter-disciplinary expert support, we applied PD concepts, methods and tools to a building design to test whether a future architecture could mitigate the urban climate while increasing environmental quality, ecological carrying capacity and access to the means of survival. Given data and time constraints, this paper only calculates when the building could potentially amortize its embodied and operating energy, water usage and carbon emissions. The conclusion is that buildings that support substantial 'ecological space' for soil, vegetation and micro-biodiversity could potentially make net positive contributions to both humans and nature.

## 1. INTRODUCTION

The paper documents an analysis that was undertaken to determine if a building could sequester carbon equivalent to that emitted in its construction and operation by building integrated vegetation, and generating energy and water surplus to usage. The potential net positive ecological impacts (relative to pre-industrial conditions) were also considered, but could not be included in this short paper.

### 1.1 *Background*

Cities, and the built environment generally, are not yet sustainable by any definition. Their designs do more harm than good to the life support system, and exacerbate most environmental problems and 'natural' disasters (e.g., flooding, earthquakes, urban heat island). Conventional sustainable development standards and tools do not yet contemplate construction that makes measurable, net positive contributions to ecological sustainability. Leading-edge positions aim to leave the environment better than under current site conditions (Lyle 1994, DuPlessis 2012, Cole 2012). However, remediation or regeneration of the environment is not enough, as the real world context has changed dramatically. Given rapidly diminishing resources, an exploding population, increasing disparities of wealth and biodiversity losses (the food chain), built environment design must do far more than regenerate the ecology on the construction site.

A fundamental paradigm shift is necessary from what is now called 'sustainable development' to net Positive Development (PD). PD theory provides a 'positive' re-formulation of policies, decision systems, design concepts, models, analyses, methods and metrics (Birkeland 2008). It is virtually the opposite of the 'negative' dominant paradigm (DP). Simply put, PD holds that to be sustainable, given existing ecological and social deficits and population growth, built environments must not only add social, cultural and economic value, they must give back to nature more than they take (Birkeland 2003). This means increasing ecosystem carrying capacity and the public estate (access to means of survival and well being). Although cities are a major cause of sustainability issues (Girardet 1996) they can be converted into drivers of sustainability. Cities can provide the space and infrastructure to increase passive or natural systems and services and replace many non-renewable resources, at no net loss of space for human activities and functions, as the present design shows as one example. The PD Sustainability Standard is defined as pre-industrial ecological conditions in the bioregion and/or site (on a floor area or ecological footprint basis) as a benchmark for the net positive impacts that a development would need to provide in order to reimburse the future for past and present impacts through increases in the ecology, ecosystems and eco-services [Appendix 1]. Eco-services are nature's services, like clean air, water, food, carbon sequestration and oxygen production, but include the intrinsic values of nature (Cf. Birkeland 2009 a & b for examples). Eco-positive design criteria follow logically from this benchmark (Birkeland 2008, pp. 257-8) and were applied to this project.

## 2. THE PROJECT

Given the ongoing impacts of cities and construction processes, retrofitting cities is essential to sustainability. However, some new buildings will always be necessary and they are more challenging in terms of PD criteria. Therefore, this exploratory research applied some PD methods, tools and metrics to a new building design. An extensive literature search did not reveal a modern building that attempts to increase the natural life support system or access to the means of survival in absolute terms. While a demonstration project for net PD was designed for a site in Canberra, Australia (ANSI 2007), it was suspended by the economic downturn of 2008 [Appendix 4]. The present research was based on a site in Brisbane, with a subtropical climate and therefore a very different design.

The research question was whether architecture could mitigate the urban climate and increase the natural life support system in measurable ways. This research quantifies some of the photosynthesis, air and water treatment functions of extensive integrated vegetation. This paper, however, is limited to carbon emissions, water cycles, embodied and operational energy and not ecological aspects or carrying capacity (forthcoming). The quantitative analysis found that a building can *conceivably* reverse these impacts through passive solar and renewable energy systems that exceed resource autonomy and by providing substantial 'ecological space' (see below). The study concludes that a conventional architecture cannot achieve this Sustainability Standard. A new eco-positive paradigm for environmental planning, design and assessment is required.

Inter-disciplinary integration and collaboration are an essential part of any sustainable design process. The positive and negative impacts relevant to water, carbon and energy were assessed with the assistance of research partners with different specializations. The authors are grateful for the support and expertise of many firms and individuals for their expertise, including: Environmental Scientist Dan Potter of Chenoweth Environmental Planning on pre-clear vegetation communities; Patrick Campbell of WSP Built Ecology on energy balance and photovoltaics; Dominic Xavier and Elena Bogdanova of Sustainable Solutions International (SSI) on water balance; Delwyn Jones, Evah Institute, for life cycle assessment; architects including Peddle Thorp Architects, Brisbane for constructive feedback; Department of Environment, Research and Development for pre-clear vegetation datasets, historical surveys, maps and other information; Dr. Mirko Guaralda of the QUT in Brisbane, Australia, for advice. None of the above is responsible for the content of this paper.

2.1 *Site selection and analysis:*

PD seeks to identify urban projects that can address urban social and ecological shortfalls and overshoots, and benefit the society and ecology as well as investors. In this case, the selected site is a 28 hectare remnant of land which was, prior to the establishment of Exhibition Grounds, used since 1862 by the Queensland Acclimatisation Society to promote the introduction of economically useful 'foreign' plants, materials and animals. This site was suitable for increasing indigenous ecosystems through physical development. The proposed use was a sustainability research and learning hub to facilitate collaboration between industry, researchers and the community on sustainability issues. An Interpretive Centre, in proximity to the Brisbane CBD, could also catalyze the social and economic revitalization of this derelict, transport-dominated and fragmented area. Therefore, a wide range of social, educational and cultural uses and values were incorporated in the design. Ecological Transformation Analysis was applied as one of 12 PD planning analyses designed to address some information gaps that would be required for ethics-based planning and design [Appendix 3]. It maps the original site ecology to guide the reintroduction of endangered species and appropriate vegetation, and to increase environmental flows (Cf. Sanderson 2009). Quantitative measures of on-site water and original rainfall data were available from historical maps and surveys and the Bureau of Meteorology. No water bodies currently exist on site, but the earliest available survey (1863) shows a creek and waterholes. This guided the location of proposed streams and biotopes and provided useful parameters for increasing appropriate soil, water and ecosystems. Indigenous plants indicate what ecosystems may be successful on the site. Predominantly three broad vegetation communities existed on this site before European settlement. Their biodiversity status is all 'of concern' or 'endangered', so these are supported by the immediate landscape and building design. The precise species of the building-integrated 'Gallery Rainforest' depend on size and soil medium of the atriums, walls, sunlight, temperature, moisture, as well as maintenance issues.

2.2 *Some design features*

The design aims to create a 'living ecosystem' that is experienced with all human senses. The environmental systems are meant to be integral with the architecture, provide services to humans and nature, and made visible for educational purposes. Some features are as follows:
Green Space Frames double as exterior walls and interior/exterior spaces. The modules harvest water and use natural systems to generate clean air, food and soil through, for example, vertical wetlands and aquaponics. The double skin walls and atriums include passive environmental controls for heating, cooling and ventilating, provide oxygen-enriched air for the occupants, and increased ecological space for ecosystems and biodiversity, which partially compensates for the land coverage.

The modular design allows for future changes in building functions or building size and can reduce costs. Although an organic form, the modular system frames internal buildings and atriums and provides multifunctional space for both human activities and natural systems. The external skin of Ethylene Tetra Flouro Ethylene (ETFE) foil provides natural lighting and allows plants to grow inside, offsetting some costs of the 'double skin' [see Appendix 4]. The atriums serve as exhibition spaces and can be expanded into the space between the inner and outer shells for special events.

Food production is integrated within the space frames on rotating trays, with pullies, that optimize sunlight for organic food production. These have precedents which assist in approximating energy requirements (AVA 2011). Some roof gardens also provide food, improve the thermal properties of the building, and reduce the urban heat island effect. The structure creates an open ground level, allowing the landscaping to flow through and avoiding slab on ground which disturbs soil life - a vital ecological resource. Due to poor soil productivity, vertical composters could be included on site. Water for the farming and landscaping is provided through catchment, storage, and passive water treatment systems that demonstrate bioconversion processes where ecosystems of micro-organisms treat wastewater and grow food or fish while providing environmental amenity (Todd 1994).

2.3 *Some assessment issues*

There have been rapid advances in building product certification tools. However, most green designs, products or production systems increase total resource flows, even if at less impact than the norm or per unit of production. Technology selection has positive or negative ripple effects through society, so the ethical implications are important. For example, new products can cause other products to be disposed of before their time for reasons of fashion. Therefore, the Hierarchy of Eco-innovation was applied to product and technology options to predict their potential to have positive system-wide ecological and social impacts [Appendix 2]. Since 'up-cycling' to a higher use usually refers only to a higher economic value, so 'eco-cycling' is added which aims for higher ecological impacts and reduced total resource flows.

ETFE foil is an example of difficulties in environmental product declarations. Product assessment generally does not consider space. Space does not embody energy, only its structural envelope does. The operating energy of buildings can largely be met by passive design. Therefore, 'embodied' energy, ecology and waste will be of growing importance in building performance. ETFE foil scores relatively well in these areas. It provides a transparent external skin which allows plants to grow inside. It has multiple values, such as being produced from agricultural waste products, having a long life span, comparing favorably to many other means of indoor thermal control, enabling the use of natural lighting and ventilation and allowing views of vegetation from the exterior and interior. It also provides automated climate and glare control through intelligent offset printing, which causes only a small reduction in light transmission (Architen Landrell Associates 2009). New construction cannot reduce total resource flows, but the double skin created by the ETFE foil can be offset by space for ecosystems and eco-services (ecological space) between the skins.

While the assessment of ecological costs and benefits are not discussed in this paper, it is important to note that one cannot amortize species extinction or offset biodiversity losses with, say, energy gains. Energy cannot actually be increased according to the 2nd law of thermodynamics, but if passive design and renewable energy produced in the development exceeds the embodied and operating energy used, energy can, in a sense, be amortized. Ecosystems may eventually return to a rough equivalence in biodiversity and complexity, but the recovery time of ecosystems must be considered (Birkeland 2007) [Appendix 2]. Methods for assessing ecosystem services in landscapes are advancing (Wang 2012), but assessing building integrated eco-services in buildings is not well developed to date. In this paper, a pragmatic measure, 'Ecological Space', has been used which is simply the space dedicated to ecosystems in or on the built structure in relation to gross floor area (discussed below). A potentially very detailed approach for assessing eco-services is the Eco-positive Design Tool or 'starfish' [Appendix 1]. This paper introduces a method for determining the Carbon Amortization Point, which is an extension of the Eco-Positive Design Tool.

## 3. QUANTITATIVE MEASURES

Once basic design concepts were developed using PD analyses and tools, quantitative tools were applied to the schematics to estimate the energy, water and carbon balance. At the time of writing, LCA has not been used to determine either net positive impacts or eco-services. LCA is not a design tool as such, as it can only be applied to a completed design. However, '$CO_2$ equivalents' can be used in LCA for environmental impacts where a uniform database is needed for comparison. While limited, this surrogate can provide preliminary results to assess the potential contribution of eco-services. Hence, quantitative evaluation included Life Cycle

Benefit Analysis (LCBA), which measures reductions in negative impacts, and now estimates carbon sequestration and oxygen production (Jones 2011). Both the 2.8 ha site of the project area, and the entire 28 ha site were evaluated.

### 3.1 *Building Information Modeling (BIM)*

The organic form of the building was modeled in the pre-release Revit plug-in Project Vasari and then imported into Revit Architecture for further development. Because the building is modular, data could be multiplied by the total number of building modules. A typical module, including an atrium, was exported as an IFC file for life cycle assessment with LCADesign® software in BIM based collaboration with the Evah Institute. The results showed the approximate total negative impacts per square meter, by comparing the default and eco-preferred materials. To include some of the positive impacts, green spaces, as carbon sinks, were used to establish approximate values for $CO_2$ sequestration and oxygen production. Variations occur for plant-related data, since sunlight, water and nutrient conditions must be optimized during operation. However, the calculations provide an estimate for the contributions of building-integrated vegetation in LCA. As a result of this collaboration, the Evah Institute has added photosynthetic oxygen generation data to the life cycle inventory database (Jones 2011). Some performance factors are provided below.

## 4. PERFORMANCE

### 4.1 *Exceed energy autonomy*

*Embodied energy:* Many assessment tools ignore embodied energy, but it would be the main energy factor if passive design in buildings eliminated operating energy as the built environment now uses more energy than manufacturing (in the USA). Low-cost simulation tools for predicting building performance do not adequately simulate passive systems to date. The Evah Institute quantified the approximate embodied energy from the imported Revit model per square meter of materials (Table 1). The results are subject to further refinement to calculate the total impact. Higher embodied energy can occur in the building *fit-out* than in the structure itself, but multi-criteria eco-labeling systems are available to help select eco-efficient products (Ecospecifier 2011).

Table 1. Embodied energy/m$^2$

| Material | Energy [MJ/m$^2$] |
|---|---|
| Steel structure | 350 |
| External walls | 200 |
| Timber frame | 90 |
| Wall cladding | 90 |
| Curtain wall | 110 |
| Curtain wall components | 110 |
| Floors | 150 |
| Shell | 350 |

*Operational energy:* The Australian Building Greenhouse Rating Reverse Calculator (NABERS 2010) was used to estimate operational energy use, as recommended by WSP Built Ecology. This tool applies to office buildings, but delivers an estimate for present purposes (Table 2). It is based on net rentable area, hours of operation and number of computers. WSP Built Ecology considered that the energy use of a 5 star NABERS rating would be reduced by 40 per cent in this project. This reduction was used in the estimated energy use and associated greenhouse gas emissions (GGE) of the building.

Table 2. Results of estimated energy use and greenhouse gas emissions for the building using the Australian Building Greenhouse Rating Reverse Calculator (Version 5.1)

| | |
|---|---|
| Net Lettable Area[1] | 8,000 $m^2$ |
| Hours of operation ≥ 20%[2] | 60 |
| Number of computers[3] | 500 |
| Max allowable Electricity use | 1,412,403 kWh/yr x 0.6 = 847,442 kWh/yr |
| Electricity GGE[4] (raw) | 1,440,651 kg $CO_2$/yr x 0.6 = 864,391 kg $CO_2$/yr |
| Gas GGE (raw) | 24,564 kg $CO_2$/yr |
| Gross GGE | 888,955 kg $CO_2$/yr |

[1] Excluding atriums and space frames which are without artificial lighting/air conditioning
[2] Based on average assumption including visitors on weekends
[3] Interpreted as average for computers and other technology such as LED screens or projectors in the conference facilities. Laboratories are not expected to have a significant energy consumption as new technology is mainly tested. If applied to the building it is expected to contribute to the overall surplus balance.
[4] Greenhouse gas equivalents [as $CO_2e$]

*Renewable energy sources:* The large roof areas of the Interpretive Centre and existing on-site buildings make PVs a suitable renewable energy source. Based on NABERS, WSP Built Ecology determined the size of the photovoltaic system needed to balance energy expenditure, (Tables 3 & 4). The pay back (in money and embodied energy) for photovoltaic systems (PV) and wind generation is being rapidly reduced. Since fossil fuels cannot pay back their externalities at all, they are prohibitively expensive from a rational economic perspective. On a similar project site for Peddle Thorp Architects, Brisbane, WSP Built Ecology showed that the financial payback period for a 340 kWp system is now between 6.9 and 8.1 years, and larger systems shorten payback periods (WSP Built Ecology 2011). At this time, wind power is most efficiently produced in centralized sources, but distribution losses, embodied energy, and energy security must also be considered. Wind power can later be added in the urban farm on the site.

Table 3. Available roof area for photovoltaics ($m^2$)

| Building type | Roof area |
|---|---|
| Interpretive Centre | 5,500 |
| Existing buildings on entire RNA site | 60,000 |

Table 4. Photovoltaic array size and performance for Centre

| Capacity (kWp) | Area ($m^2$) | Electricity Offset (kWhpa) | GGE Offset (tonne /yr) |
|---|---|---|---|
| 690 | 5,500 | 1,000,000 | 1,020 |

*Energy balance:* The available area for PVs would be sufficient to offset 15 per cent more than the total carbon emissions produced by the building itself annually. Available roof areas (6 ha) from existing buildings on site could generate over ten times this amount to increase the surplus. The surplus provides a reserve for embodied energy and potential active technologies. Energy expenses for renovation and demolition were not quantified herein, but the modular system allows for change, adaptability and reuse. The energy balance is shown in Table 5.

Table 5. Energy balance/yr

| | Electricity (kWh) | GGE (kg $CO_2$) |
|---|---|---|

| | | |
|---|---|---|
| Emission | 847,442 | 888,955 |
| Offset | - 1,000,000 | - 1,020,020 |
| Total | - 152,558 | - 131,045 |

4.2 *Exceed water autonomy*

*Embodied water:* The Evah Institute established embodied water estimates on a per square meter basis for the building materials using LCADesign® software. As with embodied energy, the figures are subject to multiplication to calculate the total impact (Table 6).

Table 6. Embodied water (L/$m^2$)

| Material | Embodied water |
|---|---|
| Steel structure | 40 |
| External walls | 30 |
| Timber frame | 10 |
| Wall Cladding | 10 |
| Curtain wall | 25 |
| Curtain wall components | 22 |
| Floors | 5 |
| Shell | 40 |

*Water consumption:* The water balance study for the site was assisted by Sustainable Solutions International (SSI). Consumption was estimated on the basis of typical wastewater flow allowances AS/NZS 1547:2000 App. 4.2D (Standards Australia 2000, see Table 7). The value for community halls was used for the expected visitors. For staff, the allowance was doubled because of longer working hours. Water is collected, stored on site and treated in alternative systems before returning to nature.

Table 7. Wastewater flow user allowances (L) Interpretive Centre

| Occupants/use | Per capita/day | Gross/day | Gross annual |
|---|---|---|---|
| 1000 Staff | 40 | 40,000 | 14,600,000 |
| 500 Visitors | 20 | 10,000 | 3,650,000 |
| Total | | 50,000 | 18,250,000 |

*Water recycling and vegetation usage:* Alternative water treatment, such as Living Machines or Solar Aquatic Systems, is for irrigation only, due to current regulations. Using SSI estimates these systems are comparable to wetlands recycling an annual average of 50 L/$m^2$/day at 800 mm depth. Because it currently cannot be used by occupants, water recycling from alternative systems is not included in the water balance in Table 11 below. For vegetation alone, SSI estimated water needs would be on average 15-25 mm/$m^2$/week.

The amount of rainfall/$m^2$ on average equals 25 mm/$m^2$/week. The transpiration rate and rainfall are well correlated throughout the year. We assume, in line with the potential production difference between landscaping and indoor vegetation, that the latter will use twice as much water per unit of land as the former. Approximately 600 $m^2$ alternative water treatment systems are integrated immediately with the building. An additional large portion of the entire site can be used for vegetation in retrofits of existing buildings and urban farming. The total irrigation requirements for the 4,000 $m^2$ building-integrated ecological space are shown in Table 8.

Table 8. Water recycling requirement from alternative systems (L/yr)

| Ecological space ($m^2$) | Required irrigation[1] ($L/m^2/day$) | Recovery factor [2] Volume = V (L) | Required area[3] ($m^2$) |
|---|---|---|---|
| 4,000 | 5.72 | V * 1.33 | 609 |

[1] Based on 40 $L/week/m^2$ for indoor vegetation
[2] Based on 75 per cent recovery rate
[3] Based on annual average of 50 $L/m^2/day$ at 800 mm depth

*Water harvesting:* Rainfall data were obtained from the Bureau of Meteorology (BOM 2007). Average rainfall for the site is 1200 $mm/m^2/year$ (1 mm rainfall = 1 L $water/m^2$). SSI confirmed catchment volumes of 95 per cent for rainwater and 30 per cent for storm water in Brisbane which includes runoff only, not water absorbed by soil and plants (Tables 9 & 10).

Table 9. Annual rainwater and storm water catchment Interpretive Centre

| Type | Area ($m^2$) | Volume=V(kL) | Total (kL) |
|---|---|---|---|
| Rainwater | 5,500 | 1.2V*0.95 | 6,270 |
| Storm water | 22,500 | 1.2V*0.30 | 8,100 |
| Total | | | 14,370 |

Table 10. Annual rainwater and stormwater catchment remainder of the site

| Type | Area ($m^2$) | Volume=V(kL) | Total (kL) |
|---|---|---|---|
| Rainwater | 60,000 | 1.2V*0.95 | 68,400 |
| Storm water | 200,000 | 1.2V*0.30 | 72,000 |
| Total | | | 140,400 |

Table 11. Water balance Interpretive Centre (kL/yr)

| Water | Quantity |
|---|---|
| Harvesting | 14,370 |
| Occupant use | - 18,250 |
| Total | - 3,880 |

*Water balance:* Almost 80 per cent of the water use requirements can be harvested. However at least 20 per cent or 3,880 kL needs to be sourced from the larger site area in order to achieve water autonomy for the immediate 2.8 ha site of the Interpretive Centre. Alternatively, the volume captured could be increased by evaporative collection from the humid air in Brisbane using commercially available products. Additional active technology could be considered. According to SSI, passive aerobic sand-filtration plus further ultra-filtration treatment would be suitable for toilets to comply with the current requirement for A+ water quality. These technologies can achieve a 95 per cent recovery rate with electricity usage of 0.35 kWh/kL. The drinking water would require Reverse Osmosis with a recovery rate of 50-60 per cent. This would result in an increase in electricity usage by 2.5 kWh/kL. The 15 per cent surplus energy from the PV system allows for high-tech water treatment if necessary.

*Water surplus:* A large surplus of water can be achieved for the entire 28 ha site from the existing roof areas. For practical purposes, this should be used for the deficit of the Centre rather than investing in active technology. Assuming that the occupants' water use in existing buildings on the site is similar to that of the Centre, more than 120,000 kL/yr would still be available for the Interpretive Centre and to support retrofitted ecological spaces in the other buildings on site. Water consumption of 20 L/m$^2$/week (SSI) for vegetation on average amounts to approximately 1,000 L/m$^2$/yr. This means the 120,000 m$^2$ water consumptive area that would be created is 30 times greater than the 4,000 m$^2$ internal ecological space in the Centre (Table 12) and could be used for additional urban farming on the site.

### 4.3 *Carbon and oxygen*

*Ecological Space:* The ecological space provides many eco-services, but cannot be used to offset deficiencies in building energy performance or vice versa. Building integrated and external Ecological Space is listed below. Divided by the Gross Floor Area (GFA), ecological space per m$^2$ can be established (Table 12). As described earlier, this does not capture ecological values but can serve as surrogate until adequate assessment methods are available.

Table 12. Ecological Space

| Ecological space | Area (m$^2$) | ES / m$^2$ GFA* |
|---|---|---|
| Green Space Frame walls | 2,500 | |
| Roof gardens | 700 | |
| Vertical Urban Farming | to meet demand | |
| Atriums | 800 | |
| Total | 4,000 | 0.32 |
| Landscaping site | 19,600 | |
| Total incl. landscaping | 23,600 | 1.89 |

* Based on 12,500m$^2$ Gross Floor Area (GFA)

*Sequestration:* It was rare to see carbon sequestration accounted for in LCA until 2010, when Ecospecifier took qualitative steps towards this approach (Jones, 2011). In order to measure some of the positive impacts of the ecological spaces, the Evah Institute generated the figures in Table 13 for carbon sequestration and oxygen production. These results were further refined by the authors. This LCA modeled 15,000 kg plant growth/ha/yr for landscaping and 90,000 kg/ha/yr for indoor vegetation (dry weight production).

The value for landscaping was calculated for the immediate site of approximately 2.8 ha of the 28 ha site. 16 trees currently exist on this part, and an additional 34 would be planted to help restore endangered species. Glasshouse vegetables in rotating planter boxes can be included in space frames, roof gardens and vertical urban farming areas for the restaurant and local organic markets. However, these cannot be claimed as C-credits as their carbon is not embodied long term. Replacing them with vines, such as *Jasminum* species, *Pandorea pandorana* would produce some C-credits.

The figures show that the building-integrated ecological space and landscaping may sequester 120,009 kg $CO_2$/year and produce 87,280 kg oxygen. The figures would need to be reduced by the percentage chosen for food production, and by a proportion according to lignified stem and root tissue.

Table 13. Carbon sequestration and oxygen production (kg/yr)

| Crop Type | Biomass Yield BY (kg/ha/yr) | C (kg/ha/yr) | kg $CO_2$e per kg C | Area A (ha) | $CO_2$ sequestered[1] (kg/yr) | $O_2$ produced[2] (kg/yr) |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| 1. Indoor vegetation (36,000 kg/yr) | 90,000 | 45,000 | 3.67 | 0.40 | 66,060 | 48,044 |
| 2. Landscaping (29,400 kg/yr) | 15,000 | 7,500 | 3.67 | 1.96 | 53,949 | 39,236 |
| Total | | | | | 120,009 | 87,280 |

[1] Carbon sequestration: $CO_2e$ (kg/yr) = BY (kg/ha/yr) / 2 * 3.67 * A (ha)
[2] Molecular weights oxygen/carbon dioxide: 32/44 (molar quantities each side photosynthesis equation)

## 5. CARBON AMORTIZATION POINT

The Carbon Amortization Point Method (Figure 1) constitutes a call-out of the Eco-Positive Design Tool to evaluate the overall energy balance and carbon sequestration (Renger 2004). It can determine when different buildings amortize their embodied and operational energy and surplus gains begin. $CO_2$ equivalence, although inadequate as an ecological surrogate, can capture many other positive and negative impacts. Figure 1 illustrates the general approach, represented by linear functions for simplicity. Passive solar design and *surplus* energy from renewable systems, plus $CO_2$ sequestration can provide a net positive carbon outcome over the life cycle. Energy amortization can be achieved earlier in the lifecycle by including substantial vegetation. The calculations are subject to further refinement.

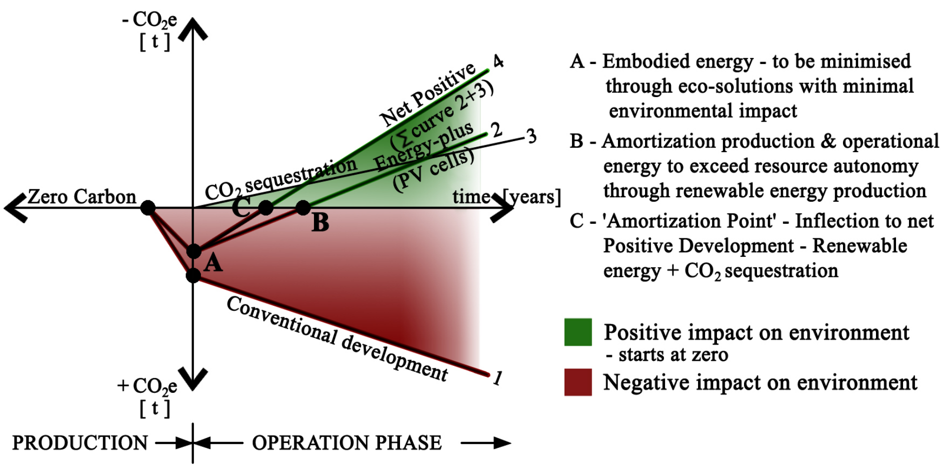


Figure 1: Carbon Amortization Point Method (cumulative balance)

## 6. SUMMARY AND CONCLUSION

The Eco-Positive Design Tool was used to approximate points on a spectrum from net negative to net positive (in relation to pre-industrial conditions and ecological footprint per floor area) as a design aid for increasing multiple eco-services [Appendix 1]. Although ecological space and eco-services were a part of this research, only carbon, energy and water are discussed here. For LCA purposes, $CO_2$ equivalents were used, as data on ecosystems, eco-services and other beneficial functions are not yet adequate. The 'Carbon Amortization Point' method expands on this design tool where energy production and carbon sequestration needs to be evaluated or compared to other buildings. Both tools can also be used for quantitative evaluation.

Net energy, water and carbon were quantified for the immediate 2.8 ha site of the Interpretive Centre, although the entire property size is 28 ha. The available roof spaces in on site buildings for PVs and the reduction in energy demand made an energy ‘surplus’ of 15 per cent possible. The water balance showed a deficit of 20 per cent but this could be increased through passive, active or low-tech technologies (such as dew harvesting). If water from the entire site is used, there would be more than 8 times the water required. However, that remaining area could be developed in the future, so it cannot be relied upon. Carbon sequestration calculations showed that approximately 120 tonnes of $CO_2$/yr could be sequestered by new vegetation alone, or 13.5 per cent of the building's estimated operational emissions through energy use. The vegetation would also produce approximately 87 tonnes of oxygen annually.

Conventional 'sustainable' design and assessment tools, despite advances, do not adequately take into account the ecology or encourage multi-functional and synergistic design for eco-positive impacts. This exploratory study shows that a building could achieve zero carbon impacts early in the life cycle by integrating renewable and passive systems for building and environmental services. Thereafter, it could generate eco-positive gains. Successful architecture has been characterized by its social, cultural and economic benefits, but this research points to the potential for architecture to also mitigate the urban climate and increase the ecological base. PD methods, models and metrics open a new research area for many disciplines within the building industry, as it addresses the need for a net increase in the life support system and improving universal life quality.

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## APPENDIX 1: ECO-POSITIVE DESIGN TOOL (STARFISH DIAGRAM)

Spider diagrams, generated by a simple spreadsheet program, are useful in visualizing multi-criteria analyses. As each spoke in the 'web' can have a different scale, only a couple of measurements on each spoke are needed. Thus, impacts need not be reduced to one kind of unit such as energy, money or carbon. The diverse impacts of a design are displayed visually, and can be converted to a single number to compare designs, if necessary. Spider diagrams have been used in life cycle analyses, however only measure reductions in negatives that might have otherwise occurred in a typical building. In fact, life cycle analyses usually score from '-1' (very bad) to '0' (zero harm). If a reference building is used as '0' and one measures improvements to best practice or better (+1), this is equally misleading . Neither create incentives for synergistic design that has net positive onsite and/or offsite benefits. Net impacts can be assessed by placing positive, negative and less negative impacts on the same spectrum. The eco-positive 'starfish' diagram measures from '-1 to 0 to +1' (Birkeland 2010, 2012).

In the example below, there are 7 distinct points on the spokes of 24 different eco-services, to estimate the benefits of 'Design for Eco-services'. The benchmark is pre-industrial conditions, represented by the inner circle ('0') on the diagram. If all pre-existing eco-services on the site were destroyed and not compensated for in some way, the center (-1) to the inner circle (ie. from -1 to 0) would be dark. The outer circle ('+1') is the floor area times the original eco-services per unit of volume or impact. '+1' therefore represents the 'target' eco-services for the building. Floor area is important because a green roof on a one story building would only reduce a fraction of the ecological impacts of a ten story building.

Both negative impacts and reductions achieved by efficiencies are assessed. Then, eco-positive impacts are added which could be created by multi-functional design synergies. For example, water storage can serve as insulation, fire prevention, air cooling, a visual or noise barrier, and so on (green roofs or Green Scaffolding could perform over two dozen beneficial functions). A retrofit that remediates the region's air or water might qualify as net positive in air and water treatment. While an overall +1 in any eco-services would be hard to achieve, a project could conceivably compensate for its impacts and have net positive offsite impacts (beyond '+1').

Energy can be used to illustrate the difference between a reduction and a gain. A 75% percent 'reduction' in energy over typical buildings is a net increase in energy use and carbon emissions. Likewise, an energy autonomous building (ie. 0 operating energy) that sells energy to the grid is not necessarily an energy positive building. Green energy purchases are a reduction in energy but not a gain and thus should not count as surplus energy (also one would need to know the use of the energy). Using passive solar design and renewable energy systems, the building could eventually 'pay back' the embodied energy used in construction and thereafter generate a surplus. If a renewable energy system is set up on site before construction, energy used to construct the building can be paid back sooner.

### *1.1 Example of Starfish Diagram in relation to water*

Let us imagine how a building can increase water beyond pre-industrial conditions, even where negative impacts are deducted.

1. A dark area from '-1' to '0' means all water entering naturally or existing on site is polluted or lost.
2. A lighter area from 0 towards -1 represents the water used in construction and operation that is restored using onsite natural systems. This 'reduces' the dark area.
3. '0' (pre-industrial conditions) would be the amount of water that would enter the site under natural or indigenous conditions and not be contaminated.
4. The dark area from '0' towards '+1' represents offsite water that is contaminated by a development, or water piped into the development and not remediated.
5. The lighter area between the outer circle (+1) and inner circle '0' represents offsite water that is cleaned onsite using natural systems (beyond that used by the project) and returned to nature.
6. The outer circle (+1) is the indigenous eco-services times the total floor area (which might include a stream that is uncovered and restored).

7. The part of the starfish outside the +1 circle represents 'surplus' eco-services such as water drawn from air (in an overly humid climate) using passive evaporative collectors.
8. The spreadsheet program then produces the net positive impacts. Coincidentally, a theoretically perfect development would look like a sun emblem.

The diagram only shows ecological impacts, but ethical and social issues could have their own diagrams and be overlaid digitally to measure total performance.

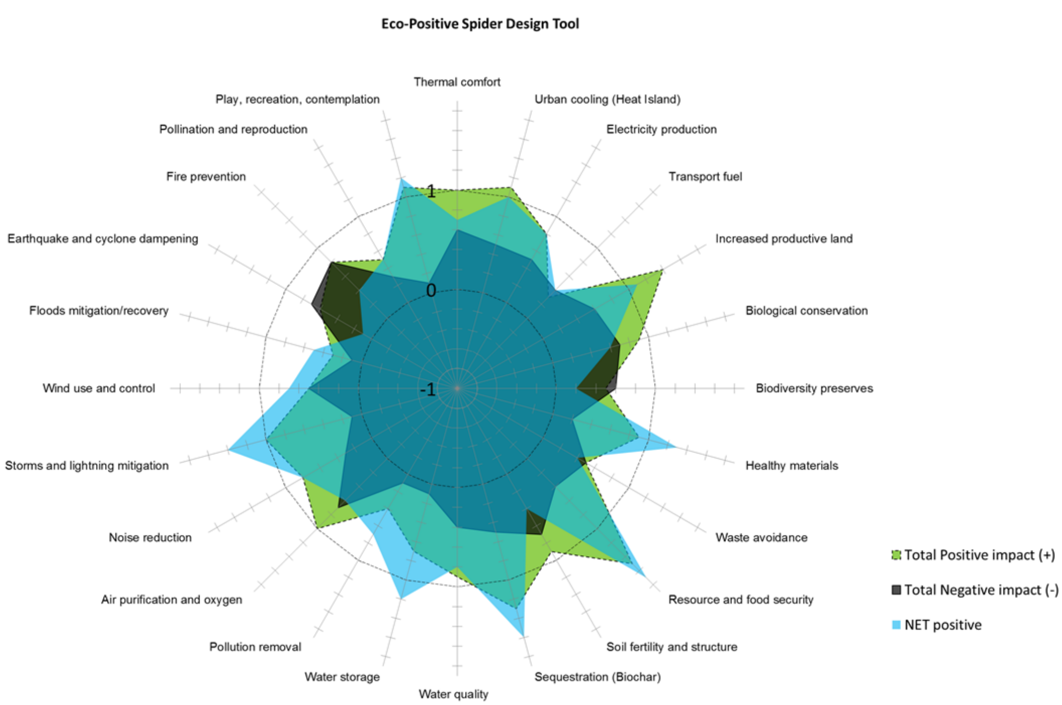
APPENDIX 2: HIERARCHY OF ECO-INNOVATION (HE)

HE Analysis is an ethics-based means for assessing the public values of alternative designs and technologies (from Birkeland 2008). Most assessment tools look at efficiency or energy, which is not the same as ethics, ecology or the public good. HE Analysis considers the net effect on total resource flows and total ecological health. Unlike rating tools, HE Analysis allows design ideas to be self-assessed during the design process before investments in a particular design or irreversible decisions are made. Design strategies are assessed according to their potential to influence system-wide ecological and social gains from ‘ordinary’ (1) to ‘eco-positive’ (6) as follows:

1. New designs, products or production systems that increase resource flows, but at less negative impact per unit than the norm, only reduce the relative impacts of future actions.
2. Innovations that reduce the impacts of waste from ongoing processes or activities, through reuse, recycling or re-assembly, can still involve some waste and a reduction of use value, or ‘down-cycling’.
3. Innovations that reduce the impacts of past development (toxins or waste in the environment) add economic value, but ‘up-cycling’ could mean an increase in conspicuous consumption.
4. ‘No-loop’ refers to innovations where waste is ‘designed out’ of an existing, ongoing or future system entirely. This could still create unnecessary products or have a rebound effect, where the resource savings are spent on harmful activities.
5. Eco-cycling is up-cycling that contributes to human and ecological health (ie is net positive) and does not increase total resource flows. However, this may still not increase access to the means of survival and resource security – the public estate.
6. Net positive innovations improve whole systems and increase both the public estate and ecological base. They can be at the building or system level:

   (a) Net Positive Development reverses existing impacts and increases the ecological base and public estate beyond pre-industrial site conditions.

   (b) Net Positive Systems innovations create levers for biophysical improvements and social transformation at the ‘glocal’ scale (eg. converting cities from fossil to solar).



APPENDIX 3: SYSTEMS MAPPING AND REDESIGN THINKING (SMARTMODE)

Planning analyses do not yet provide critical sustainability information for community empowerment, such as who wins and who loses over time. Our development control mechanisms, such as project assessment and approval processes are still poor at considering impacts in their regional and cumulative context. Sustainability-relevant information is rarely collected and mapped, because there is a tendency to use information that is already available, which was originally collected for purposes of economic growth - not ethics or ecology. SmartMode (Birkeland 2008) is intended to address such omissions in planning processes, and create transparency around resource transfers, metabolic flows, and power differentials amongst stakeholders and the general public that influence or are affected by planning decisions. SmartMode is built around a number of 'forensic audits' that aim to identify future proof planning and design solutions to improve the health of humans and ecosystems. Currently there are over a dozen analyses to generate information necessary for ethics-based decisions. Public participation in planning has always featured in planning literature (though not all countries), but it is increasingly hard to implement as tools and methods become more complex and arcane. Today, powerful multi-dimensional digital mapping tools are becoming available that can enable citizens to visualize complex SmartMode information (Jackson and Simpson 2012).

*'Institutional Design (ID) Analysis'.* ID Analysis is an advance on regulatory impact assessment, which generally only analyses the 'economic' costs and benefits of environmental regulations. The impacts of economic policies or regulations on the ecology, and/or the impacts of environmental degradation on the economy itself, are seldom considered by legislatures, let alone economists. ID Analysis would trace the actual outcomes of regulatory and market-based mechanisms and compare these to the predicted outcomes of economic policies on the ecology and vice versa. It can also show a lack of correspondence between (costly) decision systems and overall reductions of water, energy or greenhouse emissions. For example, shifting 'transaction costs' (eg. paper work) to the private sector can conceal the overall costs of regulatory and market-based environmental systems. That is, the apparent savings in costs of governance may not save society money. The alternative is to encourage 'direct design' solutions.

*'Ecological Transformation (ET) Analysis'.* ET Analysis compares the pre-industrial site conditions to the post development site and the 'ecological space' relative to the floor area. It establishes the Sustainability Standard: the net positive impacts that a development needs to create in order to compensate the future for past losses. Because most tools only look at future impacts of development proposals, they effectively treat current urban conditions as a neutral baseline - although already ecologically negative (ie. in the red). Moreover, most tools only count the costs that will be incurred from the present time. ET Analysis charts changes in ecological conditions over time and why these occurred. This helps to guide appropriate ecosystems, eco-services and 'regionally appropriate' design. In the USA, Canada, New Zealand and Australia, given their long pre-European settlement, a suitable frame of reference may be the regional ecosystem that evolved before European times.

*'Highest ecological use (HU) Analysis'.* Development control systems respond to proposed projects. These are usually irreversible, close off future options, and can only be 'mitigated' by public planning. Instead, planners could identify the best ecological use of land and determine potential land uses and projects that would make everyone better off, while also future proofing the urban environment. HU Analysis is would facilitate this 'proactive' approach by mapping the original geology, hydrology, biodiversity and so on, to better match land uses to ecological functions. Most future proofing activities (aimed at reducing the chance of floods, droughts, urban heat islands, storms, etc) can be compatible with and even enhanced by development. Through eco-positive design, most local endangered species and ecosystems can be protected without compromising the economic viability or aesthetics of the development.

*'Ecological Waste (EW) Analysis'.* EW Analysis was devised to address misleading claims from waste management and resource extraction industries. Many industries and government agencies now publish relative improvements over time, but not in the context of total resource flows and irreversible change. EW analysis would take into account the time and space that actual ecosystems need to regenerate, as opposed to just the replacement cost of the resources. For example, re-growing a forest is not a replacement for a forest ecosystem, so the figures seldom reflect the full impacts of old growth forestry. EW analysis, by including restoration time, helps to assesses ecosystems for their intrinsic values and ecosystem functions, as well as their services to humans. The elements of time and space are necessary to expose the

vulnerability of essential elements of the bioregion in order to increase ecosystem resilience.

*'Resource transfer (RT) Analysis'.* RT Analysis would determine and map the distributive impacts of resource allocation patterns over time, to help people visualize the effects of development on accessibility to resources, security and health. Financial flows are rarely if ever tracked in social impact assessment (SIA) or material flows analyses (MFA). MFA and SIA can assess cumulative negative impacts and their distribution. But while they look at effects of physical changes, they do not show how development concentrates control of resources and increases disparities of wealth over time. Some negative impacts are considered like exposure to pollutants or lack of amenities and open space, as in 'equity mapping', but resource security or accessibility to means of survival are seldom mapped. For example, instead of closing schools to save money, they could be retrofitted to serve distributive functions, such as recreation or community centres and/or urban farms which double as refuges in case of disasters.

*'Costs of inaction (CI) Analysis'.* CI Analysis (popularized by the Stern Report) would take into account the 'opportunity cost' of *lost* natural areas and resources, and the economic benefits of an undisturbed natural environment. Traditionally, the economic costs of preservation and restoration were counted as a negative, but their economic benefits were not factored in. In fact, things that save money and help the economy, like eco-services and green infrastructure, are undervalued in development assessment, not simply because they are complex, but because they are mistakenly 'seen' as mere benefits to nature and not to humans. Taking action to future proof cities is seen as a gamble, like buying insurance, even though it would have physical benefits that pay off - even if no disaster occurs. That is, it is seen as a cost instead of an investment (some of the required data would now be available from insurance corporations). Inaction due to risk-benefit calculations are evidence of a lack of design thinking, as risks can always be reduced by design.

*'Negative Space (NS) Analysis'.* NS Analysis aims to find optimal opportunities for positive planning interventions in urban areas. It is also an indicator of the deprivation of (private or public) spatial and environmental amenity. However, it targets improvements rather than limiting negative impacts, as green infrastructure requires little net resources beyond maintenance. NS Analysis can map the conversion of open space to private development or the conversion of 'the commons' to private use and control (and vice versa). This can help to identify distributional impacts of existing over-developed urban areas that could be ameliorated by open space or green infrastructure. Similarly, 'environmental space', the available renewable resources divided by the relevant population (proposed by Friends of the Earth) can be used to determine places where compensatory spatial and environmental amenities are needed.

*'Source of Energy (SE) Analysis'.* SE Analysis uses a 'multiplier for energy sources' to link energy consumption to the damage caused by the source of power itself (eg. coal, oil, gas). This is because the amount of energy used is often not as important as the source. Studies have established, for example, that there is enough solar energy to replace fossil fuels and meet all human needs, and passive solar design can provide most heating, cooling and ventilating requirements in buildings. SE Analysis adjusts energy figures which do not reflect the full costs of externalities, since full cost pricing is unlikely to occur in a market economy. For example, full cost pricing is often applied to renewable energy sources but not to fossil fuels (subsidies to fossil fuels are still labelled as 'investments'). Cumulative impacts of energy sources can be virtually mapped in a way that makes the real costs of energy sources transparent.

'*Development/ Design Functions (DF) Analysis'.* DF Analysis addresses development review processes. It takes development 'purposes' into account in impact assessment, in part by separating efficiency and value. The purposes of developments are seldom subjected to competitive alternatives, because any proposal that gets across a line will be approved. This is in part due to the ubiquitous Pareto Optimum which holds that people should be allowed to do anything that does not (unduly) harm others. DF Analysis recognizes that the inherent purpose of an efficient design may ultimately not be good for society as a whole. The zero waste 'green bomb' and eco-efficient cigarette factory are cases in point. Even an eco-efficient system could delay the transition to whole systems improvements, because it leads to the continuation of a sub-optimal parent system. For example, recycling has sometimes created vested interests in waste streams.

# APPENDIX 4: ECO-POSITIVE DESIGN ILLUSTRATIONS

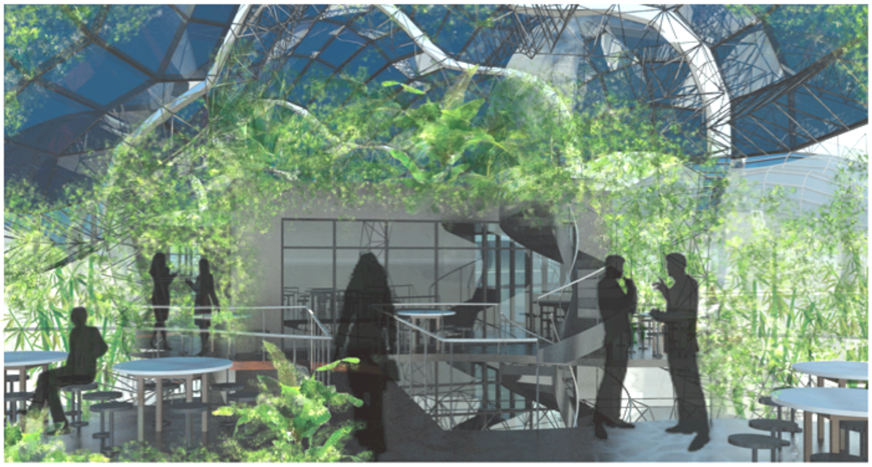


Figure 1. Sustainability Centre Proposal for Brisbane designed and rendered by Christina Renger.

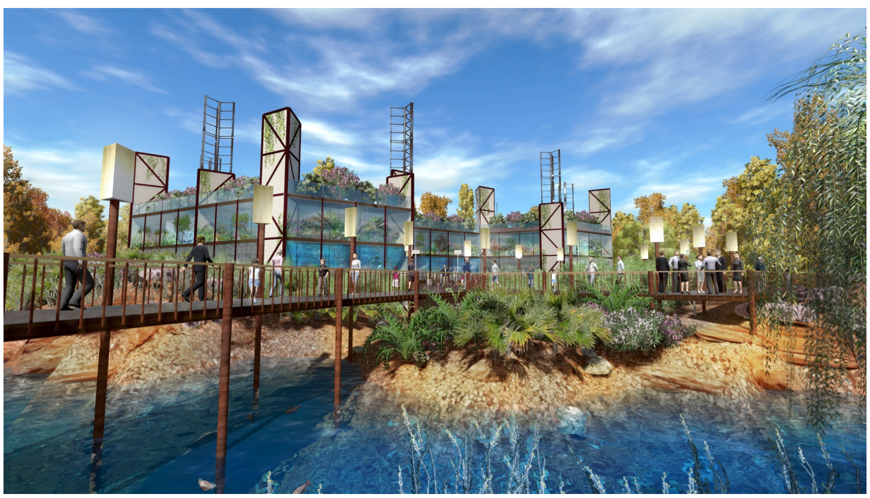


Figure 2. ANSI Sustainability Centre Proposal, by Birkeland and rendered by David Wong (student)

Some of the attributes of the designs (for different climates) include:

- Green space walls support natural systems that provide environmental and building services, and protect small animal and plant life in modules that double as walls
- The structural system is modular and can be constructed off site to gain the savings of prefabricated constructions, and be expandable or demountable over time
- The open plan, modular design and versatile exterior walls can be easily modified over time to integrate unanticipated changes in technology or society.
- The plan has commercial areas with additional floors for office and low-cost eco-hotel accommodation for students. Whole floors could even be added or removed
- Internal atriums, space frames and roof greenhouses provide thermal functions and collect or distribute warmth and coolness and also create internal garden-like work spaces
- Modules are individually climate controlled and face multiple directions to show that buildings can be solar heated in any orientation
- Ecosystems can be moved to other parts of the building if the microclimate proves unsuitable. They preserve endangered ecosystems and provide for research studies

- Modules containing ecosystems will be managed by the local herpetology and entomology societies and/or other community groups, while providing 'living wallpaper'
- Ventilated eco-modules have different kinds of exterior screens controlled by interior sensors that roll down as needed, including a storm curtain
- Food production such as vertical urban farming can be integrated with the structure, creating employment opportunities and produce for local restaurants
- Modular walls include some ceiling height gabions containing small rocks to collect and store solar heat in winter, and circulate it throughout the building
- A suspended walkway through an indigenous bird, mammal, insect and reptile species terrarium helps to integrate indoor and outdoor living with visual amenity
- The structure respects the soil. It is off the ground (with under-floor insulation). It uses vertical thermal mass for heating and cooling, which is provided in certain walls.
- The structure 'floats' on the site above the flood level, allowing the landscape to flow through the building.
- The vertical structural trusses that support the space frames only require punctual concrete footings in some cases.
- The modular structure provides a visually unifying framework, so different materials and insulation methods can be displayed without creating a cluttered effect
- Buildings and grounds utilize literally dozens of new eco-innovations that apply to eco-retrofitting as well as new buildings
- The internal spaces are cooled via ducts in the vertical triangular trusses from under the building, and/or through water storage cisterns
- The water treatment system circulates through interpretive Living Machines on site that are powered by children's play equipment and accompanied by an adult par course
- Rainwater is treated in 'solar cone' type collectors for use in the building and for cooling mists in particularly hot weather

# The Centre for Interactive Research on Sustainability, UBC: Creating Net Positive Benefits at Multiple Scales

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ABSTRACT: This paper examines three key ways in which the Centre for Interactive Research on Sustainability (CIRS) building at the University of British Columbia is expected to provide 'net positive' benefits to the environment and its inhabitants. First, while CIRS has added a 5,800m$^2$ building to the UBC campus, it reduces campus energy use and carbon emissions, and causes a reduction in potable water demand for the campus. Second, the CIRS building has been designed to produce a suite of benefits and engagement opportunities that are designed to increase the health, productivity and happiness of its inhabitants. Third, the project not only responds to its immediate micro-site requirements, but also is intended to have positive environmental and social impacts at the community scale. The paper presents the design features embedded in the building that collectively support net positive performance, the efforts underway to monitor performance through time and the range of supporting research initiatives.

## 1. INTRODUCTION

### 1.1 *Centre for Interactive Research for Sustainability (CIRS)*

The Centre for Interactive Research on Sustainability (CIRS) is a 5,800m$^2$ building on the campus of The University of British Columbia (Figure 1) that was designed to operate at the frontier of sustainable performance in both environmental and human terms, and serve as a living laboratory of, and research test-bed for, sustainable practice over its lifetime. CIRS achieved occupancy in September, 2011. From the outset, the design of CIRS was guided by the desire to be Green, Humane and Smart, and achieve net positive performance in both human and environmental terms (regenerative sustainability). These overarching notions have defined a set of specific performance goals. This paper will explore the potential ways and extent that these guiding principles and goals shaped the design of CIRS and the subsequent direct and indirect consequences for the anticipated building inhabitants. Moreover, since CIRS aims to be highly replicable, the paper will identify the extent to which these approaches are different from conventional practice and transferable to other situations and building projects. Although the CIRS program extends beyond typical green building technologies and practices, this paper focuses on the building design and implementation.

The CIRS building is intended to provide 'net positive' benefits to the environment and its inhabitants. First, while CIRS adds to the UBC building stock, it was designed to reduce campus energy use and carbon emissions, sequester more carbon in its structure than required to build the building and reduce the campus demand for potable water[xi]. This is intended to be supportive of UBC's long-term goal of showcasing the Vancouver campus as 'the world's first net positive energy and water campus. An effective, integrated energy and water plan will be critical to success in that venture.' (UBC, 2008) Second, the CIRS building has been designed to produce a suite of benefits and engagement opportunities that are designed to increase the health, productivity and happiness of the inhabitants. Third, the project not only responds to its immediate micro-site requirements, but is also intended to have positive environmental and social impacts at the scale of the district or community.

*Figure 1: Centre for Interactive Research on Sustainability, UBC (Perkins+Will, 2011/Photo: Martin Tessler)*

### *1.1.1 Environmental Characteristics*

The use of onsite renewable energy and other fortuitous energy supply options derived from the surrounding context became an important strategic choice after all possible energy efficiency and passive strategies had been pursued. Based on LEED energy modeling performed by Stantec Consulting in August 2010, energy use in the building is expected to be 78 kWh per square metre of floor-space (gross) per year. Once unregulated energy uses have been subtracted to allow comparison, this is roughly equivalent to the German Passivhaus and Swiss Minergie Label standards. Onsite renewable energy options (building integrated PV cells, a solar thermal hot water system, and a ground source heat pump (GSHP) system sized to the building cooling load are place-specific – dictated by the seasonal climatic variations and any modifying effects resulting from the surrounding physical context. Fortuitous energy sources and exchange opportunities are also place-specific and dependent on the ways and extent that the energy profiles of an adjacent building and associated heating system match that of the one being designed.

The CIRS building captures waste heat exhausted from the nearby Earth and Ocean Sciences (EOS) building, satisfying its remaining thermal needs (over those provided by the GSHP and solar hot water systems) and then returning excess back to EOS. Since this reduces natural gas use at the university's central steam plant by more than the total amount of electricity purchased for CIRS, the overall effect is to reduce the university's overall energy use. And since that purchased electricity is much lower carbon than the natural gas burned in the university's steam plant, this also reduces the campus' carbon emissions.

CIRS relies entirely on rainwater to meet its potable water needs, and all the wastewater generated in the building will be treated on-site and recycled in the building to meet non-potable water requirements. Rainwater falling CIRS that cannot be used as a source of potable water for the building is redirected into an infiltration well that recharges the local aquifer, eliminating storm water discharges from the building. Because of advantageous economies of scale, the CIRS wastewater treatment system was designed to treat roughly four times the amount of wastewater generated in the building which enables CIRS to import sewage from surrounding buildings and return reclaim-quality water to campus for non-potable applications, thus reducing the campus demand for water.

Finally, CIRS is also designed to be net positive in structural carbon. The building structure sequesters more carbon than all the carbon emitted in building and and in manufacturing all the furniture, fixtures and fittings found in the building.

### *1.1.2 Human/Social Attributes*

CIRS aims to provide a socially and biophysically healthy environment for human habitation which adapts to changing needs and uses over time, and which contributes to a continuous improvement in the health, productivity and happiness of building inhabitants. In addition to offering fully daylit, wood-intensive, and naturally ventilated interiors, the project provides opportunities for inhabitants to connect with others through informal meetings and interactions, to the natural world with views to living things, and to the campus by permeable campus pathways that invite people to pass through parts of the facility. It allows inhabitants to share ideas and food in its on-site sustainable food café and its generous and accessible meeting spaces. Finally, the building will provide not only real-time display of building performance for all environmental systems, but also the ability to vote on controls strategies for the building. The goal is to convert building occupants (i.e., passive recipients of building technologies), into inhabitants with a sense of place and engagement with the building.

### 1.2 *Synergies*

While a university campus allows opportunities not often permissible in most contexts that architects operate, CIRS nonetheless is illustrative of the opportunities and potential implications of how design strategies can offer multiple environmental and social benefits beyond the boundaries of an individual building. In order to achieve the potential offered by the synergistic biophysical and social links outlined above, the building program must engage with a host of sociocultural factors such as a willingness to accommodate renewable energy, matching of energy quality to operation use, enabling inhabitants to understand energy processes and adjust the systems to meet their changing needs, developing programs that allow building operators to interact with building inhabitants and meet performance goals, etc. These factors in turn intersect in complex ways with the net positive human system goals of CIRS.

The CIRS building allows testing of the hypothesis that there need not be a “scalar contraction” between aspirations and realities in the design profession – environmental synergies support the mutualistic co-evolution of sociocultural and ecological systems and provide evidence that regenerative interventions are possible at the scale of a single architectural commission. As a “living lab” in which changes will continue to be made over the life of the building, the CIRS project does not attempt to guarantee a certain future but to enable the emergent flourishing of both human and environmental systems that permits choice, creativity, exploration and adaptability. Its unfolding performance and consequences will be fully monitored and documented, and such feedback mechanisms used to support the notion of emergence and a co-evolutionary process. A major goal is to document and learn from these engagement processes.

### 1.3 *Transformation of Process*

All of the key aspects of the CIRS vision—the inter-institutional academic partnerships, the relationship with non-academic partners, the governance structure, the sustainability goals, the building design process, obtaining funding, negotiations between capital and operating costs in new ways—involved going beyond standard operating procedures for UBC and other partners. Moreover, mobilization of the various stakeholders and industry partners required the development of new partnership models based on principles of mutual benefit and synergy of goals. The transformation they underwent as they began to realize and fulfill their critical role in the integrated design process of CIRS became a lasting legacy of the process. (Brown *et al.*, 2009) The shift is evident in the larger process of campus planning in which CIRS has become enmeshed.

Partly as a result of the discussions engendered by CIRS' plans to scavenge heat from a neighbouring building, and partly because of a strong tradition of sustainability analysis and planning that has been established at UBC over the past decade, UBC has adopted an approach to campus planning that envisions the whole campus as a test-bed for sustainable energy, water, waste and food systems (Robinson, *et al.*, 2013).

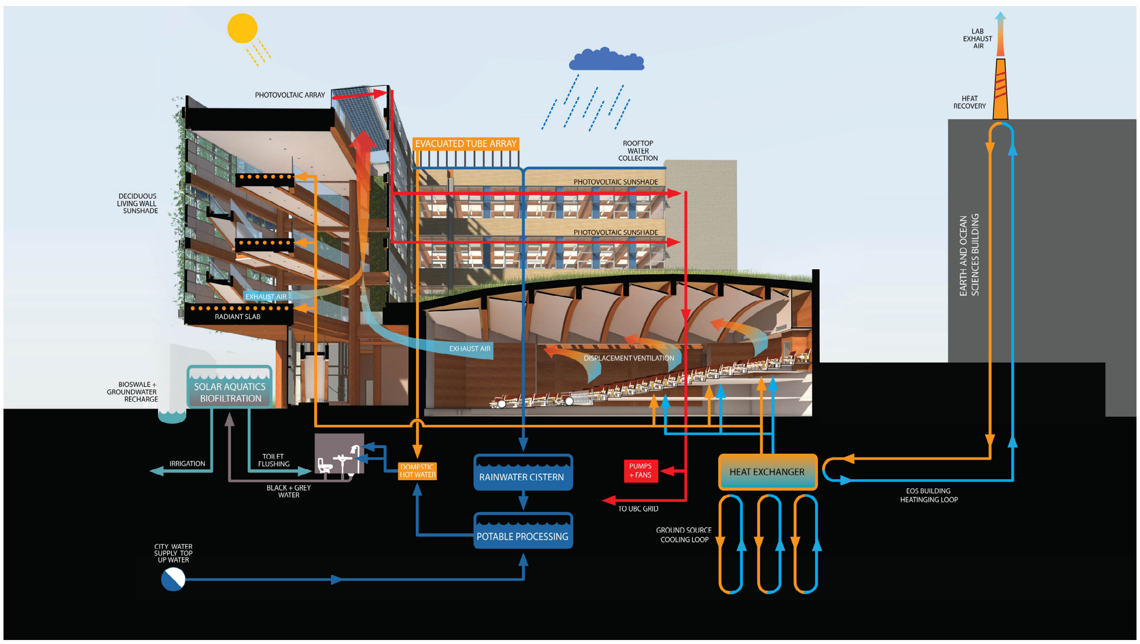


*Figure 2: CIRS Environmental Systems (Perkins+Will, 2011)*

## 2. DESIGN FEATURES SUPPORTING NET-POSITIVE GOALS

To meet the CIRS vision and agenda, the building itself is used as a research laboratory for operations, monitoring and assessment of energy and water use, daylight harvesting, indoor environmental quality and inhabitant behavior. To determine operating conditions of the building, over 3000 points of monitoring have been implemented in CIRS to measure total energy use and $CO_2e$ emissions, total water use, captured waste energy from EOS, harvested solar and geothermal heat, PV electricity produced, grid electricity consumed, energy use by different building systems (lighting, HVAC, plug loads, etc.), heat returned and accepted by the EOS building, as well as its associated natural gas savings and $CO_2e$ emissions, energy savings associated with natural ventilation and day-lighting strategies, rainwater treated and supplied to the building, wastewater treated and reused in the building, and storm-water runoff redirected into the local aquifer, among others

The design process engaged the active participation of the user community, including researchers as well as public and private sector partners. The CIRS progressive regenerative process stands as an example of an explicit recognition of the need to engage social and behavioral dimensions of comfort, as well as the potential for improved dialogue and communication to improve building performance. Not every goal for CIRS was achievable with present technologies at reasonable cost on opening day. But the CIRS facility was not 'finished' the day it opened; it has been designed for change over time, adopting and adapting new technologies. The overall goal is continuous improvement over time in human and environmental conditions.

### 2.1 *CIRS as 'Green'*

Moving beyond providing a building that is "less bad" than conventional practice, the CIRS goals were to have a positive impact on both the local and global environment, while living within, and contributing to, the biophysical flows available on its own site. The specific Green design goals for CIRS that were developed through an integrated design process and several charrettes were (www.cirs.ubc.ca):

1. Design with time in mind:

- Climate Change: Heating, cooling and water systems designed to adapt to anticipated changes in climate over the next 100 years.
- Life Cycle Analysis: Building structure and systems are to be evaluated and designed over a time frame of 100 years.

2. Zero materials waste:

- Design for assembly, modification, and disassembly.
- Avoid toxic materials.
- Materials choices informed by life-cycle analysis of environmental impact, including embodied energy and greenhouse gas emissions—minimize $CO_2$ emissions associated with construction.
- Design a materials-handling strategy for supplies and components entering the building over their life that seeks to eliminate solid waste going to landfills.
- Process all liquid 'waste' into pure water and useful feed-stocks.

3. Energy use has a net positive impact on ecological health:

- CIRS facility will reduce the overall UBC campus energy use.
- Direct energy consumption target: 75 $kWh/m^2/yr$ overall, 15$kWh/m^2/yr$ for heating.
- Building operation should be greenhouse gas neutral.
- Efforts will be made to balance the scale and quality of the energy used with that required for the task.
- All energy used in the building should come from clean and renewable or scavenged energy sources.

4. Ecological health:

- The facility should be able to live on the budget of the rain falling on its site.
- Efforts will be made to balance the quality of the water with that required for the task.
- Water leaving the site should be as good or better quality than when it arrived.

• Site design should provide a net positive impact to the ecological health of the surroundings.

• Net increase of biomass on site.

• Zero net runoff from site.

Many of these demanding performance requirements, while context dependent, extend beyond the footprint of the building to embrace the larger campus. The consequences of the Green goals and strategies on building inhabitants are captured in the following "Humane" and "Smart" sections.

2.2 *CIRS as 'Humane'*

CIRS aims to provide a socially and biophysically healthy environment for human habitation which adapts to changing needs and uses over time, and which contributes to a continuous improvement in the health, productivity and happiness of building inhabitants.

Specific design goals included:

1. Ongoing assessment of inhabitant comfort:
• On an ongoing basis, assess the interaction between the environment provided by the building and the health, productivity, and happiness of those who work and visit it.

2. Outstanding IEQ:
• Provide a comfortable, healthy environment for inhabitants, under local control to adapt to individual differences and differing activities:
  - Air that meets or exceeds outdoor air quality.
  - Light levels and quality appropriate to tasks, with the option of relying on natural light whenever available and appropriate to the task.
  - Provide for acoustic separation and privacy.
  - Provide areas for the preparation and sharing of food: deal with food human waste in ways that recognize them as an environmental opportunity

3. Connections within and beyond:
• Provide opportunities for inhabitants to connect with each other and the world:
  - Connect to the natural world: views to living things, breezes.
  - Connect to others in the facility: promote informal meetings and interactions.
  - Connect to the campus and world: be permeable to campus pathways to invite people to pass through parts of the facility and share food and ideas:
    > on site café (emphasizing 100-mile diet options when available).
    > conference, teaching centre, walk-through accessible.

The physical form of CIRS was profoundly shaped by these humane concerns:

• Narrowed floor plates ensure that all workspaces are daylit.

• A pleasant view of the green roof of the atrium is visible from office and lab spaces on upper floors.

• Inhabitants have access to ventilation, lighting and temperature controls.

• A breezeway cuts through the lobby and atrium, providing a covered pedestrian walkway and promoting public access.

• A café located on the entrance level engages the campus community and disperse the sustainability values of CIRS while providing an interaction hub for building inhabitants.

• A 60-seat auditorium presents visualizations of regions and communities in future climate scenarios, drawing the public to CIRS and to UBC campus in the interest of sustainability research.

• 3,000 monitoring points inside the building consistently monitors and assesses how the building is meeting inhabitant needs and comfort standards.
• The innovative strategies are visible, accessible and understandable to inhabitants and visitors.

In addition to the wide-reaching humane goals noted above, a program of active engagement of people working in CIRS has begun to be developed, in accordance with the objective to convert 'occupants' to 'inhabitants':

• Every person working in CIRS will sign a Sustainability Charter, committing them to engaging with the process of creating a socially and environmentally regenerative building. The Charter is not expected to directly affect inhabitant behaviour, but to contribute to creating a stronger sense of community among inhabitants.

• CIRS offers a suite of benefits and engagement opportunities to all inhabitants. These include individual control of ventilation at their work stations, access to real-time feedback and monitoring of the building's technical systems and performance (including the opportunity to express preferences about operating conditions), high levels of air quality, a work environment characterized by wood, access to natural light, social spaces for interaction, and a sustainable food services outlet.

Inhabitants thus play a critical role in the success of the building and its community while experiencing the attributes of a workplace intended to optimize inhabitant comfort and productivity.

2.3 *CIRS as 'Smart'*

CIRS seeks to integrate building performance with the performance of inhabitants in an ongoing interactive dialogue intended to improve the green and humane features of CIRS over time. The CIRS building process applies design intelligence augmented with monitoring and feedback to engage building inhabitants to get the most out of the available energy and material flows afforded by the site and its surroundings. 'Smart' is defined in terms of four key attributes: adaptiveness, responsiveness, effectiveness and economic efficiency. Feedback is considered key to ensuring the building systems and inhabitants are responsive and adaptive to changing internal and external conditions and needs. Detailed, ongoing monitoring is instrumental in meeting the 'living lab' vision and research agenda for the building, allowing for the assessment of existing and future building systems and technologies.

CIRS develops approaches towards constructing, operating and maintaining the building and meeting human needs at the lowest life-cycle costs, providing solutions that can be economically replicated and adapted into buildings worldwide. The Smart design goals for CIRS included:

1. Provide instrumentation and controls to allow feedback and learning:
• The building should learn from its inhabitants.
• Deliver comfort where and when it's needed.
• The inhabitants should learn from the building.
• Provide feedback to building operations staff for identifying systems performing poorly.
• Provide feedback to inhabitants as to how their behavior affects energy, water, and material use.
• Allow building inhabitants to express preferences for building operating conditions and procedures.

2. Produce a core building that exemplifies replicable, economical solutions:
• Make design and operation choices based on the lowest life-cycle costs.

• Allow for experimentation with approaches that may not yet be cost-effective.

Elements of the Smart goals for CIRS which have had a direct expression on building design process and form include:

• Inputs from UBC campus stakeholders led to insights into potential synergies with neighboring buildings, existing campus policies, infrastructure constraints and future growth plans for CIRS and for the UBC campus.
• Detailed, ongoing monitoring to:
  - Understand the energy and water flows through and within CIRS, both from quantitative and qualitative standpoints.
  - Understand the interaction of building inhabitants with the range of advanced green strategies and technologies.
  - Understand the impact of immediate and distant contexts on energy and water flows, e.g., heat exchange with a neighboring laboratory building.
  - Compare between building design and actual performance, and feedback on the operational performance of individual and collective systems and technologies.
• The use of a 'biofilter' approach to water treatment based on the compelling nature of the biofilter as an educational tool.
• A daylighting system that establishes a hierarchy of control over shading devices to accommodate inhabitants and different program uses.

Smart attributes of CIRS will have direct and indirect consequences for anticipated building inhabitants, particularly in the ways that inhabitants engage with adaptive opportunities provided to them and received feedback on their actions.

## 3. IMPLEMENTATION AND RESULTS

The planning and design process of CIRS spanned almost a decade. While the sustainable design goals of CIRS remained fundamentally intact throughout this time, the design strategies and local context opportunities changed over time. The site of the building moved from UBC to the Great Northern Way Campus (approximately 15 km away) and back to UBC. The last and final iteration of the CIRS design in 2008 benefited from a set of opportunities that were not available during initial attempts to develop CIRS. First, the Cascadia Green Building Council launched the Living Building Challenge rating system in 2006 which became a catalyst for the implementation of many of the design goals of CIRS. Secondly, the site chosen for CIRS at the UBC campus opened up the possibility of a more direct interaction between CIRS and its community.

CIRS was built on a previously developed site but provided a net increase in landscaped and living systems area that benefits the southeast quadrant of the UBC campus. The design of CIRS also preserved a path that existed before the construction of CIRS which became a breezeway between the main lobby/atrium of CIRS and the transparent Solar Aquatics Bio-filtration wastewater treatment facility. Through its overall water strategy CIRS has established a strong link with the adjacent Sustainability Street infrastructure, benefiting from the 90-metre deep well drilled there that is now capturing for aquifer infiltration and recharge all the surplus rainwater that CIRS cannot use as a source of potable water. The CIRS energy strategy resulted in the capture of large amounts of waste heat from the EOS building which through the return of a substantial amount of heat to EOS via CIRS, provided an opportunity to make EOS more efficient and less reliant on campus-generated steam which is produced burning natural gas. This in turn will result in a reduction in UBC's natural gas use (greater than the increase in electricity purchases caused by CIRS), and a net reduction of UBC's $CO_2$e emissions.

From an architectural program perspective the initial mandate of CIRS as a research and demonstration facility expanded with its 2008 design at the UBC campus. The building program now accommodates the addition of a 425-seat auditorium visited by 2,000 undergraduate students daily and the addition of a sustainable food and operations café run by UBC Food Services The CIRS project team and UBC Food Services partnered to create 'The Loop', a food outlet with very aggressive sustainability objectives such as eliminating the use of plastic bottles and cans, a flexible and reconfigurable space, and a food and menu hierarchy that gives preference to produce originated at the UBC farm and other local sources.

The construction and commissioning of CIRS raised a number of significant challenges in terms of implementation, which remains a work in progress. While many of the technologies used were available off-the-shelf, some of the systems in CIRS, such as the water treatment system, had not previously been implemented at UBC or even in Canada, CIRS had an extremely ambitious program of system integration, requiring the working together of multiple subsystems, such as the various energy efficiency systems, heat scavenging processes and renewable energy technologies, or the combination of rainwater harvesting, wastewater treatment systems and use of reclaimed water.

In many cases, the significant obstacles were not technical or economic, but institutional. It took over a year after building occupancy, for example, to obtain operating permits for the water harvesting and treatment systems. The design team, construction manager, commissioning agent, and now building operators, have all had to learn to work with the integration of novel technologies and systems. System integration gave rise to challenges that could not be anticipated based on the previous use of individual technologies. Some of these, like the small vibrations felt in the atrium long-span connecting bridges, or the water damage to some wooden structural components of the building, could be solved during construction and commissioning. Others, like meeting the design intent of the heat transfer between CIRS and the EOS building, will require retrofits. Others still, like the expansion of the concrete basement of CIRS to accommodate a campus-wide need for storage space, after the structural carbon modeling had been done, will reduce the amount of the net carbon sequestration effect of the CIRS wooden structure and other wood-based components of the building.

Initial results from monitoring the environmental performance of CIRS indicate that the design goals of net positive performance are not yet being met. It is expected that the environmental goals related to energy, operational carbon and water will be met over the next few years, and further work is being undertaken to determine the structural carbon balance. On the human side, while considerable research has started on the behavioural consequences of inhabiting CIRS, the inhabitant engagement program is still under development. As of January 2013, rigorous monitoring had not started on the three net positive goals (productivity, health and happiness) in this area.

## 4. RESEARCH PROGRAM

Research underway at CIRS goes beyond work on the CIRS building itself and focuses on the "performance gaps" between the predicted environmental performance of the built infrastructure and its actual performance; between claimed concern for environmental issues and the actual behavior of citizens; and the implementation gap between the expressed goals of environmental policies, bylaws and plans and actual outcomes. The research explores the gap between "potential" and "performance", acting as a catalyst for the integrated study of processes, strategies, policies and technologies for regenerative sustainability at the building, urban and regional scales. The CIRS building and its interactions with its community on the UBC campus and beyond is being used as a test-bed for this analysis. The CIRS research will be integrated both conceptually and practically and will focus in three areas:

1. *Sustainable Building Design and Operation:* This includes incorporating the process of

sustainable building design and the integration and lifecycle performance analyses of environmentally sustainable technologies, systems, and strategies into the CIRS building, as well as the study of the interplay between the building and its subsystems and the building inhabitants. Energy systems, water systems, and material use, as well as the impact and influence of building inhabitant preferences and behavior will be used to assess building performance and to what degree is CIRS meeting its net positive environmental and human well-being performance goals;

2. *Visualization Tools and Community Engagement:* This includes the study of cognitive and behavioral responses of individuals and institutional stakeholders to new simulation and visualization tools for exploring sustainability issues at multiple scales. This will be underpinned by the creation of an immersion environment (decision theatre) for community engagement that links cutting-edge simulation and visualization techniques with expert knowledge to assess the impact on individual behaviors and policies on sustainability objectives;
3. *Regenerative Sustainability beyond the Building Scale:* This research theme builds on parts 1. and 2., and is grounded on the notion that whenever human activity can be made regenerative, this is preferable to merely reducing damage or harm. This research will study the aspirations and key principles of regenerative sustainability that are beginning to emerge from several converging historical threads, and explore the process of codifying, operationalizing and evaluating regenerative sustainability so that it can be applied at the neighborhood and regional scales. An important part of this research is to identify concepts and methodologies that can inform the construction of a framework that assesses regenerative sustainability at the neighbourhood level. Early findings suggest that while many sustainability assessment approaches exist, few approaches embody regenerative sustainability or are designed specifically to address regenerative sustainability at the neighbourhood level. This research will study the technical, economic, and social dimensions of technologies, systems, behaviours, and policies, as well as integrating qualitative policy analysis with quantitative data and modeling of key relationships among systems.

The cross-cutting objective of the three-part CIRS research program is to accelerate the adoption of more sustainable practices in society by bringing the fruits of the CIRS research into the public, private and civil society decision-making arenas through the implementation of partnerships that demonstrate, replicate, disseminate and commercialize sustainable products, systems, practices, processes and technologies. A recent study conducted at CIRS illustrates this point. Researchers in the Department of Psychology at UBC posed the hypothesis that the unique confluence of above factors creates an environment whereby CIRS actively and intentionally embodies and promotes a message of sustainability. For instance, The Loop cafe at CIRS employs both constraining (e.g., no bottled drinks are available for purchase and all utensils are compostable) and suggestive approaches (e.g., persuasive signs which explain where the food comes from) which could shape and influence user behavior. From the perspective of evaluating the effects of these contextual factors on behavior, CIRS provides the perfect environment to test the idea that being in an environmentally conscious surrounding can elicit environmentally conscious behavior. Researchers tested this idea by secretly observing peoples' food disposal habits as this action involves a decision not constrained by the building itself (i.e., people have to make a decision about where to throw their items). As a comparison, they also observed people dispose behaviour in the eating area at UBC's Student Union Building (SUB), a building that was not designed with sustainability in mind although importantly it has comparable categories of disposal bins. The findings were clearcut: people are much more likely to correctly choose the proper disposal bin (garbage, compost, recycling) in a building designed with sustainability in mind compared to a building that was not. Perhaps the most remarkable finding however was that the researchers also determined through interviews that participants at

CIRS did not self-identify as "pro-environment" and the majority were also regular patrons of the SUB. Patrons of The Loop were at CIRS because of convenience. The effect of CIRS represents a power example of the principle that human cognition and behaviour is 'situated', meaning that real-world contexts can actively and subtly change how one perceives the world and acts within it. In short, being in a sustainable context, acting on objects designed for sustainability induces pro-environmental behavior in CIRS. Convergent with this conclusion the researchers found that the patrons in CIRS rated themselves significantly higher in environmental consciousness compared to patrons at the SUB. Thus this study exemplifies the importance of environmentally sustainable developments. Not only are these developments themselves more sustainable in a physical sense, but they influence a large number of users within them to act and think more sustainably as well.

## 5. CONCLUSIONS

CIRS represents an ambitious attempt to implement a regenerative sustainability agenda at the building and community scale. While the actual degree of achievement of the sustainability goals of the building, both human and environmental, remains to be determined, important lessons have already been reached about the development of design, construction and commissioning processes required to develop and implement such goals. Future work will document these lessons in more detail, and begin to report on the operating performance of CIRS, and how it adapts over time to changing conditions, and the learning of building operators, inhabitants and the building systems themselves.

Through the design, building and operation of CIRS, UBC is exploring the hypothesis that it is technically and financially feasible for buildings to harvest from renewable sources and return to their communities more energy than they take from utility grids; that buildings can live off rainwater (where geographically appropriate), and treat and recycle their liquid waste and generate no municipal storm-water runoff; that buildings can sequester more carbon within their structures than is emitted during the extraction, manufacturing, transportation, installation, and decommissioning of other materials used to build them; that a high quality indoor environment coupled with an active *inhabitant-building interplay* can result in measurable increases in inhabitant productivity, health and happiness; and that regenerative sustainability performance in both human and environmental terms can be achieved cost-effectively and with current off-the-shelf technologies.

Finally, the aggressive floorspace expansion underway at UBC to meet the growing demand for new academic and student housing buildings on campus represents a significant opportunity to implement a "regenerative" building development framework based on CIRS principles that in turn can directly contribute to meeting UBC's overall sustainability objectives and GHG emission reduction targets.

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ENDNOTES

[1] Vancouver Coastal Health did not permit surplus reclaimed water to be re-injected into the local aquifer due to concerns about endocrine-disruptive chemicals and other human-originated pharmaceuticals that cannot be removed by the onsite Solar Aquatic System treatment process. However, the building recharges the aquifer with rainwater it cannot use thus completely eliminating storm-water runoff, and, by treating raw sewage from other facilities and returning reclaimed water back to campus for non-potable uses, it causes a net reduction in campus potable water demand.

# UWM as Zero-Discharge: Pondering Net-Positive Stormwater Infrastructure

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ABSTRACT: In 2006 the Milwaukee Metropolitan Sewerage District funded a stormwater masterplan for the University of Wisconsin-Milwaukee campus with the goal of bringing UWM's 100 year old, 90 acre urban campus to a '100 year/ zero-discharge' standard for stormwater runoff. This plan has led to four signifi cant demonstration projects capturing six acres of hardscape, including vegetated roofs featuring native plantings and integrated photovoltaics; a parking lot treatment train that has transformed a service zone into a wildflower garden; a pair of sculptural cisterns that create a stormwater fountain by diverting the Power Plant's roof drain through the wall in dramatic fashion. This initiative continues with a design for UWM's School of Freshwater Sciences campus that includes spawning habitat utilizing aquaculture process water and other novel attempts to think like nature and maximize healthfulness, ecological productivity and beauty rather than simply reducing the use of this locally abundant resource.

## 1. PROJECT SCOPE

> "Cooperative, compatible, sustainable development is an essential goal of campus planning, and the university has a responsibility to provide leadership to achieve this goal."
> *University of Wisconsin System Campus Physical Planning Principles. September 2001*

The UWM as a Zero-Discharge Zone (ZDZ) plan was undertaken initially as a funded academic research project intending to prove the technical feasibility of transforming our 91 acre urban campus into an ecological waterscape meeting the same stormwater discharge rate for a 100 year storm event as it would have in its pre-(European)settlement state.

The underlying purpose of the study has been to lay the groundwork for an ongoing campaign of demonstration projects intended to both reduce flooding adjacent to the campus and to reduce the campus's contribution to combined sewer system overflows into Lake Michigan. Located on a compact University campus, these demonstration projects have also offered unique opportunities for research and public education.

From the author's perspective, the ZDZ Masterplan is faculty activism aimed at aligning the campus with the Green Campus Movement through design. From the perspective of the Milwaukee Metropolitan Sewerage District (MMSD) that funded the Masterplan and several of the subsequent demonstration projects, the Masterplan is an investment in a long-term program of green infrastructure demonstration and implementation. And from the UWM Administration's perspective, the Masterplan offers a means to address localized infrastructure problems, enhance the campus landscape aesthetically and serve a leadership role in the community.

## 2. INTEGRATED PLANNING

The ZDZ Masterplan was initiated through a series of design charrettes including students of architecture, civil engineering and related sciences, professionals and community members. Subsequent work was undertaken by the P.I. and others working with graduate students in architecture and civil engineering.

As a design study, the ZDZ Masterplan is unique in its fi ne-grained evaluation of each and every horizontal surface in terms of the potential to keep stormwater distributed as diffusely as possible. The categories include: 1.) Internally drained roofs, 2.) externally drained roofs, 3.) pedestrian hardscape, 4.) vehicular hardscape, 5.) drained landscape, and 6.) opportunities for subterranean capture and daylighting before entering the combined sewer system. A parallel demonstration project design effort cut across this grain by weaving multiple strategies together to capture every surface within a single four acre drainage.

The ZDZ Masterplan preceded and was adopted wholesale by the most recent official campus planning effort, making the aspirational commitment to green infrastructure the most aggressive environmental performance goal established by the official 2009 UWM Campus Masterplan. UWM has subsequently been listed in the Princeton Guide to Green Campuses with the ZDZ Masterplan and attendant demonstration projects featured; a validation that has in turn reinforced the campus' commitment.

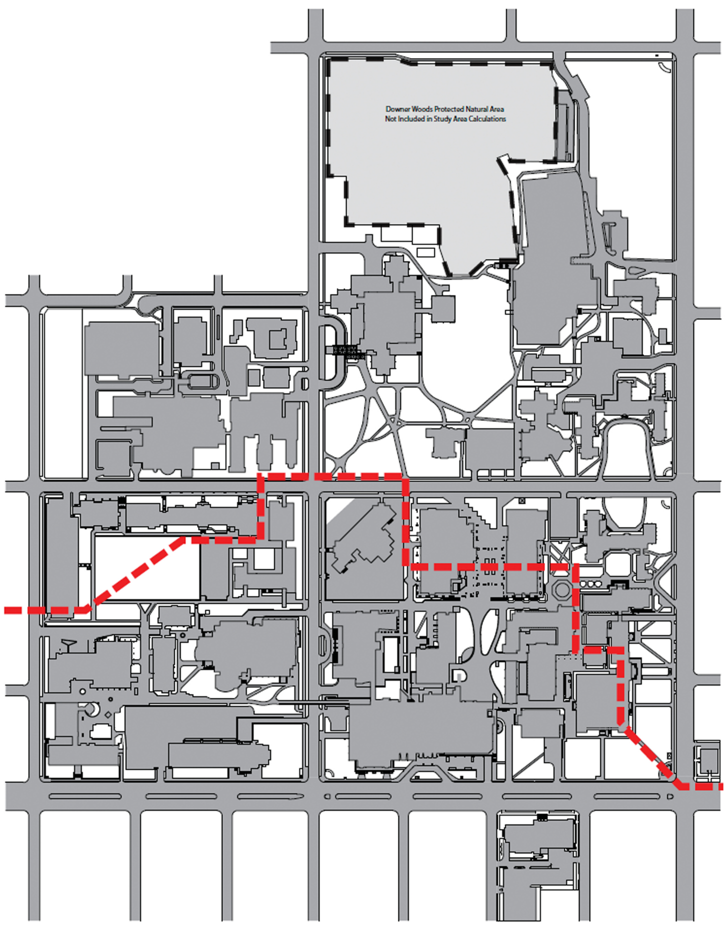


Figure 1. Campus Map/ Site Plan. This map states the essential challenge- over half of the surface area of the campus is impervious.

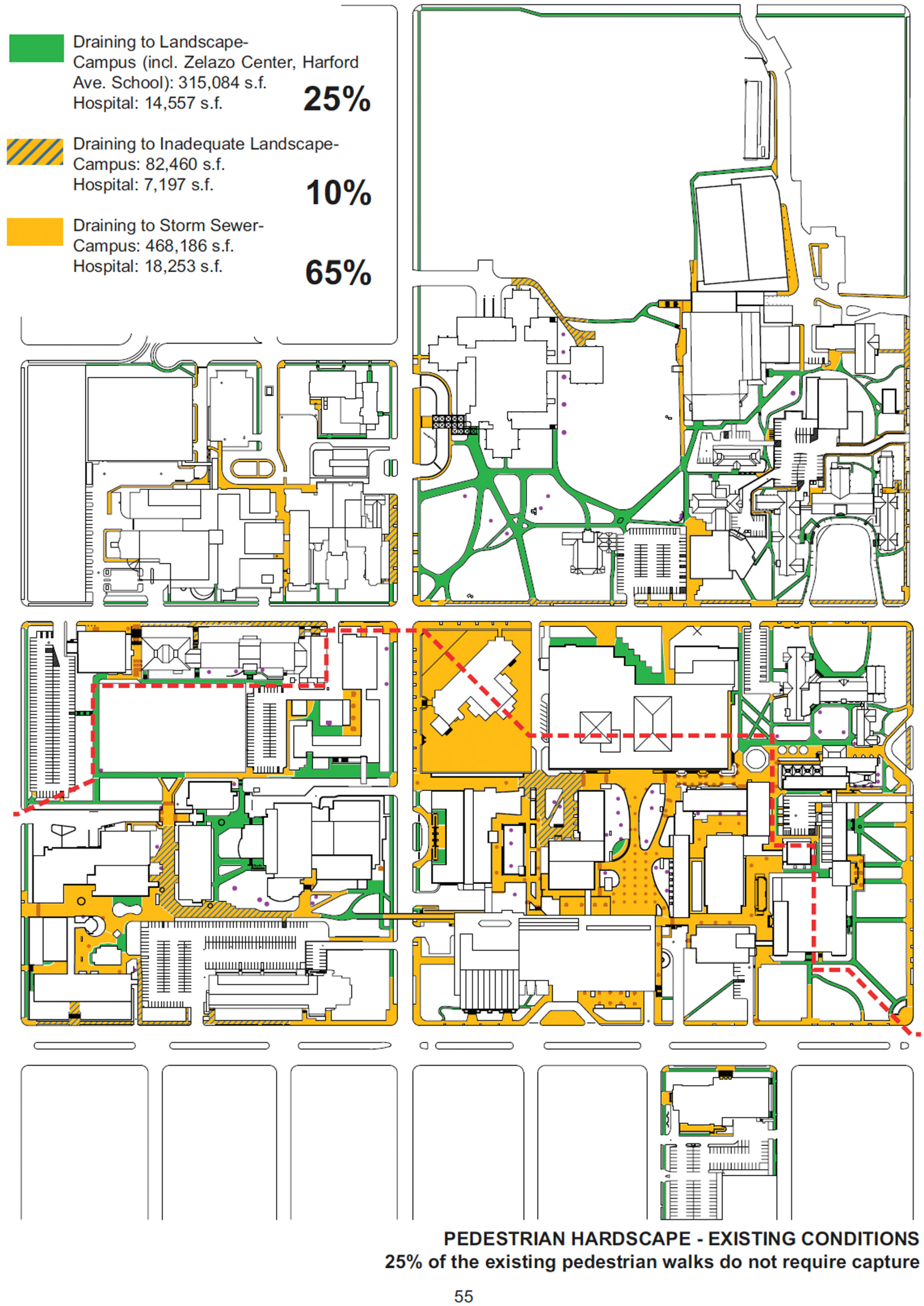


Figure 2. Zero-Discharge Zone Plan: Pedestrian Hardscape. One of many maps illustrating individual horizontal surface studies, this analysis of the existing Pedestrian Hardscape indicates the attention to detail of the study as a whole.

## 3. IMPLEMENTATION

Demonstration projects completed to date include the Sandburg Commons Green Roof (2008), phase I of the Pavilion Gateway Project- the Spiral Garden (2009), and the Golda Meir Green Roof and Integral PV Array (2011). A fourth project, the Power Plant Cisterns, will be completed in the spring of 2013 and add capacity to the Spiral Garden.

The Sandburg Commons Green Roof is a 36,000 s.f. vegetated roof on the commons of the campus' only residential tower complex. The design integrates native wildflower beds into an extensive sedum field, with the penthouse roof an experimental Wisconsin dry prairie. The 53,000 s.f. Golda Meir roof experiments instead with the integration of a photovoltaic system kept cool by sedum surrounds.

The Spiral Garden is phase I of the Pavilion Gateway Project, which was designed in tandem with the ZDZ Masterplan. This project features a large treatment train planted with native wildflowers capturing a 2-acre parking lot. Secondary gardens capture the surrounding pitched roofs via sculptural downspout disconnections.

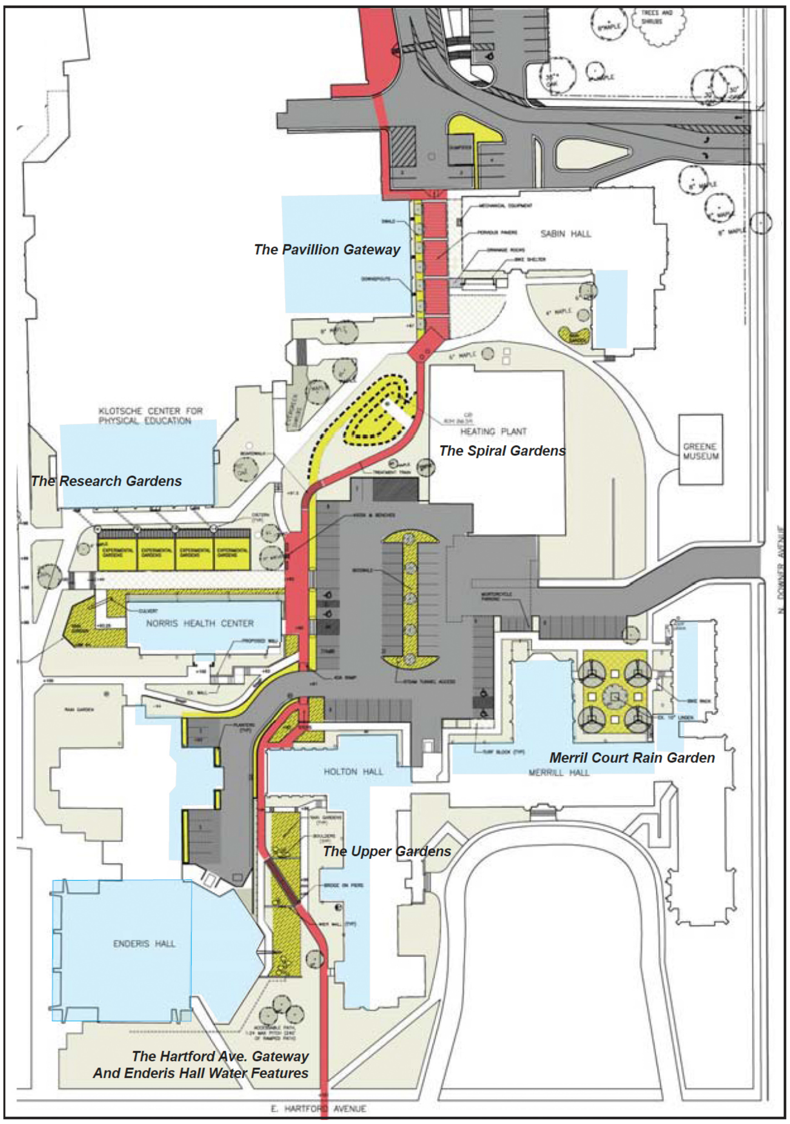


Figure 3. Pavilion Gateway Project and the Spiral Garden- the ZDZ Masterplan's tandem demonstration project. A four acre drainage basin in which every surface is captured, making an interpretive landscape of a service zone of the campus.

The Power Plant Cistern Project currently under construction adds drama and capacity to the Spiral Garden, capturing the 13,000 s.f. internally drained roof of the UWM Power Plant and redirecting that water out the wall of the building 20' above grade and into the first of a pair of interconnected sculptural cisterns. The second cistern will overflow into the head of the Spiral Garden, creating a stormwater fountain that will slowly drain following each filling.

## 4. RESULTS

The plan proposes to remake UWM's urban campus as an oasis of native gardens. In the abstract, it has proven that the surge of runoff causing regular flooding can be reduced by 75% to what it would have been before European settlement. The final increment of this result requires pump-powered features harvesting water from the campus's drainage trees before they join the City's combined sewers, but otherwise this capacity is created by capturing realistic proportions of each surface type examined.

The above demonstration projects to date have touched approximately six acres or 11% of the northern drainage. Implementation has continued to provoke new insight in two primary ways. Each project has been forced to adapt to hidden conditions and each has suggested novel ways of layering strategies in return. The Spiral Garden sits adjacent to the current Power Plant and on the ruins of an earlier plant. Unidentified tunnels and pipes have added complexity at every turn, defining 'urban' ecological infrastructure as a distinct design challenge. At the same time, the structural analysis that ruled out a green roof for the Power Plant also revealed that the entire drainage tree within the building could be daylit through the wall adjacent to the Spiral Garden, giving birth to the Power Plant Cistern Project.

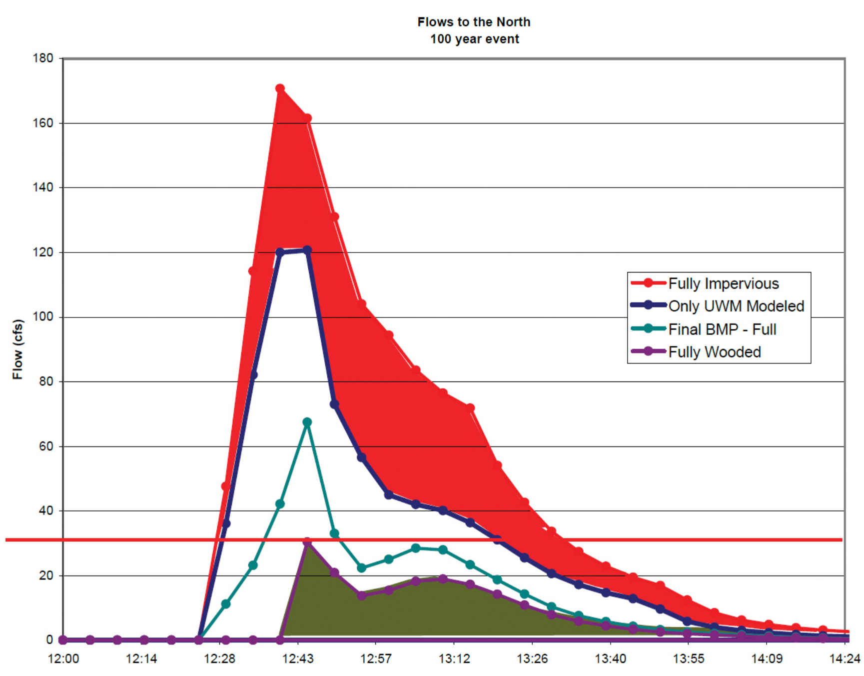


Figure 4. Bracketing the Critical Northern Drainage. SWMM model by CEE Thesis student Libby Locke. RED represents the limiting condition of being completely impervious. GREEN represents the opposite limiting condition in which the entire area is returned to forest. The 30 cfs peak discharge rate of the forest nicely matches the 100 year/ zero-discharge rate of 0.5 cfs over the 60 acre northern drainage.

## 5. PONDERING NET-POSITIVE ECOLOGICAL URBAN STORMWATER INFRASTRUCTURE

### 5.1 *Positive in What Ways? By What Criteria?*

The measurable criteria of the ZDZ Masterplan is the reduction of peak discharge rates from a specific sewer-shed draining to a specific drainage tree that is undersized and as a result causes localized basement back-ups of the combined sewer system. By this very real criterion any well designed green infrastructure installation is offering an improvement over the present situation. The next level of that question would be to surpass the stated goal of the Zero-Discharge Zone project, which would be to reduce that peak for a 100-year storm event to the rate that it would have been in an undeveloped state. This standard was chosen as the engineering standard seen as the extreme case by the sewerage district and the consulting engineers on the project team. It translates into roughly six inches of rain as opposed to the roughly two inches that would be the two-year event that the local regulatory standards design for.

One could take this experiment further by modeling even less frequent events- adopting a 500-year event standard for example. It's quite possible that the level of retention doesn't change in the pristine system once a certain threshold is reached… this suggests that further modeling might identify a plateau in the natural system under a range of event durations that could be identified as a stable baseline. To reduce this peak by providing more storage capacity than the pristine condition would allow could then be said to be net-positive. Given that the UWM campus sits on a poorly drained clay bluff, that peak flow rate might be stable at a much lower threshold than the 100-year event that we modeled, and we could in fact reduce our targets.

As this illustrates, one interesting lesson of the ZDZ Plan is how specific the critical problem can be. If we were to look at establishing a separately argued performance target for the southern half of campus that drains to the Milwaukee deep tunnel system without local bottlenecks, the issue of peak rate fades and the total volume held back would come to the fore. As we have found working on the subsequent School of Freshwater Sciences Campus Project, there are areas of the City that drain directly into the Harbor. In these cases, the rate and volume are of concern only insofar as they are related to our ability to improve water quality.

Figure 5. An Ecological Waterscapes Plan for Greenfield Avenue and the UWM School of Freshwater Sciences. Here, amongst other proposals, aquaculture process waste water becomes the source for a man-made spawning stream aimed at improving the aquatic habitat of the Milwaukee River estuary.

A second complexity that this line of argument raises is that of the impact of climate change on the establishment of any baseline. Climate change is predicted to alter precipitation and temperature trends in the Midwest and to result in increases in storm frequency and intensity. Thus even a net positive solution modeled on historical data is likely to be overwhelmed by future events.

5.2 *Criteria Other Than Stormwater Management*

Taking a larger view, much of this same green infrastructure is justified as a strategy to reduce the urban heat island effect. Whether a green roof could be said to be net-positive in relation to the pristine land that urbanization displaced would depend on the character of that displaced land. The likelihood seems extremely low in Southeastern Wisconsin, given the inherent limitations of the water storage capacity of a green roof compared to a deep rooted prairie or a forest canopy. Without water to evaporate, the vegetation is cooler only than the roof it covers. This dynamic itself could be altered if for example the green roof was irrigated specifically to cool its surroundings an introduction of stored water, energy and intelligence into the system.

A second more general criteria might be that the stormwater infrastructure be net-positive in terms of balancing the energy inputs and carbon emissions generated to create and sustain the feature with the energy outputs and carbon sequestration generated by the increased biological productivity of the infrastructure. In the realm of green building, stormwater infrastructure is one of the few elements of design based in part on directly supporting biological processes, and so it is uniquely positioned to be conceived of in this way. At a recent charrette on the Ecological Waterscapes Plan for the School of Freshwater Sciences featuring EPA and US Forest Service scientists, the idea was put forward to use fast-growing street trees that are being studied in terms of their stormwater filtration capacity as a wood pulp source for brownfield remediation work on adjacent properties. At a parallel charrette on on-site sewerage treatment, global examples were discussed in which the excess bio-mass generated within the project boundary augments wastewater sludge as a source for methane, which in turn powers the process. In suggesting that stormwater features be designed with the harvesting of bio-mass in mind, these two examples are a reminder that we are talking about human landscapes- gardens that can be coaxed to maintain unnatural levels of biological productivity. This would seem to be a key aspect of a net-positive framework.

Figure 6. Sandburg Commons Green Roof. The mechanical penthouse of the commons is planted exclusively with Wisconsin native and endangered dry prairie plants, which have survived as well in four inches of substrate as the sedum of the main roof while providing habitat for butterflies and the like.

5.3 *The Soft Criteria of Mindfulness*

For the Sake of the Lake

Our Concrete Trees

Need Green Leaves

This rumination barely scratches the surface of the questions generated by pondering the technical objectives that green stormwater infrastructure responds to on one hand and the question of what the baseline for comparison should be on the other. A third question that has not even been mentioned here is to ask at what scale the solution is most appropriate. Here one could contemplate the fact that the MMSD has been producing and marketing organic fertilizer from sewerage sludge since 1925, closing the nutrient loop. Furthermore, the District is in the process of bringing landfill methane to the facility and has plans to make the entire regional operation carbon neutral. Why should this scale be excluded from the equation?

In place of a longer argument on the metrics of defining a net-positive future, I am drawn back to the slogan developed to promote the Zero-Discharge Zone Masterplan. "For the Sake of the Lake/ Our Concrete Trees/ Need Green Leaves."

This koan makes two points. First, the urban scale sewer infrastructure that initially made Milwaukee famous for its progressivism before being overwhelmed by further urbanization and evolving public sentiment is not simply going to be replaced by distributed green infrastructure. On the contrary, it is intending to incorporate this soft canopy of buffer capacity in order to expand its resiliency. And this makes sense not only because it allows the existing infrastructure to continue to function, but because the sorts of ecological stormwater technology championed here are equally limited in their efficacy. Arguably, such a hybrid system produces a better outcome in terms of the sustainability of the City and the health of Lake Michigan than a purely site based approach would, could it ever be implemented at that same scale. This line of argument would maintain that having a central treatment facility in line to treat urban runoff that has either passed through or overwhelmed the capacity of the soft infrastructure leads to higher water quality overall as long as the soft system can prevent the combined sewer overflows that result when the hard system is itself overwhelmed.

Second, the koan creates a mental image of both the problem and its solution; an image that locates the solution metaphorically in relation to other natural forms and processes. And as the slogan promotes mindfulness of nature in a small way, the incremental transformation of each small storm-sewer branch on the UWM campus into a branching structure supporting 'green leaves' or ecological stormwater features finds one of its highest values in promoting awareness of natural forms and processes in general.

The point of these demonstration projects is to educate the public about issues of urban ecological stormwater management. These engineered natural systems could be said to be net-positive in terms of promoting biophilia; even perhaps measured against a baseline site unspoiled by human hands in that they convey the role of those human hands in engaging natural processes in this way.

The positive value that I would point to is much narrower and more tightly bound to the education of a green designer. Ecological urban stormwater infrastructure solutions are inherently weak in their individual impacts and gain strength only in being ubiquitous.

This technology necessitates mindfulness towards the potential to exploit small opportunities. It demands a frame of mind that acknowledges both that nature is a process and that progress towards positive solutions happens incrementally. It argues for the increased differentiation of the physical environment- for a higher order of complexity to be achieved at the small scale than would otherwise be called for. It promotes thinking of architecture as gardening in other words, and it allows the sort of low-cost incremental experimentation that the design of larger elements of the built environment can't. The work of designing and constructing demonstration projects has been a great educational activity for this reason.

## 6. CONCLUSION

Perhaps the role of ecological stormwater infrastructure in articulating a net-positive design standard is the role that it typically plays already- that of the most immediate stand-in for nature as a model for every other process related aspect of design. With water, the loops are all visible and comprehensible- at the scale of the site and neighborhood but also the city and region. So, the question might be: Does this design exploit its niche to the fullest in the service of contributing to the ecological sustainability of larger systems that it participates in? Perhaps the metric should be not the extent to which the solution becomes independent of the larger scale, but the degree to which it leverages incremental performance improvements at the larger scale.

In this example of campus scale stormwater infrastructure, three proximately close sites present three subtle but profoundly different imperatives to design for; reducing peak flows, reducing total flows and improving water quality. Two have a small but critical role to play in enhancing the ecological sustainability of a regional sewer system that is not perfect but is evolving. The third has no role in that arena but a unique opportunity to address aquatic habitat issues in a local estuary. All three exist within a well defined and jealously guarded, though not perfectly managed, watershed loop- the Great Lakes basin. The challenge that I would offer for defining a net-positive outcome in this situation is to understand and put a quantitative value on these efforts as feedback loops within the larger systems that they participate in.

To use the Living Building Challenge standard as a straw man- the LBC's structure starts with the individual site as the closed loop and specifically rules out interaction with municipal systems. This work argues rather to define a net-positive outcome by starting with the watershed rather than the site and balancing the energy, carbon and other inputs necessary to construct these features against the leveraged positive impacts that they have on the ecological health of the whole.

Figure 7. Sandburg Commons Green Roof.

Figure 8. The Golda Meir Library Green Roof and Integral Photovoltaic Array.

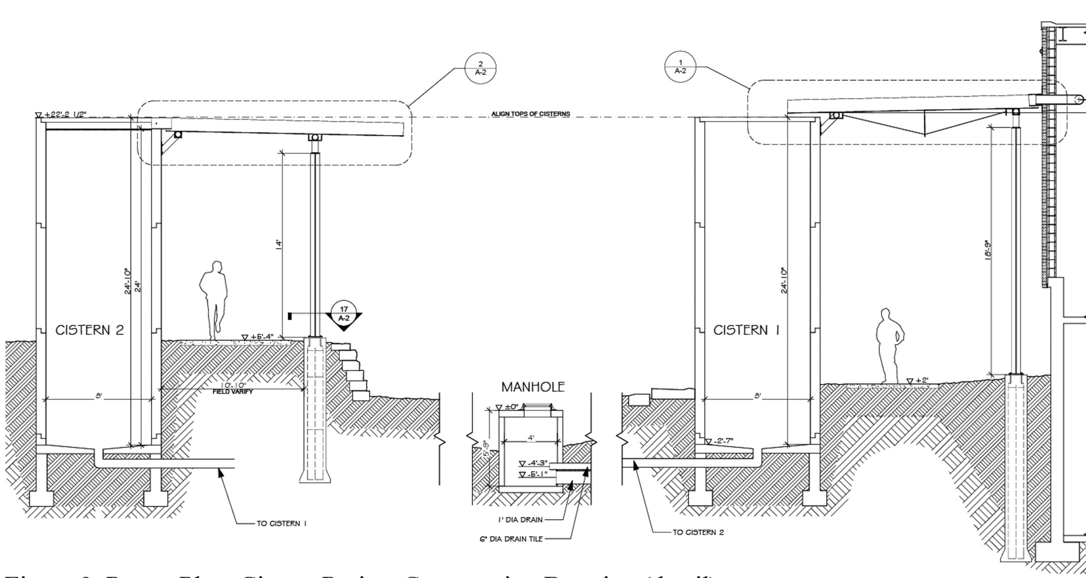


Figure 9. Power Plant Cistern Project Construction Drawing (detail)

Figure 10. The Spiral Garden. This basin is the largest in a series of gardens that capture run-off from the surrounding hardscape. The Power Plant Cisterns will add both capacity and drama, bringing water through the wall of the Power Plant in the center of the second bay into Cistern 1 and ejecting overflow water from Cistern 2 at the location where the photograph is taken. Together they form the northern gates of the Pavilion Gateway Project.

# Connecting Canadian Buildings to Natural Ecologies

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ABSTRACT: A growing number of architects, environmentalists, city planners and urban designers are grappling with how to build for a zero-carbon future, today. The York Region Forest Stewardship Education Facility is a groundbreaking eco-effective building project currently targeting all Petals of the Living Building Challenge and LEED Platinum. We believe this innovative building in a rural forest might provide insights about designing urban eco-effective buildings that are regenerative, carbon neutral (or better), produce environmental services, increase resilience, provide a rich experience, and operate in harmony with local and regional ecologies. We will also suggest how tying the carbon budgets of urban structures to sustainable forest management can render attainable the aspiration for net-zero carbon buildings.

## 1. LEARNING FROM THE FOREST

### 4.1 *Starting with ecologies*

Before we explore the ecological implications of this project it is worth reviewing some of the key terminology associated with the field of ecology. We often hear the term "ecosystem", yet ecosystems form just part of the nested hierarchy of ecologies. Ecosystems are situated within ecoregions, themselves part of larger bioregions. Ecozones comprise many bioregions and an even greater diversity of ecoregions. The smallest unit of ecology is the ecotope, a landscape that has its own characteristics but also is inextricably interconnected with its ecosystem.

### 4.2 *A green building in a rural forest*

DIALOG was recently commissioned to design the new York Region Forest Stewardship Education Facility (YRFSEF). The project is situated at the Hollidge Forest Tract, owned by York Region since 1924 when it was acquired as a part of a broad environmental restoration program. The tract is one of 19 tracts managed by the region and has been restored as a forest through tree planting and management over the past eighty-seven years (Silv-Econ Ltd., 2008). The YRFSEF project is being approached as a continuation of this decades-long forest ecology restoration process, and York Region determined that targeting LEED Platinum and full certification under the Living Building Challenge (LBC) for this project would be the most rigorous benchmarks against which to measure the environmental effectiveness of their project. It is important to note that even though they recognized the significant challenge involved in undertaking the LBC—there are currently no fully certified LBC buildings in Ontario – they also recognized that it would require everyone involved in the project to deeply explore what is necessary to achieve a truly eco-effective, ecologically integrated building project.

### 4.3 *Inviting the forest into the design process*

The YRFSEF project has required a unique approach and expertise. It has demanded an understanding of the forest and the process of forest restoration that could serve to inform and define a bold green design strategy. DIALOG partnered with Community Forests International (CFI) on this project to leverage their sustainable forest stewardship and education expertise, bringing a deep understanding of forest ecosystems to the table during the design process. The CFI team has been able to translate for the team the significance of restoring a disturbed forest and the role this new building could play in that process. As part of these explorations, the potential of an FSC sustainably managed forest to absorb carbon was compared to the potential carbon that would be produced by the building project. The result is a net-zero carbon building that, as a result of its relationship with its local ecosystem, sequesters more carbon dioxide equivalent ($CO^2_e$) than it generates in its construction and operation.


Figure 1. A rendering of the York Region Forest Stewardship Education Facility (YRFSEF).

## 5. THE YORK REGION FOREST STEWARDSHIP EDUCATION FACILITY

### 5.1 *Net-zero carbon*

Forests overwhelmingly dominate the terrestrial carbon cycle, harnessing 86% of the planet's aboveground carbon and 73% of the planet's soil carbon (Sedjo, 1993). Building in the midst of an 80 hectare forest transformed a typically immense challenge—designing a zero-carbon building—into a readily achievable goal.

CFI has calculated that the Hollidge Tract, at 80 ha, would sequester 1.5 tonnes of C (carbon) per hectare per year, and 5.51 tonnes of $CO^2_e$ per hectare per year for the next 100 years of its restoration period. After this time, carbon will continue to be sequestered and stored in wood products, with live tree carbon pools essentially saturated around 160 tonnes of C per hectare. Significant potential still exists to augment and increase soil carbon pools, thereby further increasing forest growth and carbon sequestration. Preliminary calculations suggest that the embodied energy of the YRFSEF building will be 1681 GJ with a $CO^2_e$ of 83 tonnes, representing less than 1 year of carbon sequestration and storage at the Hollidge tract.

As such, the YRFSEF project, including its site, will not only be carbon neutral, or net-zero carbon, but will in fact be carbon negative, sequestering more $CO^2_e$ in the forest over the next year alone than required to build the project. This allows us to create an annual carbon budget to offset the small amount of carbon produced both on site in the course of operation and by people traveling to and from the site (measures have been put into place to reduce dependency on automobiles for travel, such as showers and bicycle racks). There is a further surplus of carbon sequestered in the wood used to construct the facility and the model does not take into account the 87 previous years of land sequestration.

5.2 *Net-zero energy*

Net-zero energy is a critical subset in achieving net-zero carbon. The YRFSEF building will achieve net-zero energy through a roof-mounted 35kW solar PV array that will generate all of the building's electricity requirements. A solar shading modeling study was conducted to confirm that the forested site would allow enough solar energy and locating the building at the centre-north of the site with south facing windows maximizes solar gain. The 80 ft forest canopy made the shading studies particularly critical and offers some interesting parallels with building in a dense urban environment.

The YRFSEF building will receive sun from 9:30 AM to 4:30 PM at the spring/fall solstice, 7:30 PM - 4:30 PM at summer solstice, and just 12:00 PM - 2:30 PM at winter solstice (Fig. 2). In spite of this our modeling and calculations indicated that the PV panels would generate somewhat more energy than the building requires throughout the year.

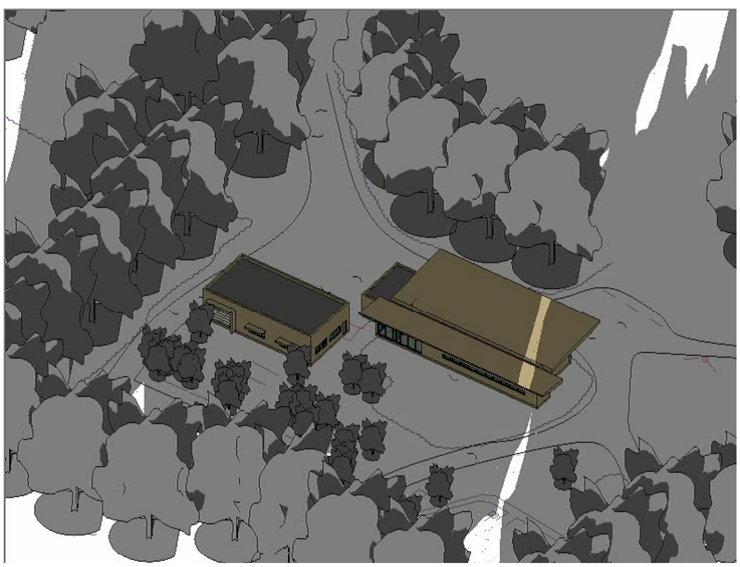

Figure 2. Site shading study, noon, winter solstice.

The design of the building will target ultra-low energy use with highly insulated roof and walls, triple pane argon gas filled windows in fibreglass frames, LED lighting controlled by daylight and occupancy sensors, and a variable refrigerant flow heat pump system to heat and cool. A central hearth will be the only instance of combustion, using as its source sustainably harvested wood from the Hollidge Tract Forest, mostly dead trees and tree prunings, or trees at the end of their lifecycle.

The approach for energy conservation at the YRFSEF building is something we have termed "Passivhaus lite". The "lite" comes from the fact that we need more ventilation than a typical Passivehaus as a result of the greater amount of heating energy required to cover the increased ventilation that is required with a higher occupancy building. Also, we are incorporating somewhat more glass than a typical Passivhaus would have – resulting from the client's desire to balance the need for ultra-low energy use with the provision of natural forest views as part of the project's community education mandate. Roof insulation is R 60, while a still low window-to-wall ratio is maintained with wall insulation at R 40, and windows that are triple glazed, double low-e coated, argon filled, set in fibreglass frames with a U < 0.20.

A rigorous commissioning program will be implemented so that all systems function as designed. Moreover, the construction of the building envelope will also be a critical focus of the commissioning process, with careful inspection of the installation of insulation, membranes, glazing systems, etc. to minimize thermal bridging and air leakage resulting from faulty construction.

Owner operation of the building will be the important final ingredient for our net-zero energy strategy. The owners of this project are highly motivated and inspired by the green ambition of the YRFSEF building and are committed to measures such as turning lights off, monitoring plug loads, keeping doors shut, and deep setbacks on thermostats for unoccupied periods. All told, our net-zero energy strategy generates 19 LEED energy performance points and 7 renewable energy points (Fig. 3).

The ambition to design a net-zero energy building is not without its pitfalls. It is quite evident from our research that there is a gap between theory and practice, with buildings often varying widely from their models in terms of both energy production and use (Mehrotra, 2012). Again, however, this is why effective commissioning is such an important part of the process.

### 5.3 *Net-zero water*

Because the building is situated on a large aquifer, net-zero water primarily involved water-recycling processes consistent with the water recycling done naturally by the forest's ecosytems. In a forest, all water is recycled, cleanly and efficiently and this informed how we approached the YRFSEF building and site. Water is treated to 'tertiary standards', suitable for release into a sensitive ecosystem. Rainwater is collected, reused within the building to flush low-flow toilets and urinals, and, where not collected, is channeled through a landscape complete with bioswales and natural wetlands featuring native species that mirror the natural features of the tract.

### 5.4 *Local, benign materials*

Use of materials is a critical and complex part of the LBC, and much more stringent a set of requiremets than those required by LEED. The LBC 'Red List' of banned materials is extensive and forces a careful rethinking of the use of many materials that are now ubiquitous in the building industry.. The LBC also requires that building materials be 'Appropriately Sourced' which translates to 'as local as possible'. Balancing these two important (yet often at-odds) requirements contributes in no small measure to the "challenge" aspect of the LBC.

Moreover, we deemed that construction materials and finishes should also all be certified to the most demanding standards for VOC emissions and indoor air quality. In this project, we have also regarded the question of materiality as a way of expressing the purpose of the building and history of the site—to help the community to better understand their forest. To this end the building is constructed using both wood structural systems and wood finishes. The structural system is comprised of cross laminated timber (CLT) decks supported by laminated wood columns. The walls have also been constructed with CLT infill panels. All of these materials are used as both structure and the interior wall and ceiling finishes to both reduced the need for additional interior finish materials as well as to showcase wood as both an important and beautiful construction material.

### 5.5 *Living learning*

A large part of the mandate of the YRFSEF building is the cultivation of sustainable urban forestry practices within the broader York Region community. The resulting design strategy therefore understands the facility as both as a building that meets its functional programatic requirements, and as an educational tool that presents its use of various wood products as an aid to help teach about the forest, responsible forest management, viticulture, plant life, sustainability, and green design. Indeed, the whole building is designed as a teaching tool, and the teaching spaces are designed to spill out across the site and into the forest beyond. The primary mandate of the project is to instill an understanding and appreciation of sustainable urban forestry and sustainable building practices within the York Region community. As such, the inner workings of both the building and the forest will be exposed: "Truth holes" will allow people to view the building's various mechanical and electrical systems; glulam and CLT structural members will be exposed and identified; monitor screens will display energy production and consumption in real time, offering visitors the opportunity to impact the performance of the building; outdoor classrooms will allow people to engage with the forest; and landscape features such as bioswales will also be used for education purposes to explore how forests provide ecological services.

5.6 *Equity and beauty*

A unique aspect of LBC is its requirement that the building be both beautiful and inspiring as well as embrace equity and community. In terms of equity, the Hollidge Tract is unusual and very innovative in being one of the very few fully wheelchair accessible forests in North America—allowing anyone to use the extensive trail system to experience and learn from the forest. The YRFSEF building and site is therefore designed as an extension of this philosophy, and fully comply with the current Accessibility for Ontarians with Disabilities Act (AODA) standards. It will also be accessible to people of all walks of life as there will be many free events and free shuttles to the site.

In addition to being elegantly designed, beauty is also addressed through 'biophilic design', echoing the natural features, materials and forms of the surrounding forest. Wood is the primary building material, being used as structure, sheathing, siding, and interior paneling, and all wood is FSC certified as responsibly harvested and extracted sustainably from the site itself. There are very visible elements of the forest incorporated into the design. Glass is used mindfully to connect outside and inside, wood cladding to break down the distinction between building and forest.

As such, the YRFSEF building will be a reflection of the community values of the York Region, and its vision for a more sustainable and simultaneously vibrant future.

**DIALOG™**
**YR Forest Stewardship Education Facility**

| LEED Canada NC 2009 | | TARGETED | UNDER CONSIDERATION | DISMISSED | REQUIRED FOR LIVING BUILDING | | |
|---|---|---|---|---|---|---|---|
| | | 80 | 18 | 12 | LBC | TARGETED CERTIFICATION: | Platinum |
| **Sustainable Sites** | | 11 | 9 | 6 | 0 | | **Responsibility** |
| Construction Activity Pollution Prevention | | PREREQUISITE | | | | SSp1 | Civil Engineer |
| Site Selection | 1 | 1 | | | LBC | SSc1 | Architect |
| Development Density & Community Connectivity | 5 | | | 5 | | SSc2 | |
| Brownfield Redevelopment | 1 | | | 1 | | SSc3 | |
| Alternative Transportation: Public Transportation Access | 6 | | 6 | | | SSc4.1 | Architect |
| Alternative Transportation: Bicycle Storage & Changing Rooms | 1 | 1 | | | | SSc4.2 | Architect |
| Alternative Transportation: Low-Emitting and Fuel-Efficient Vehicles | 3 | 3 | | | | SSc4.3 | Architect |
| Alternative Transportation: Parking Capacity | 2 | | 2 | | | SSc4.4 | |
| Site Development: Protect and Restore Habitat | 1 | 1 | | | | SSc5.1 | Landscape Architect |
| Site Development: Maximize Open Space | 1 | 1 | | | | SSc5.2 | Landscape Architect |
| Stormwater Design: Quantity Control | 1 | 1 | | | LBC | SSc6.1 | Civil Engineer |
| Stormwater Design: Quality Control | 1 | 1 | | | LBC | SSc6.2 | Civil Engineer |
| Heat Island Effect: Non-Roof | 1 | | 1 | | | SSc7.1 | Architect |
| Heat Island Effect: Roof | 1 | 1 | | | | SSc7.2 | Architect |
| Light Pollution Reduction | 1 | 1 | | | | SSc8 | Electrical Engineer |
| **Water Efficiency** | | 10 | 0 | 0 | 0 | | **Responsibility** |
| Water Use Reduction - 20% | | PREREQUISITE | | | | WEp1 | Mechanical Engineer |
| Water Efficient Landscaping | 4 | 4 | | | LBC | WEc1 | Landscape Architect |
| Innovative Wastewater Technologies | 2 | 2 | | | LBC | WEc2 | Mechanical Engineer |
| Water Use Reduction - 30, 35 or 40% | 4 | 4 | | | LBC | WEc3 | Mechanical Engineer |
| **Energy & Atmosphere** | | 33 | 2 | 0 | 0 | | **Responsibility** |
| Fundamental Commissioning of Building Energy Systems | | PREREQUISITE | | | | EAp1 | Commissioning Agent |
| Minimum Energy Performance | | PREREQUISITE | | | | EAp2 | Energy Modeler |
| Fundamental Refrigerant Management | | PREREQUISITE | | | | EAp3 | Mechanical Engineer |
| Optimize Energy Performance | 19 | 19 | | | LBC | EAc1 | Energy Modeler |
| On-Site Renewable Energy | 7 | 7 | | | LBC | EAc2 | Energy Modeler |
| Enhanced Commissioning | 2 | 2 | | | | EAc3 | Commissioning Agent |
| Enhanced Refrigerant Management | 2 | 2 | | | | EAc4 | Mechanical Engineer |
| Measurement & Verification | 3 | 3 | | | | EAc5 | M&V Consultant |
| Green Power | 2 | | 2 | | | EAc6 | Client/Owner |
| **Materials & Resources** | | 7 | 2 | 5 | 0 | | **Responsibility** |
| Storage & Collection of Recyclables | | PREREQUISITE | | | | MRp1 | Architect |
| Building Reuse: Maintain Existing Walls, Floors, and Roof | 3 | | | 3 | | MRc1.1 | Architect |
| Building Reuse: Maintain Interior Non-Structural Elements | 1 | | | 1 | | MRc1.2 | Architect |
| Construction Waste Management | 2 | 2 | | | LBC | MRc2 | Contractor |
| Materials Reuse | 2 | | 1 | 1 | | MRc3 | Architect |
| Recycled Content | 2 | 2 | | | | MRc4 | Contractor |
| Regional Materials | 2 | 2 | | | LBC | MRc5 | Contractor |
| Rapidly Renewable Materials | 1 | | 1 | | | MRc6 | Architect |
| Certified Wood | 1 | 1 | | | | MRc7 | Architect |
| **Indoor Environmental Quality** | | 9 | 5 | 1 | 0 | | **Responsibility** |
| Minimum Indoor Air Quality (IAQ) Performance | | PREREQUISITE | | | | EQp1 | Mechanical Engineer |
| Environmental Tobacco Smoke (ETS) Control | | PREREQUISITE | | | | EQp2 | Architect |
| Outdoor Air Delivery Monitoring | 1 | 1 | | | LBC | EQc1 | Mechanical Engineer |
| Increased Ventilation | 1 | | | 1 | | EQc2 | |
| Construction IAQ Management Plan: During Construction | 1 | 1 | | | | EQc3.1 | Contractor |
| Construction IAQ Management Plan: Before Occupancy | 1 | 1 | | | | EQc3.2 | Contractor |
| Low-Emitting Materials: Adhesives and Sealants | 1 | 1 | | | | EQc4.1 | Architect |
| Low-Emitting Materials: Paints and Coatings | 1 | 1 | | | | EQc4.2 | Architect |
| Low-Emitting Materials: Flooring Systems | 1 | 1 | | | | EQc4.3 | Architect |
| Low-Emitting Materials: Composite Wood and Agrifibre Products | 1 | 1 | | | LBC | EQc4.4 | Architect |
| Indoor Chemical & Pollutant Source Control | 1 | | 1 | | | EQc5 | Architect |
| Controllability of Systems: Lighting | 1 | 1 | | | | EQc6.1 | Electrical Engineer |
| Controllability of Systems: Thermal Comfort | 1 | | 1 | | | EQc6.2 | Mechanical Engineer |
| Thermal Comfort: Design | 1 | | 1 | | | EQc7.1 | Mechanical Engineer |
| Thermal Comfort: Verification | 1 | | 1 | | | EQc7.2 | Mechanical Engineer |
| Daylight and Views: Daylight | 1 | | 1 | | | EQc8.1 | Architect |
| Daylight and Views: Views | 1 | 1 | | | | EQc8.2 | Architect |
| **Innovation In Design** | | 6 | 0 | 0 | 0 | | **Responsibility** |
| Innovation in Design: Green Building Education | 1 | 1 | | | | IDc1.1 | Client/Owner |
| Innovation in Design: Green Cleaning Plan | 1 | 1 | | | | IDc1.2 | Client/Owner |
| Innovation in Design: Exceptional Performance - Protect or Restore Habitat | 1 | 1 | | | | IDc1.3 | Landscape Architect |
| Innovation in Design: Building Envelope Commissioning | 1 | 1 | | | | IDc1.4 | Building Science Expert |
| Innovation in Design: TBD | 1 | 1 | | | | IDc1.5 | Client/Owner |
| LEED® Accredited Professional | 1 | 1 | | | | IDc2 | LEED Consultant |
| **Regional Priority** | | 4 | 0 | 0 | 0 | | **Responsibility** |
| Durable Building | 1 | 1 | | | | RPc1 | Building Science Expert |
| Regional Priority: Site Selection | 1 | 1 | | | | RPc2.1 | LEED Consultant |
| Regional Priority: Protect and Restore Habitat | 1 | 1 | | | | RPc2.2 | LEED Consultant |
| Regional Priority: Optimize Energy Performance > 40% Energy Savings | 1 | 1 | | | | RPc2.3 | LEED Consultant |
| **TARGETED TOTAL** | | 80 | 18 | 12 | | | 80 / 110 |

Updated: 31-1-2013 CERTIFIED 40-49 SILVER 50-59 GOLD 60-79 PLATINUM 80-110

*DISCLAIMER: Using the information available as of the issuance date shown, this document represents our understanding of how the Project might ultimately align with the identified LEED Rating System. Project certification is pursued after substantial completion of construction and will be subject to the LEED certification processes and procedures. These processes and procedures are outside the control of DIALOG, may not be uniformly implemented, and are subject to change at any time. This document implies no warranty or assurance that LEED certification will be attained for or by the Project. This document is the sole property of DIALOG and may not be used for any purpose without the express written consent of DIALOG.*

Figure 3. LEED scorecard with corresponding LBC requirements for the YRFSEF project.

## 6 THE GREEN BUILDING PARADOX

### 6.1 *Carbon and climate change*

As we developed our design solution for this project, it became very clear that, not only did we have to think about our project as a specific response to a community's programmatic needs set within a rural community, we also wanted to understand this project as part of the bigger environmental context, and more specifically, how our design solutions might speak to the issue of greenhouse gase emissions and their role in climate change. Currently, our built environments exhibit both high levels of embodied energy and therefore embodied $CO^2_e$ (equivalent), and then continue to generate $CO^2_e$ throughout their lifecycles. In addition to $CO^2_e$, new research suggests that the climate effects of black carbon - the soot produced during combustion - is twice what was previously thought, second only to carbon dioxide in terms of its climate forcing effect (Bond et al., in press).

### 6.2 *The need for an urban solution*

Cities already play an important role in reducing per capita $CO^2_e$ emissions. One study showed that city dwellers produce less $CO^2_e$ per capita than the average in their respective countries. For example, Washington D.C., the highest emitting city in the study at 19.7 tonnes per capita (more than double the next highest city), still produced only 82.5% of the $CO^2_e$ of the average citizen in the USA (Dodman, 2009). Given that just over 50% of the world's population is now living in cities, and that by 2050 it is estimated that 70% will be urban (Canada is already over 80% urban), how carbon is managed and reduced in cities will therefore be a crucial piece of the climate change puzzle (UN-Habitat, 2008; Statistics Canada).

### 6.3 *Increasingly green building standards*

To begin to address the challenge of climate change, North Americans have increasingly embraced new green design standards such as LEED, and increasingly at Gold and Platinum levels. According to the US Green Building Council, the area of LEED-certified space exceeded two billion sq ft in mid 2012 with an additional seven billion sq ft as registered projects and two million sq ft of commercial building space certified each day in over 130 countries around the world (Katz, 2012). This is truly a feat given the compact timeframe. Yet many architects like DIALOG are already looking past LEED to what lies beyond, exploring notions of resilient and regenerative buildings, buildings that can create their own self-sustaining ecosystems.

### 6.4 *More green, less urban*

However, even though it is clear that cities are by there very nature less carbon intensive than suburaban and rural areas, DIALOG's research suggests that one of the unintended consequences of the increasingly stringent zero-energy and zero-carbon green standards such as the LBC is that these projects tend to be more feasible in suburban or rural areas where there is greater space available for the generation of renewable energy—typically solar PV or wind turbine power. Net-zero energy buildings now tend to fall into the 2000-8000 sq. ft. range (Marshall, pers. comm.). This is occuring, we believe, for two reasons: first, the capital investment required for this kind of ambitious project at the scale of a large commercial high rise project could pose additional financial risks that current markets for commercial space would not support; and, second, there is the lingering question as to whether it is even feasable to build net-zero—carbon, energy, or water—at that scale. Typically, at Canadian latitudes, our energy density calculations suggest that it requires about one $m^2$ of PV solar collector to power one $m^2$ of floor area in an NRCan average building (Truyens, pers. comm.), and therefore, for a building to be entirely powered by self-generated renewable solar energy, a building can be no more than one or possibly two storeys in height – that is, given the current relative inefficiency of vertical façade mounted PV (Philips, 2009). Net-zero water, while more easily achievable at under 10,000 sq ft or at remote locations, would also not likely be possible in a 40 storey mixed-use residential building in the middle of a city given the constrained sites, high densities, and the technologies of today. In sum, by requiring buildings to generate their own energy, and supply their own water, we may be pushing them away from the urban spaces where the greatest per capita energy and material use efficiencies are to be obtained.

## 7LINKING URBAN BUILDINGS TO RURAL FORESTS

### 7.1 *Forest environmental services*

The YRFSEF project has clearly highlighted the opportunity for the built environment to be in dialogue not only with its local ecosystems but also with the extensive forests of its bioregion that provide the hugely important environmental service of providing large-scale carbon sequestration. The Living Building Challenge, as part of its requirements, dictates that for each hectare of land on site, an equivalent parcel of land must be set aside in perpetuity as part of a habitat exchange. And the potential for this exercise to deliver environmental services is significantly magnified if that tract is a sustainably managed forest. Indeed, one of the key insights that emerged from this project was the notion that we should be understanding buildings as integral parts of larger regional ecosystems. By extension, we would argue that we should be considering the feasibility of having every new building project, whether rural or urban, paired with a specifically designated area of sustainably managed forest in order to balance the environmental services consumed by the building with the environmental services generated by the forest. Indeed, given that carbon does not respect property boundaries or the edges of our cities, we can no longer afford to think about resolving the carbon issue simply within the framework of building and site, and there is an ever more pressing need to create a response that expands beyond site specific ecologies into the broader context of eco- and bioregions.

### 7.2 *The carbon offset controversy*

There is certainly controversy when one begins to discuss the notion of balancing or “offsetting” carbon. Some regard offsets as an “indulgence”, a penance to be paid. However, the approach we took with YRFSEF was to directly link the building and its carbon emissions to a specific tract of land, looking at the building as an integral part of both its site and its ecoregion. In the case of the YRFSEF, the project was immersed in the forest, but there is no logical reason why building and forest need to have been contiguous for this logic to work. Indeed, given that many of our cities, particularly in the northern hemisphere, exist within the same eco-regions and bioregions as significant forest tracts, and understanding as noted above that atmospheric carbon clearly does not respect the edges of city boundaries, starting to think about linking how we build to how we manage our forests presents an important opportunity for lowering our net greenhouse gas emissions while at the same time improving both our building stock, and our regional ecosystems.

## 8 DESIGNING AN URBAN ECO-EFFECTIVE BUILDING

### 8.1 *Theoretical features of an urban eco-effective building*

Designing a building such as the YRFSEF in an urban environment would be a significantly more difficult challenge, but it is one that we are edging ever closer toward. An eco-effective building would need to be designed as an ecotope in relationship to its local ecosystem but also in response to its eco- and bioregions. Specific design elements to reduce energy consumption and associated carbon production, as well as to better integrate the project into a city’s natural ecosystems would include:

**Reduced glass to wall ratio:** Designed for high energy efficiency and including glass-to-wall ratios of between 20 to 40% to reduce energy lost through glass.

**Extensive use of "green façades":** To provide an infrastructure for the growing of plant material that will not only screen a building from the summer sun, but also provides a resilient screen (created by the stainless steel mesh structure that supports the plant materials) against high speed projectile debris produced during extreme weather events. This green façade also provides natural cooling for the building in summer by means of natural evapotranspiration by the plant material, which reduces the air temperature between the screen and the building façade. (see Figure 4)

**Natural ventilation:** Designed to take advantage of natural ventilation using operable windows. Most interestingly, because the green façade acts as a buffering wall, the higher wind velocities higher up the building that would typically prevent the use of operable windows, are reduced to a manageable level.

**Production of Environmental Services:** A green façade and extensive use of green roof remove $CO_2$ from the air, and produce oxygen through photosynthesis. This micro-ecosystem also helps clean the air, and provide habitat for micro to macro organisms.

**Biological Human Waste Treatment:** Designed to include an "eco-machine" to process waste produced by the buildings inhabitants through biological means.

**Rainwater Retention and Use:** Rainwater would be stored for use in flushing toilets and urinals, as well as for irrigating the green façade.

**Use of Infinitely Recyclable Materials**: To reduce the hugely negative impact resource extraction has on the natural environment, designed as far as possible to be constructed with materials that could be infinitely recycled. The three key building materials were therefore steel (for structure), glass and aluminum (for building envelope).

**Use of Wood:** FSC Wood would be used wherever possible, as it is a sustainable carbon sequestering material. Floor slabs would be designed as CLT (cross laminated timber) decks—which are fire resistant, durable, and are naturally beautiful.

**Heating and Cooling:** Radiant heating and cooling—the ventilation and heating/cooling systems would be decoupled to reduce energy needs and mechanical sizes (e.g. fans, shafts, and ducts)

**Heat Recovery:** Heat recovery from exhaust air as well as discharge of this air through the underground parking to reduce ventilation costs

**Daylight Harvesting:** Photocell control of lighting to maximize benefit of daylight harvesting in combination with external solar shading provided by the "green screens" on southern exposure, as well as the minimization of glazing on east and west exposures

Figure 4. Eco-effective Urban Mixed-Use Prototype, Craig Applegath, DIALOG, 2012.

## 9. CONCLUSIONS AND IMPLICATIONS

### 9.1 *Buildings as ecologies*

There is already an ongoing conversation about the evolution of green design involving architects, engineers, environmentalists and urban planners and designers.. LEED buildings have become the standard with ambitious teams embracing more stringent standards such as the Living Building Challenge. These standards lay the foundation for a more rigorous exploration of the notion that buildings can generate their own self-sustaining ecologies and generate key ecosystem services. Yet we need to be mindful that more stringent standards—in their requirement for net-zero energy, water and carbon—may also tend to push these groundbreaking green buildings out into remote and rural environments instead of locating them in our urban environments where they can be most effective.

### 9.2 *Ecologies as buildings*

The York Region Forestry Stewardship Education Facility, targeting LEED Platinum and all the Petals of the Living Building Challenge, represents an early attempt to design a new paradigm of green building that positions buildings as an integral part of their regional ecologies rather than standing apart from them. Eco-effective buildings are regenerative, carbon neutral (or better), produce environmental services, increase the resilience of their structures to future shocks and stresses, provide a rich human experience, and operate in harmony with their local (ecosystem) and regional (eco- and bioregions) ecologies. Sustainably managed forests, with their critical role as carbon sinks, could be inextricably linked to urban eco-effective buildings thus playing a role in overcoming the challenge of constructing net-zero buildings in the city. This strategy has particular relevance in Canada with our highly urban population and generous allotment of forested land.

9.3 *What next?*

Our work on the YRFSEF eco-effective building suggests that architects might ask the following questions in relation to their future green building projects:

- How do we engage ecologists and biologists as part of an integrated design approach to green building?
- How can we design urban green buildings that move beyond LEED Platinum and Living Building Challenge full certification?
- How might we inextricably link urban buildings with rural forests to achieve net-zero carbon?

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# Net Positive – Beyond Zero

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ASTRACT: Three high performance buildings will be reviewed for their Beyond Net Zero performance and how these buildings might have attained an even higher level of Net Positive Performance. Each of these buildings is targeting a high LEED Platinum certification, two buildings are targeting Living Building Challenge certification, and one building underwent a significant Regenerative Design process. Specific performance issues examined include energy use, emissions related to energy use and building materials, water use and reuse, and healthy building materials.

Key Words: Living Building Challenge, energy use, water use, emissions, healthy materials, regenerative design

## 1. INTRODUCTION

Net Zero Energy, Water, and/or Carbon buildings are being discussed in the marketplace and a number are being constructed and operated in North America. But is Net Zero performance good enough to make a positive impact on the planet in such need of help? The opportunity for buildings and communities to make a positive contribution in energy, water and carbon beyond their own requirements is a direction for development in the future. In this paper, the opportunities for net positive performance will be examined for three projects along with what additional opportunities exist for higher performance.The three projects being reviewed are:

- Centre for Interactive Research on Sustainability at University of British Columbia, Vancouver, BC
- VanDusen Botanical Gardens Visitor Centre, Vancouver, BC
- 100 Bed Hospital Proposal for Kaiser Permanente, Lancaster, California

## 2. CENTRE FOR INTERACTIVE RESEARCH ON SUSTAINABILITY

The Centre for Interactive Research on Sustainability (CIRS) opened in 2011 and is a 5,000 $m^2$ office/research building with a 500 seat auditorium located at the University of British Columbia (UBC). The Perkins+Will Vancouver office started the project design in 2003. (See Figures 1 & 2.) The project goals were established in a design charrette in 2004. Obtaining project funding slowed the final design and construction of the project, completed in late 2011.

Some highlights of the original project goals include:

- 10% Net Positive Energy,
- Carbon Neutral Operations,
- Net Zero Water,
- No Water Leaves the Site,
- Healthy Materials.

The project initially targeted LEED Platinum certification but with the publication of the Living Building Challenge in 2006, Living Building Certification also became a project goal. Some details on how these goals were achieved are outlined below.

Figure 1. CIRS Street Side
(photo: Martin Tessler)

Figure 2. Green Roof over Auditorium
(photo: Martin Tessler)

2.1 *Energy*

Stantec provided the MEP engineering services. The building configuration features major North/South facing facades for the office areas with shading on the South exposures. The West façade features an exterior trellis structure with deciduous plants that provide shade in the summer and lose the leaves in the winter for winter heating. (See Figures 1 & 3.) Glazing areas are reasonable at about 40% of the overall façade. The 10m wide office wings work toward 100% daylighting and cross natural ventilation. The annual energy use for CIRS alone was modeled to be 71 kwh/$m^2$/yr. The energy transfer systems increased this to 111 kwh/$m^2$/yr.

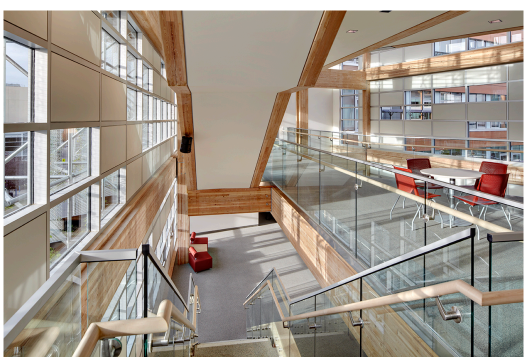

Figure 3. West Facing Commons
(photo: Martin Tessler)

Figure 4. PV in Roof over Commons
(photo: Martin Tessler)

The Earth and Ocean Sciences (EOS) laboratory building is adjacent to CIRS. Heat recovery coils were installed in the rooftop lab exhaust system in EOS. These heat recovery coils were connected to heat pumps in CIRS to provide all of the heat that CIRS needs on the coldest days. There is also a small ground source field installed as part of operational research. Excess heat available in more moderate weather is returned to EOS to preheat the ventilation air and heating supplied to the EOS labs. With the project plan, CIRS is able to return more energy to EOS (622 kWh/yr) than all of the CIRS systems use (610 kWh/yr). But 1,036 kWh/yr of steam boiler input gas is saved along with 177 tonnes $CO_2$e/yr due to boiler and distribution losses. (See Table 1.) In other words, with CIRS in operation, the overall energy use and emissions for UBC are decreased! It is true that CIRS is using a small amount of higher exergy energy (electricity) to conserve a larger amount of lower exergy energy (high pressure steam).

Table 1. Planned CIRS Energy Use and GHG Emissions

| Scenario | Total Energy ekWh/yr | GHG Emissions $tCO_2e/yr$ |
|---|---|---|
| CIRS Alone (LEED boundary) | 391,930 | 8.6 |
| CIRS + EOS Preheat | 610,550 | 13.4 |
| Heat Used by EOS | 622,070 | n/a |
| UBC Plant Savings (60% efficient) | 1,036,780 | 185.6 |
| Energy & Emissions Saved | 426,230 | 177 |

There are some photovoltaic panels integrated into the glazed roof of the West Atrium/gathering spaces. (See Figure 4.) Evacuated tube solar heat collectors also collect heat for use in the building heating system.

While not an original goal, the carbon emissions related to the building construction materials were also evaluated during schematic design and recently by UBC researchers. Fast + Epp, the structural engineers, used wood was as the major structural material. The emissions related to the extraction and manufacturing of the construction materials including concrete, steel, aluminum and glass (1,070 tonnes $CO_2e$) were found to be reduced to 166 tonnes $CO_2e$ net after considering the carbon absorption of the wood used in the structure. This is almost a 90% reduction in carbon emissions in construction materials of some 31 buildings studied at the UBC. (1)

### 2.2 *Water*

The potable water used on site is from the storm water on the roof that is collected, stored and treated to potable water standards with NovaTech Engineering's assistance. Water is collected from only the hard roof surfaces and not the green roof areas. The roofing materials and membranes were reviewed to not impart any chemicals to the water stream.

The sewage from the building is treated on site by a Solar Aquatics system that uses bioreactors followed by clarifying tanks with large leafy plants whose roots help in the cleansing process. The sewage treatment equipment room is at grade in a glazed enclosure at the front corner of the building. (See Figure 1.) Final ultra-violet, fine particulate and other filters bring the final reclaimed water effluent to appropriate reclaimed water standards for toilet/urinal flushing and irrigation.

Storm water drainage from the green roof, excess storm water from the storm storage tank, and any excess reclaimed water is discharged to an adjacent existing vertical drainage pipe going through the clay layers. UBC is covered by some clay layers that direct storm water flow horizontally to the cliffs, causing significant erosion. The vertical drainage pipes get the excess water below the clay layers to recharge the aquifers and avoid erosion to the cliffs.

### 2.3 *Healthy Materials*

With the Living Building Challenge "Red List" of banned substances (2) and Perkins+Will's Precautionary List (3), only suitable materials that are not made with harmful substances and do not off-gas were used throughout the project. One of the great success stories with CIRS is that one of the support staff for the lead researcher was having some regular health challenges in their previous building. Since moving into CIRS, these health issues have disappeared.

### 2.4 *Beyond Zero for CIRS*

The CIRS project is already producing some Beyond Zero results but there is always more that could have been done.

The planned Beyond Zero results were:

- CIRS saves more energy than it uses,
- A net reduction in carbon emissions at UBC due to the operation of CIRS, and
- A net carbon reduction in the construction materials used at CIRS.

The actual energy transfer from CIRS to EOS has not met expectations due to some operational constraints at EOS. The opportunity to substitute multi-zone rooftop unit reheat coils for the outdoor preheat coils has been reviewed with the CIRS management and operations personnel. This opportunity will result in even more significant heating energy and GHG savings than originally planned due to the reheat energy used by the existing system.

Some additional Beyond Zero issues that could have been implemented include:

1. While there is zero potable water drawn from the water mains, there are both storm water and reclaimed water discharged to the ground. The reclaimed water is available for irrigation of nearby landscaped areas but this has not yet been implemented.
2. More photovoltaic and solar heat panels could have been used to increase the amount of renewable energy.
3. The ground field capacity could have been larger to increase the amount of heat sent to EOS to displace the heat and emissions from the gas/steam heating system.
4. A further review of potential construction materials could result is more carbon being captured in a wood structure than is used in other building materials.

## 3. VANDUSEN BOTAINICAL GARDENS VISITOR CENTRE

The VanDusen Botanical Gardens Visitor Centre is a 1,900 $m^2$ facility developed for the City of Vancouver Parks Board. While the original mandate for the project was for a minimum LEED Gold facility, the project mandate to attract people combined with the conservation mandate of the botanical garden led to LEED Platinum and Living Building Challenge certification goals.

Figure 5. The VanDusen Botanical Garden Visitor Centre
(photo: Nic Lehoux)

The Perkins+Will Vancouver office built on the botanical theme and the building roofline was developed with an open flower petal in mind. Inspired by organic forms and natural systems, the project seeks to create a harmonious balance between architecture and landscape from a visual and ecological perspective. The dynamic single-story structure includes an innovative prefabricated roof form that appears to float above the building's curved rammed earth and concrete walls. The building form flows seamlessly into a central oculus and the surrounding landscape. The oculus is part of the summer natural ventilation approach. (See Figures 5 & 6.)

The building houses a central gathering area, café, library, volunteer facilities, garden shop, offices, and flexible classroom/rental spaces. The Garden's mission is one of conservation, and the new building was designed with the same philosophy in mind by mimicking natural systems, collecting water, harvesting sunlight, and storing energy until needed. Partially due to the new Visitor Centre, the number of visitors to the Botanical Garden has increased. (See Figure 7.)

Figure 6. The Visitor Centre's green roof and solar chimney (photos: Nic Lehoux)

Figure 7. Entry (photo: Nic Lehoux)

Some highlights of the project goals include:

- Net Zero Energy,
- Carbon Neutral Operations,
- Significantly Reduced Water use,
- No Water Leaves the Site,
- Healthy Materials.

3.1 *Energy and Carbon Emissions*

In an integrated design process, the team worked with Integral (Cobalt) Engineering, the MEP engineers, to develop the energy systems. The Visitor Centre works with an adjacent, existing building, the Garden Pavilion, to achieve overall net zero energy use. Solar heat collectors and geo-exchange boreholes/heat pumps provide heating for the Visitor Centre with excess heating capacity providing heating to the Garden Pavilion. Photovoltaic panels and solar heat collecting tubes supplement the building's energy systems. As the building uses natural ventilation with the central oculus and thermal mass for most of the summer cooling, the excess solar heat collected in the summer helps to recharge the geo-exchange field. (Refer to Figure 8.)

The Visitor Centre and the Garden Pavilion systems are planned to use 208,550 kWh/yr of electrical energy. The building systems transfer 250,930 kWh/yr of heating energy to the Garden Pavilion offsetting 153 GJ of gas heating energy for a net site building energy reduction of 42,380 kWh/yr. The site carbon emissions will be reduced by 38.7 tonnes $CO_2e$/yr. Overall energy use is 110 kWh/$m^2$/yr based on the Visitor Centre area.

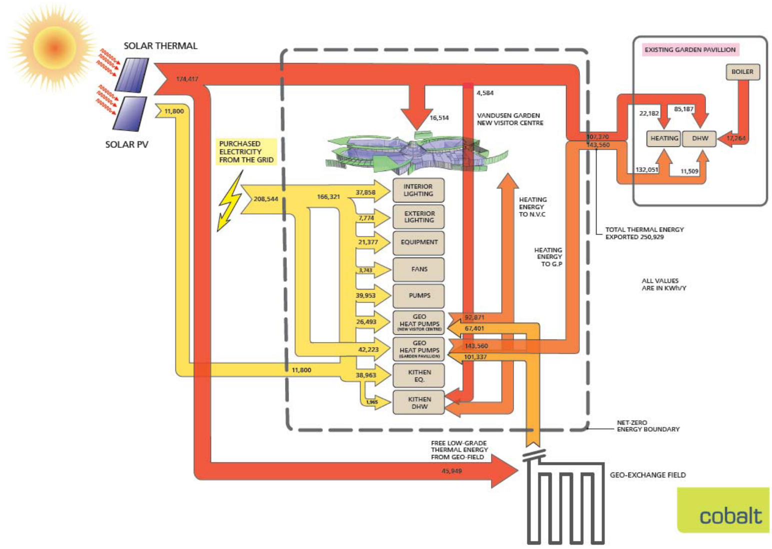


Figure 8. Energy Transfer Schematic for VanDusen
(courtesy of Integral (Cobalt) Engineering)

3.2 *Water*

Rainwater is collected from roof areas without green roofs, filtered, stored in underground tanks, and used for the building's toilet/flushing and irrigation requirements. The reuse of storm water for potable water was not allowed by local authorities. All of the blackwater is treated by an on-site bioreactor and released along with excess storm water into a percolation field located in the garden.

3.3 *Healthy Materials*

Wood is the primary building material for the roof, storing carbon dioxide for the life of the building. Fast + Epp were the structural engineers who worked with Structure Craft to prefabricate the challenging roof shapes and integrate the sprinkler and electrical systems in the factory. A simple pallet of materials was used for the project with polished concrete floors, concrete and rammed earth walls, natural wood, and finishing materials that are not harmful. With the Living Building Challenge "Red List" (2) of banned substances and Perkins+Will's Precautionary List (3), only suitable materials that are not made with harmful substances and do not off-gas were used throughout the project.

3.4 *Beyond Zero for VanDusen*

Going beyond Net Zero was not a project goal for the VanDusen project. Net Zero energy performance was achieved by reducing the energy use and emissions from the site. However, a number of things could have been done to increase the Net Zero performance.

1. Using collected storm water for potable water use in the building through suitable water treatment.
2. Increasing the level of treatment of the blackwater system to tertiary treatment and reclaimed water quality for toilet flushing and site irrigation. These two opportunities could bring the project to Beyond Net Zero Water use.
3. The area of the photovoltaic and solar heat collectors could be increased to reduce net building energy use and provide more heat to the Garden Pavilion building to displace more gas use. There are limitations on the solar collector area available due to the trees on the site and the effect of shading.

## 4. 100 BED HOSPITAL - SMALL HOSPITAL, BIG IDEA

The Perkins+Will New York team was a winner in a design competition for a standardized design for a 100 bed hospital for the future for Kaiser Permanente, a healthcare provider in California. The town of Lancaster CA was selected as the site for the competition location. Lancaster is located on a desert plateau at 719m altitude, inland from Los Angeles. (See the project birds-eye view in Figure 9.) The team set project goals for a regenerative design process that would also result in LEED for Healthcare Platinum Certification.

Figure 9. Birds Eye View of Hospital
(courtesy of Perkins+Will)

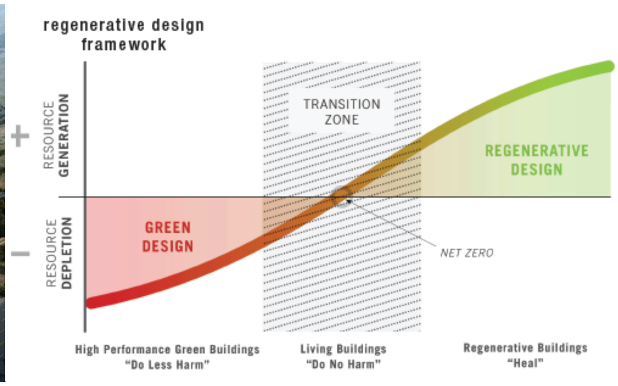


Figure 10. Regenerative Design
(courtesy of Perkins+Will)

A day and a half team charrette lead by Regenisis focused on regenerative design issues. This was a much broader process exploring project options than most of the team had participated in previously. The process was quite challenging to think about issues from a new perspective but also very invigorating and rewarding. Regenerative design looks for opportunities for a development to give back more than it uses – whether for energy, water, materials, site regeneration, or whatever for Beyond Zero performance. (See Figure 10 to see how regenerative design goes beyond green design and the Living Building Challenge. Figure 11 shows the proposed main floor plan and site plan.)

Figure 11. 100 Bed Hospital Ground Floor and Site Plan
(courtesy of Perkins+Will)

### 4.1 *Energy*

The MEP energy team was led by M+NLB engineers as part of the integrated design approach. To limit the capacity and cost of the energy systems, the overall integrated building design resulted in a low annual energy use of 236 $kWh/m^2/yr$ (75 $kBTU/ft^2/yr$) that is about 1/3 of new North American hospital energy use. Access to daylight for patients and staff was an important priority as it has been shown to help patients with healthier outcomes and reduced hospital stays. Direct sunlight was controlled to avoid the cooling load while allowing daylight. Interior courtyards brought light into the treatment areas.

The ability of the hospital to operate should a disaster occur was an important issue and part of resilient design. Biogas from a nearby landfill site and from the organic waste, food waste and site waste water treatment system would fuel a BloomEnergy solid oxide fuel cell to generate the majority of the electricity needed. Photovoltaic panels on the roof provided additional electricity to achieve Net Zero energy use and Carbon Neutral operations. (In Figure 12, the blue area under the upper curve is the excess daytime power sent to the grid while the red area is night time power drawn from the grid.) Normal emergency generator operation would allow full hospital operations in the event of the electrical grid failure.

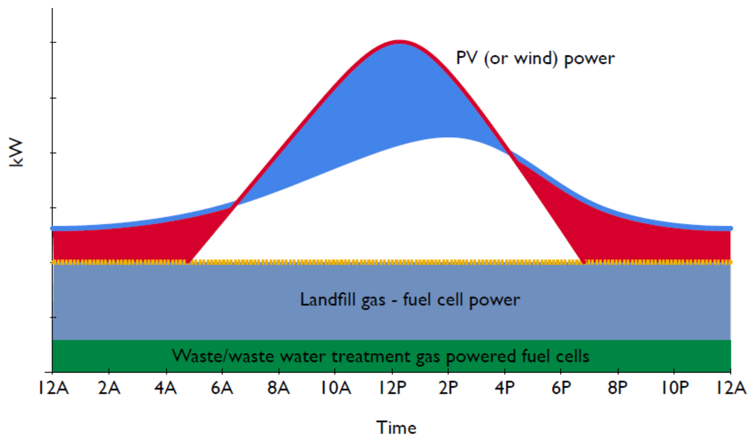


Figure 12. Electrical Power Use and Generation over a typical day.(courtesy of M+NLB)

M+NLB engineers have provided Figures 12 and 13 to outline the performance of the energy systems for the project. Figure 13 outlines the integration of the energy, water, and waste systems in the hospital.

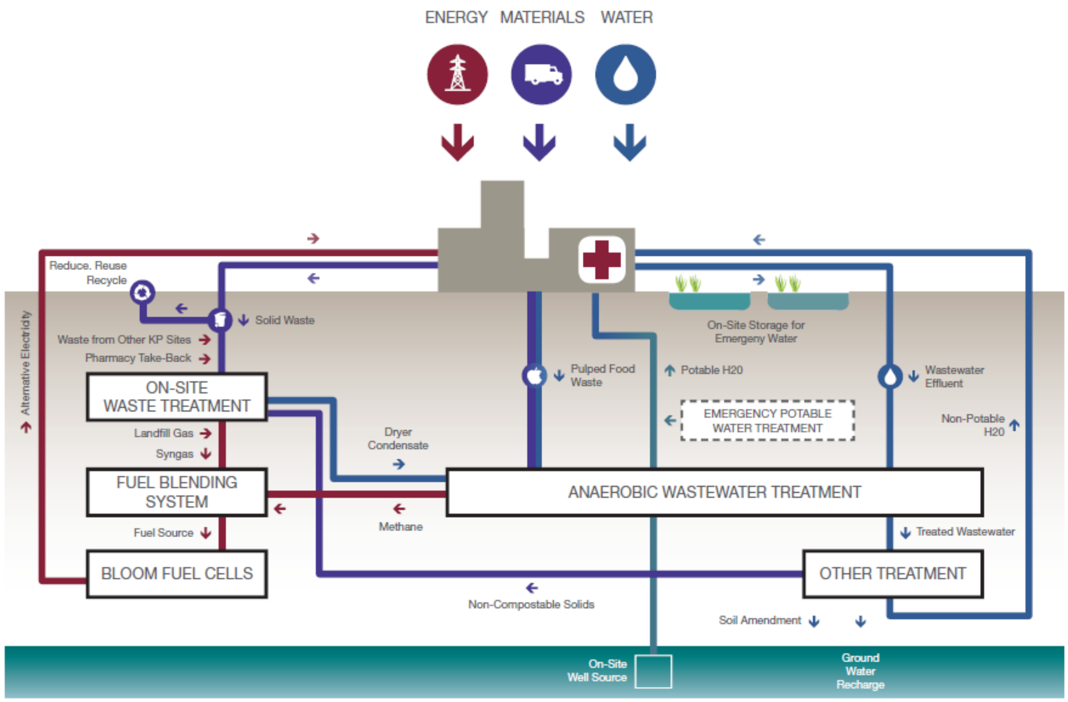


Figure 13. Integrated Energy, Water and Waste Systems for the 100 Bed Hospital (courtesy of M+NLB)

### 4.2 *Healthy Hospital*

In addition to access to daylight, there was goal of a healthy hospital with a specific focus on the materials used for construction. Only materials that have been proven not to be harmful, emit noxious gases during their use or use dangerous materials during their manufacturing would be used as per Perkins+Will's precautionary list (3). With the ventilation systems, this would result in a superior quality indoor air quality and a healthy environment for patients and staff.

A wellness clinic is included in the facility to head off healthcare issues before there is a need for a hospital stay. Local businesses like bicycle shop/rental and fitness centers are supported by clinic programs supporting the local economy.

### 4.3 *Water and the Site*

Wells located on site provide the potable water for the hospital after filtration and treatment. With the desert environment, there is very little annual rainfall so annual well water use will be quite low due to the fixtures/equipment used and reclaimed water reuse. An on-site tertiary sewage treatment with anaerobic digestion and pharmaceutical removal provides reclaimed water for reuse in the hospital, irrigation and to regenerate the adjacent arroyo. Before the valley was leveled for farming, there were wetlands with water draining from the mountains. Currently the arroyos are usually dry and the team worked to restore the waterways and the related flora and fauna. The excess reclaimed water is discharged to the arroyo, regenerating the waterway and creating a treed and shady walking/respite area near a renewed stream for both on site and downstream of the site. The trees and related vegetation will stabilize the stream bank and provide habitat.

### 4.4 *Beyond Zero*

The hospital project did achieve Net Zero performance in many areas including:

- Net Zero energy use,

- Carbon neutral emissions due to building operation.

As in any project, more could have been done to further develop a net positive contribution to the community.

1. Lancaster, CA is a good wind power location but large wind generators on the limited site might not be appropriate. The hospital could partner with a wind power provider to create a wind farm nearby to generate clean electricity for the hospital and the community. The power from a wind farm could be on a different time cycle than the PV power and provide a Net Positive energy option.
2. More PV panels could be installed and possibly provide additional exterior shaded areas to generate additional electricity for Net Positive energy option. Emerging energy storage systems could provide reliable power when wind and solar energy are not available removing any reliance on the electrical grid while excess providing power to the grid.
3. Full waste to energy options were examined but not included in the plan. An appropriately sized system would need to include the community waste stream. There are opportunities to deal with both some organic/food waste and solid waste from the community to produce additional energy for the hospital and community.

## 5. CONCLUSIONS

Three projects, CIRS, VanDusen, and the 100 Bed Hospital have been presented and have shown that Net Positive performance in energy and water with Net Reductions in GHG emissions in building performance are happening. Some follow up tuning of building performance, such as for CIRS, is required to achieve their original goals and indeed provide even higher performance than planned. While providing quite impressive results, each project could have even higher performance with opportunities for upgrades and modifications provided to achieve Net Positive – Beyond Zero results.

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(2) Living Building Challenge download https://ilbi.org/lbc/LBC%20Documents/lbc-2.1
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# How effective are earth tube systems in delivering net positive human well-being?

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ABSTRACT: This paper will review building usage and present research carried out on health studies of buildings and occupants, in the context of standards of indoor environmental quality (IEQ). Through the investigation of conventional building heating, ventilation and air-conditioning (HVAC) systems, the performance and effectiveness of supplying fresh air – at prescribed air change rates – will be reported through case study review. The methods of earth coupling will be presented – drawing from the author's own projects in BC – and other projects in different climatic zones. The data gathered from monitoring of the earth tubes systems – including temperature, humidity and energy – will be presented and discussed in the context of net-positive healthier buildings. The paper will also acknowledge where further system analysis and modification may be required to provide fuller assurance that earth tube systems can deliver higher performance buildings that are net-positive with respect to human well-being.

Keywords: Earth tubes; net-positive; healthy; IEQ; sustainability; ventilation; well-being

## 1. INTRODUCTION

The paper will begin with a review of the way in which buildings are being designed, constructed and operated with respect to providing healthy internal environments for occupants. Reference will be made to published industry standards and recommendations associated with indoor environmental quality (IEQ). Specific focus will be made to air quality, $CO_2$ concentrations, humidity, moisture and mould.

In order to set a baseline for review, conventional engineered systems that provide heating, ventilation and air-conditioning (HVAC) will be assessed in terms of design in relation of the IEQ criteria. The author notes that the definition of 'conventional' is too ambiguous – and in his current experience as a practitioner – conventional methods can be used to describe highly energy efficient buildings as well as those that just meet minimal building code compliance. Therefore he will present a range of buildings that have different levels of performance standard and HVAC systems.

The concept of earth tube systems are fairly well known through the construction industry, although in the author's experience, the level of detailed required to implement a fully successful project is often lacking. One of the reasons for this is due to the cross-discipline design that is often led by the mechanical engineer, although the specification is more suited to the civil engineer who is more familiar with buried pipes. Similarly, this disconnect often repeats itself during construction, where the interface between earthwork and mechanical contractor requires a greater level of communication than would be expected on a standard project.

The dry Okanagan climate is ideal for the application of earth coupled ventilation systems to pre-heat/cool the incoming fresh air to a buildings HVAC system. These earth tube systems take a variety of different sizes, and at the Salmon Arm (Savings and Credit Union) building, there are 3no. 750Ø feeder pipes, into a single 1000Ø header. The concrete pipes are buried under the ground slab, with around 6 feet of soil on top (Figure 1).


Figure 1. SASCU earth tube system under construction, 2012.

As well as the coordination issues that need to be addressed, there have also been concerns about the air quality that emerges through the buried ducts – and whether there is a greater risk of mould-borne illness that could arise from condensation of humid air inside the tubes. There have been well-documented cases (Urbana, 2004) where the monitored resultant air quality has been at risk to health, and through investigations, there have been lessons learnt from these examples that should ensure that these mistakes are not repeated.

At the same time there are also monitored reports that show that earth tube systems improve indoor air quality, when compared to conventional systems (Fluckiger et al, 1998). This is especially true in climates that have extremes of temperature that result in high energy costs to condition outside air for ventilation purposes to mitigate health risks and to improve operational effectiveness. This is the goal of this paper, and the stream of the conference – that addresses creating a net positive effect upon health and well-being of building occupants.

Monitored data of earth tube systems from the author's own projects – in British Columbia (BC) will be presented to show the performance over different seasons. There will be specific focus on thermal performance – the delta T ($\Delta T$) of the 'entering' outside air to the 'leaving' supply air to a building's ventilation system. Based on this $\Delta T$, the operational costs will be compared with conventional systems.

Further added benefits will be examined to include, $CO_2$ concentration, humidity control and mould risk. The findings will indicate that within clear parameters of design, building use and climate, earth tubes systems, when compared to conventional systems, have the potential to provide a net-positive effect to human well-being and health.

The paper will conclude with further ongoing studies that are investigating how performance can be improved that would result in greater enhancement of health and well-being of building occupants.

## 2. BUILDING USE & HEALTH

### 2.1 *Occupancy*

One of the emerging trends of the 21st Century is that people are staying inside buildings for longer periods of time. According to Wargocki P, Fanger. O (1999) et al, in the US the occupancy figure is about 90% of the time. The impact of indoor living, is that people inhabit artificial 'man-made' environments for greater periods of time, and the impact upon their physiological needs being adequately met are being under investigation on many fronts both qualitatively and quantitatively.

### 2.2 *Sick Building Syndrome*

Sick building syndrome (SBS) as a term was first used in the 1980's through the World Health Organisation (WHO 1983 & 1986) and referred to illnesses of occupants of buildings that they worked or lived in. The term is now ubiquitous with any building that occupants do not feel well, and it is important to note that there are definitions that state exactly what is SBS.

### 2.3 *Indoor Environmental Quality (IEQ)*

The common indicators of performance are categorized through key performance indicators of Indoor Environmental Quality (IEQ) – and this includes cleanliness of air, light, acoustics and temperature. The purpose of this paper is to investigate the role that earth coupled ventilation systems can perform in improving IEQ with specific reference to air quality – through comparison of conventional ventilation systems. The goal is to see whether earth tube systems can provide a better quality of life – net positive in terms of health.

### 2.4 *Air quality*

The criteria being considered for air quality are measured in terms of concentration of carbon dioxide ($CO_2$) and humidity. The author recognizes that this limits the research that has been carried out by Fanger et al (1999) – where odor, moisture, Carbon monoxide, formaldehyde and other contaminants are listed. However, the purpose of this paper is to investigate the potential for earth tube systems to deliver an improved, net-positive indoor environment for health.

There are various standards across the world that lists recommended 'safe' concentrations of $CO_2$ within buildings. These include, World Health Organisation (WHO), American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE), have been researched widely throughout the world. The generally held view is that $CO_2$ levels should not exceed 600 parts per million. When $CO_2$ concentrations become too high, the occupants often complain of headaches, drowsiness and in the worst case, the building begins to be labeled as a source of "Sick Building Syndrome", which would result in costly repairs.

## 3. CONVENTIONAL HVAC

### 3.1 *Codes of Practice*

The author is a practicing engineer with fourteen years experience in the UK and now working in British Columbia, and since 2008. Through his work as an engineer, he has worked on a wide range of HVAC systems for a variety of building types including offices, hotels, retail, education, industrial and residential. The Codes of Practice for ventilation design are as follows:

- ASHRAE 62.1: Ventilation for Acceptable Indoor Air Quality;
- British Columbia Building Code (BCBC);
- Model National Energy Code for Buildings (MNECB).

The volumes of fresh air requirements are listed in cubic feet per minute (cfm) per person, and for typical buildings such as offices, the volume is 20cfm/person. According to ASHRAE 62.1, this volume of 20cfm per person, "prescribes supply rates of acceptable outdoor air required for acceptable indoor air quality. These values have been chosen to dilute human bioeffluents and other contaminants with an adequate margin of safety and to account for health variations among people and varied activity levels".

This is the volume used generally in the North American industry for design of HVAC systems and it compares well to European Standards of 10 litres per second (l/s) per person (Building Regulations, Part F, 2010).

### 3.2 *Typical HVAC Design*

The typical HVAC system – as common practice in 2012 – would be to calculate the fresh air requirements based on occupancy or floor area to get a total air supply rate. The next step would be to specify a mechanical air handling unit that is capable of supplying this volume of fresh air the building, whilst taking into account the static pressure losses associated with ductwork, dampers and supply grilles.

The thermal energy required to heat (or cool) the air is provided via heating coils / batteries at the air handling plant, which are served by a variety of thermal sources. These could include gas boilers, heat pumps, district energy or direct expansion (DX) refrigerant coils. The thermal output of the coils must have adequate capacity to meet the thermal demand of heating fresh air through all seasons.

The fresh air, once thermally moderated and supplied to the building occupants, becomes contaminated with the internal environment and must therefore be removed from the building. This is normally provided by a combination of exhaust fans – that draw the air out of the building – and by pressuring the building slightly to allow air to leak through the façade.

Heat recovery systems can be employed to collect the thermal energy on the exhaust air to preheat (or pre-cool) the incoming fresh air. There are a variety of heat recovery units available – with different efficiencies – and their application is becoming more mainstream as part of a drive toward energy efficiency.

## 4. THE EARTH TUBE SYSTEM

### 4.1 *Background*

The use of air ducts buried at a depth below the ground surface to moderate air temperatures are fairly well understood – at least in concept. There are examples of this system with origins from the Middle East, China and other locations with strong climatic seasonal variations.
The recent and growing popularity of earth tube in this era began with the work of John Hait in the Rocky Mountain Research Centre, (Hait 1983) on the Geodome house in Minnesota. The

author first used the system on a project (Mile End Park) in England in 1998 comprising five earth-sheltered buildings.

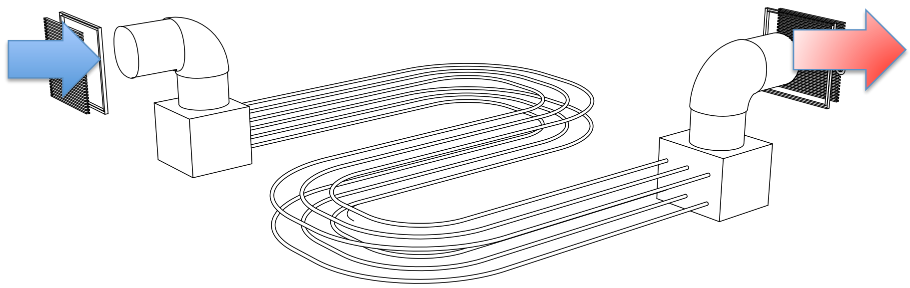


Figure 2: Earth tube system, with multiple pipes.

The principles of the system is that air is drawn through buried pipes in the ground to absorb some degree of the earths thermal energy – that is constant at about 6 feet deep, depending upon a number of criteria including: seasons, geography and geology (Figure 2).

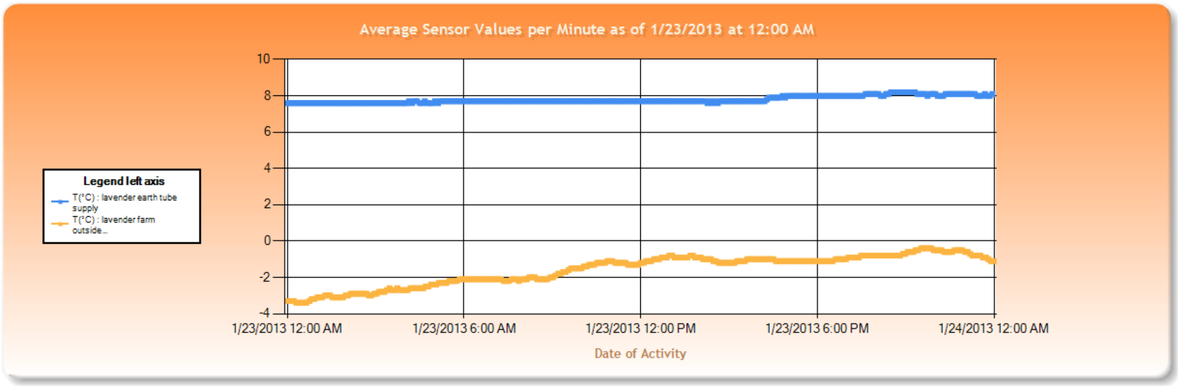
According to Hait (1983), the design of the system is dependant upon climate, soil and velocity. Further research carried out by Jacovides et al (1995) focuses more upon the system characteristics such as the pipe material, length, and diameter.

4.2 *Performance*

The performance of earth tubes for pre-heating/cooling varies from each site and location. For the purpose of this paper, the author has monitored data from two installations in the interior of British Columbia, to use as examples for winter operation. Summer time performance is available for only one of the projects as the sensors were not installed until autumn 2012, and the so the system is being monitored now.

4.3 *Lavender Farm*

The air is drawn though a parallel system of eight, 100mmØ rigid plastic ducts, one hundred feet long each. The air is used for drying lavender and other herbs between harvest and processing. The winter performance for a typical January day is shown in Figure 2.




This shows that temperature difference between outside air and delivered air is between 7-11°C. Another point to note is the steady temperature of the earth tube air supply at around a constant 8°C. The airflow rate is calculated as follows: Q = A * V;

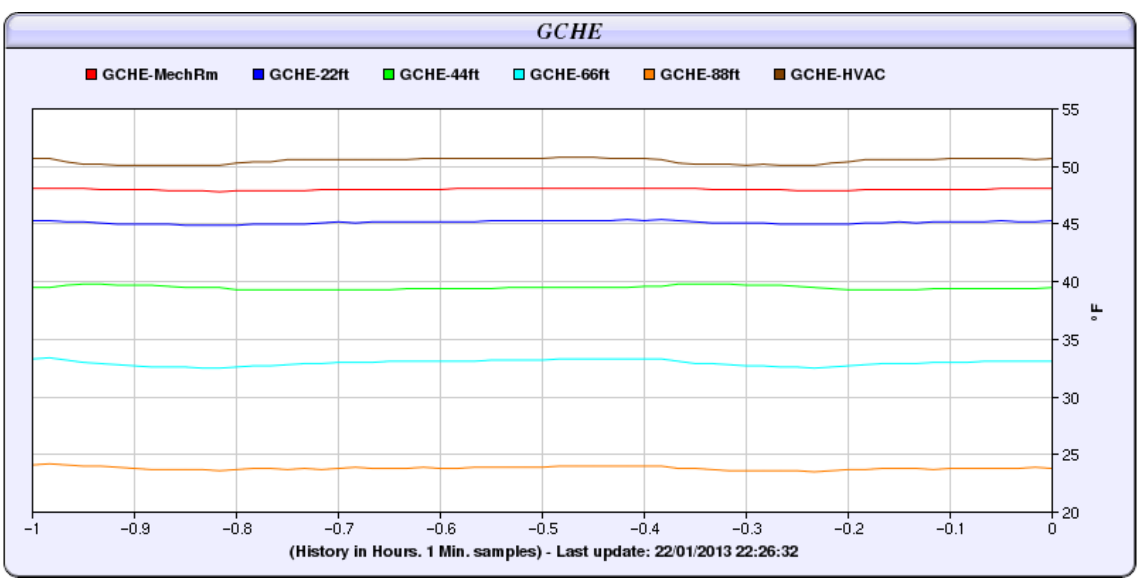
Cross-sectional area = 8 * ($\pi$ * $(100/2)^2$) = 0.063 $m^2$

Velocity = 1.5 m/s

Volume = 0.1 m3/s, say 100 l/s

4.4 *Private House*

The air is drawn though a parallel system of seven, 100mmØ rigid plastic ducts, one hundred feet long each. The air is used as preheat to the geoexchange furnace to serve the dwelling. The winter performance for a typical January day is shown in Figure 3.



This shows that temperature difference between outside air and delivered air is between 26-28°F (15°C). Similarly to the Lavender Farm project the steady temperature of the earth tube air supply at around a constant 51°F (10.5°C). The airflow rate is calculated as follows: Q = A * V;

Cross-sectional area = 7 * (π * $(100/2)^2$) = 0.055 $m^2$

Velocity = 1.5 m/s

Volume = 0.08 m3/s, say 82 l/s

## 5 COMPARATIVE PERFORMANCE

### 5.1 *Conventional vs Earth Tubes*

The results show that for two different cases in the BC interior, a temperature difference (ΔT) of between 10°C and 15°C can be expected on the fresh air supply in winter, by passing the fresh air supply through the earth tube system (Table 1).

| | **Outside Air Temperature °C** | **On-coil Temperature °C** | **Off-coil Temperature °C** | **ΔT °C** | **Heating Energy** |
|---|---|---|---|---|---|
| **Conventional System** | **-3 °C** | **-3 °C** | **24 °C** | **27 °C** | **100%** |
| **Lavender Farm** | **-3 °C** | **7 °C** | **24 °C** | **17 °C** | **63%** |
| **Private House** | **-3 °C** | **12 °C** | **24 °C** | **12 °C** | **44%** |

Table 1.

The two earth tube systems show that there are significant energy savings available. The Lavender Farm saves, 37% and the Private House saves 56% of heating energy to bring the outside air up to an off-coil temperature of 24°C.

### 5.2 *Added benefits*

The off-coil temperature is observed at being relatively constant with respect to the outside air temperature. This means that when the temperature drops lower, then the ΔT will increase, and hence the heating energy savings will be greater.
The goal of the earth tube systems is to deliver fresh air that has been tempered by the earth's stable temperature, to save energy. By saving energy for heating (and cooling) it is more likely that the fresh air volumes will be maintained at a safe level.

## 6 NET POSITIVE

### 6.1 *Measurement*

The goal of achieving a net positive benefit to health and human well being through earth tubes systems will be measured and verified by indoor air quality. The scope of this paper is to present the results of monitored data from earth tube installations during winter to see how much potential energy savings are available.

This is important, for buildings of all sizes, as the cost of heating fresh air that is needed for comfort of occupants – can be significant during a Canadian winter. With higher energy costs, there is a temptation to reduce the fresh airflow into buildings during this season and hence put at risk the occupants health and well being. This is further problematic, especially on buildings where there is no heat recovery system installed as part of the ventilation plant.

### 6.2 *Healthier IEQ*

The results show that using earth tubes, the energy associated with heating fresh air for building supply is approximately reduced by half. This means that is more likely that the minimum safe requirements for health and well being will be met.

By looking at this the other way around, it means that the volume of fresh air could be doubled with no extra cost of heating energy.

This extra volume of fresh air would aid in flushing out further contaminants, moisture, mould and other gases that could build up. This is especially relevant in winter months when windows are closed and overall 'natural' ventilation benefits are at an all time low. Therefore with more reliance upon mechanical systems, they could double the energy flow at no extra cost – or provide the safe minimum for a 50% saving. Either way, the occupant will experience a net positive benefit in health.

## 10 FURTHER STUDY

The scope of the paper has focused on pre-heating winter air to reduce energy costs, and then to encourage higher volumes of fresh air to be supplied to buildings. The author recognizes that summertime cooling should also be presented – as this is a growing demand upon energy due to a number of factors such as climate change, longer occupied hours and growth in electronic equipment that give off heat. The systems monitored by the author have shown a summer performance in the range of 8-10°C: further study is required to gather more data and to determine the risks of heat saturation.

The earth tube system design and installation should also be tested to see how they would perform. Different criteria would involve, pipe materials, depth, air velocity etc.

## 11 CONCLUSIONS

The conclusions show that earth tubes can be used as a method of improving indoor environmental quality – and that this has a direct net-positive impact upon a person's health and well-being.

The current economic climate is such that simple, cost effective systems are required to assist in energy efficiency, construction costs and ultimately occupant safety. The earth tube systems are capable of satisfying these requirements.

Improved health and well-being is important to productivity, economics as well as psychological aspects associated with people, who as was shown are spending around 90% of their time inside buildings.

It will be important for any outstanding doubts or concerns about the air quality from the earth tubes to be addressed in order for a wider adoption of this system to be realised. This may include design guidance based on climatic zones that address humidity and how condensation can be controlled or avoided in the earth coupled system. Studies have shown that the interior of BC and Prairie Provinces (Lee, 2004) – where the air is drier than the coast – have beneficial tempering in both summer and winter.

There are also practical installation aspects to consider – as the construction process covers more that one single Division: mechanical – air handling plant sizing; civil – pipe laying; electrical – sensors and monitoring. It is essential that the interface between these components is clearly understood and managed through the design, construction and commissioning process.

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# A framework for net positive buildings from building scale to urban scale in Japan

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ABSTRACT: Many strategies relating to energy saving and carbon reduction are implementing in building sector in Japan. Most of strategies focus on individual building scale and house scale. To achieve zero energy and carbon neutral condition, or net positive condition, it is needed to consider relationship among buildings, natural environment, and social condition in urban scale. The purpose of this study is to describe a framework to assisting net positive design from Japanese context. This study reviewed several leading edge examples that show how building projects connect neighborhood condition and affect both negative and positive impact. The review covers several projects from a traditional building project to latest urban block project and a house project. Based on review, this study specifies key actor and aspect which contribute positive impact of the project and describe the framework.

## 1. INTRODUCTION

Many strategies relating to energy saving and carbon reduction are implementing in building sector in Japan. Most of strategies focus on individual building scale and house scale. To achieve zero energy and carbon neutral condition, or net positive condition, it is needed to consider relationship among buildings, natural environment, and social condition in urban scale.

"Positive Development" and net positive design concept are not still common at practical situation in Japan. This study tries to prepare primary information to bridge the gap between current leading edge strategies and net positive design strategies considering Japanese context, and describe a framework to assisting net positive design from Japanese context, and also specifies key actor and aspect which contribute positive impact of the project and describe the framework.

## 2. TREND OF ENVIRONMENTAL STRATEGIES IN JAPAN

### 2.1 *Policy and program*

This study investigated the energy and environmental strategies, policy and program relating to building after 2000. Table 1 shows main energy and environmental strategies in Japan. It is classified as the enforcement main constituent at the government, the local government, and other organizations. For the scale of the strategies, it is classified in building level, building & city level and city level.

In the early 2000s, the strategies focused on simple building scale. After the 2010s, some strategies cover both building and city scale. Especially, the Law Carbon City Act has introduce in 2012 and it applies combination of low carbon area zoning and low carbon building regulation.

In latest years, some financial institutions developed environmental rating tools and have stated building rating and financing.

These trends show an expanse both scale of physical boundary and stakeholders boundary relating to buildings.

*Table 1 Main environmental strategies since 2000 in Japan*

| Actors | Scale | Law, Program, Certification and others |
|---|---|---|
| Government | Building scale | ・Energy code for buildings and houses revised, 2010-<br>・Eco-house model project, 2008-11, 20 houses<br>・Low Carbon Building Program, 2012- |
| | Building & City | ・Leading program for Low carbon Houses and Buildings, 2011-<br>・Low Carbon City Promotion ACT, 2012- |
| | City scale | ・Eco - Model City Initiative, 2008, 13 cities (5 large cities, 4 medium cities, 4 Small cities)<br>・Future City Initiative, 2011, 11 cities |
| Local government | Building scale | ・Tokyo Met.Gov. Green Building Program, 2002-<br>・CASBEE, 24 local governments |
| | Building & City | ・Tokyo Met. Gov. Cap and Trade program, 2010- |
| | City scale | - |
| Others | Building scale | ・CASBEE NC, 2002-, 184 buildings<br>・CASBEE home, 2007-, 87 houses<br>・Sumitomo Mitsui Banking Green Building Financing, 2011-<br>・Development Bank of Japan Green Building Certification, 2011-<br>・CASBEE Property Appraisal, 2012- |
| | Building & City | ・CASBEE UB, 2006- |
| | City scale | ・CASBEE City, 2011- |

2.2 *Leading edge projects*

This study reviewed the leading edge buildings examples that open information on what kind of strategies are applied. Table 2 shows the results of review and it classified depending on the building size and the location place, as large buildings in city, small buildings in city, large buildings in local area and small buildings in local area.

In addition, about the environmental, social and economical strategies that are applied to these projects, it classified these strategies into the building scale and the scale beyond the building.

Common strategies;

・Passive design

・ Energy efficiency equipment

New and green strategies relating to energy beyond building scale are follows;

・ Improving energy efficiency of district heating and cooling (DHC) plant

・ Providing energy each others among surrounding buildings

Building No.11 connects hot and cooling water supply from DHC plant, and this building uses low temperature water, which enhancing cascade uses of hot and cooling water after uses of surrounding buildings. This building contributes to improve energy efficiency of DHC plant by installing cascade use of hot and cooling water. Building No.17 also connects DHC and improving energy efficiency of DHC by installing large thermal storage and store hot water or cold water and shifting peak demand. These two examples are still not popular strategies today, but it is expected that series of the low carbon city act and low carbon building program will assist these strategies.

Unique strategies relating to community system are follows;

・ Car sharing

・ Virtual community or remote community by using ICT

・ Energy monitoring and visualization in community scale

・ Providing a learning opportunity about energy and environment issues

The targeted values of CO2 reduction in buildings are around 20-50%, and some houses aim to reduce CO2 around 100%.

*Table 2 Trend of leading edge projects*

| Size | Bldg. No. | Bldg. Type | CO2 reduction target | CASBEE Rank | Strategies for building scale | Strategies for beyond building scale |
|---|---|---|---|---|---|---|
| Urban Complex | 1 | Hospital, DHC | 12% | | RE, PA, VS.,GR | EE, EM,GR |
| | 2 | Office, Resi., | | | PD, EE,RE, GR, EM, | EL, EM, GR, Tenants, VS,CS |
| | 3 | Office, Uni., DHC | 25% | S | EE, PD, GR, EM, | UE, CS, Edu,CP |
| Urban Large | 4 | hospital | | | EE, RE,UE, EM, VS | |
| | 5 | Retail | | | EE,RE, PD, GR | LS, EV |
| | 6 | Complex | 25% | S | PD, EE, RE, UE, GR, EM,VS | EL, EM, Vis, |
| | 7 | Complex, DHC | 32% | | PD, EE, UE, EM, VS | EL,EM, |
| | 8 | Complex | 21% | | PD,EE, GR, EM, VS, | PD |
| | 9 | Office, House | 40% | S | MU,PD, EM, GR | |
| | 10 | Retail | 35% | | RE, EM, VS | CP |
| | 11 | Office | 50% | S | RE,EE, PD, GR, MU, EM, VS, | Ecd, GR, TP |
| | 12 | Office | | S | RE, EE, PD, GR, EM, VS, | |
| | 13 | Office, Hall | 26% | | PA, RE,UE,G, EE,ReM,EM, Vis, Edu | |
| Urban small | 14 | Office | 55% | S | PD, EE, RE, EM, VS | |
| | 15 | School | | S | RE, PD,GR, Edu,EV,VS | RB, LS, |
| | 16 | Office | | S | PD, RE, MU, GR, EM, VS | |
| Local large | 17 | Government | 20% | | PS, EE | Ecd |
| | 18 | University | 23% | | EE, EM | |
| | 19 | Research | | | | |
| | 20 | House | | | | |
| | 21 | House | 66% | | RE, EE,VS | CS, RE, EM,Edu, CP |
| Local small | 22 | Hospital | 60% | | RM, RE, UE, EM, VS | |
| | 23 | | | | | |
| House | 24 | House | | | EE, UN, MU,GR | |
| | 25 | House | 100% | | EE, RE, VS, Ecm | |
| | 26 | House | 60% | | PD, EE, VS, | |
| | 27 | House | 100% | | PD, RE, EE, VS | |
| | 28 | House | 54% | | RE, EE, VS | |
| | 29 | House | | | RM, PD, RE | Virtual community |
| | 30 | House | 73% | | RE, EM, VS | EM, VS |

Legend;

| | |
|---|---|
| CP: Community participation | MU: Material use |
| CS:Car share | PD: Passive design |
| Ecd:Energy Contribute DHC | RB: Regional Biodiversity |
| Ecm; Economical mechanism, Green certificati | RC: Regional climate |
| Edu.: Education | RE: Renewable energy |
| EE: Energy efficiency equipment | Rec: Recycle |
| EL: Energy link with others | RM.:Regional materials |
| EM: EnergyMonitoring and Management | SC: Security |
| EV: Regional events | TP.: Transportation |
| GR: Greening | UE: Unused energy |
| LS: Landscape | VS.: Visualization, "Mieruka" |

## 3. FRAMEWORK FOR ASSISTING ENVIRONMENTAL STRATEGIES BEYOND BUILDING SCALE

### 3.1 *Summary*

Through the review of strategies and leading edge examples, following framework is examined. Figure 1 shows a draft diagram of a boundary around a building and it can assist to visualize mapping of stakeholders and built environment and social system from surrounding of building to regional scale. It provides an opportunity to consider which aspect to be discussed or which can integrate each other by using this of diagram.

### 3.2 *Framework for assisting building scale and beyond building scale*

Table 3 show the checklist to be considered in building scale and beyond building scale. The rows specify social, economical and environmental strategies, and columns specify building, site, neighborhood, city, region and the Global scale, and also who are the stakeholders for each scale.

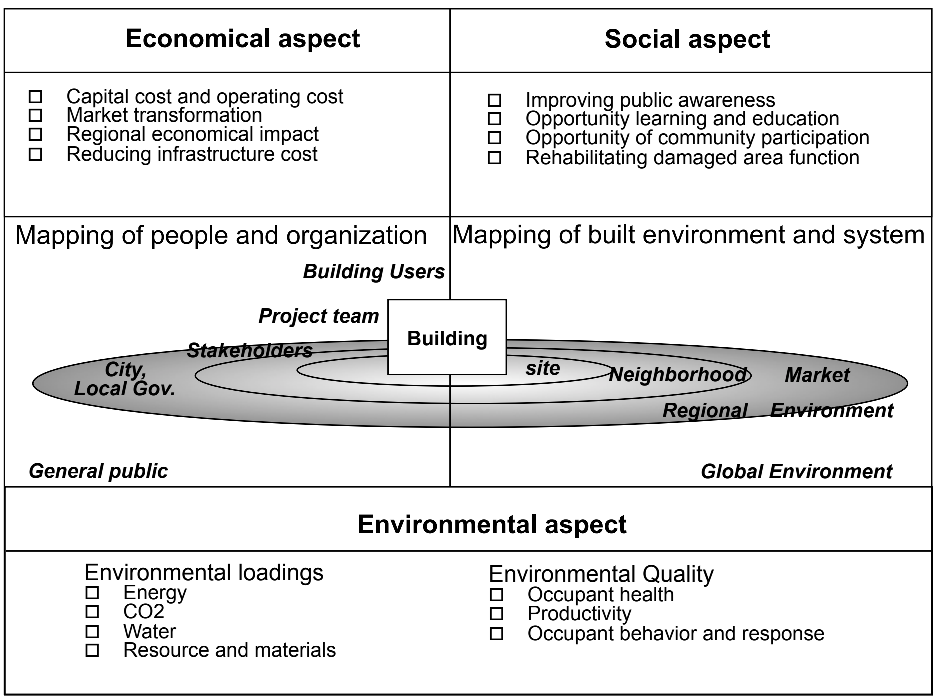


*Fig.1 Diagram of building environment and its boundary*

*Table 3 Checklist to be considered in building scale and beyond building scale*

| | Building | Site | Surrounding site | City | Region | Global |
|---|---|---|---|---|---|---|
| **Social aspect** | Integration with community and public | Public accessibility | Positive impact surrounding area<br>Public image | Public image<br>Public awareness<br>Learning opportunity | | |
| **Econm. aspect** | Capital cost<br>Operating cost<br>Investment | | Reducing energy, water cost around area | Market transformation<br>Positive impact on regional economy<br>Reducing infrastructure cost | | |
| **Env. aspect** | Energy saving<br>Carbon neutral<br>Occupant health | Creating landscape<br>Native habitat<br>Stormwater | Improving energy, water performance around area | Reducing loadings on Infrastructure | | Carbon neutral |
| **Stakeholder** | Occupant<br>Users | Occupant<br>Neighbors<br>Public | Neighbors<br>Public | City | Local government | National<br>World |

## 4 CONCLUSION

This study reviewed the strategies relating to environmental program and measures in building area and leading edge buildings. As a result, in the early 2000s, there were many strategies focus on the building it self, but in late years the change that the strategies about both in building and the surrounding area or city.

Many building project introduce visualization of energy or other building performance by using ICT. Visualization at early stage of introduction, most of cases applied it to within building, but today some of building projects apply it to neighbors of building site or community scale.

In addition, many building projects are used to provide opportunity for users and general public to learn energy and environmental issues.

The trend suggests that the building projects are demanded to seek an opportunity to lead to energy saving, CO2 reduction considering across building scale to city scale. It is important to read surrounding and neighboring environment carefully in each project for every project has different opportunity and different context. In such a process, the diagram and framework, which this study discussed, will be used to support the process.

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# Clarifying Net Energy Positive Design

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ABSTRACT: Over the past decade, numerous building projects have been presented as "net zero" energy or carbon "neutral." Such claims have been made through using a variety of different approaches – onsite renewable energy technologies, carbon sequestration, purchasing green energy credits, etc. Efforts have subsequently been directed at formulating clear definitions of net zero and carbon neutral and these have provided some degree of clarity and theoretical framing of these notions. The emerging notion of "net positive energy" which, rather than simply being considered an extension of net-zero energy, raises a host of new theoretical and practical issues. This paper is directed at clarifying the notion of net energy positive design with particular focus on what constitutes appropriate boundaries, baseline conditions and associated timeframes.

## 1. INTRODUCTION

Increasing public and political awareness and concern regarding climate change and global environmental degradation is translating into a greater demand for demonstrated environmental responsibility across all sectors of society. Within the building industry this is manifest in the demand for higher environmental performance requirements of buildings. Moreover, this development is occurring concurrently with a host of other significant shifts: greater interest in systems approaches and associated synergies between strategies, acknowledging relationships between buildings and infrastructure rather than a sole focus on individual buildings, and the recognition and engagement in local/community initiatives as a powerful means to effect positive change.

### 1.1 *Changing Performance Expectations*

Building environmental performance is, in part, shaped by aspirations. Current performance aspirations themselves have been shaped, again in part, by the widespread use of building environmental assessment methods. In North America, the USGBC's LEED offers "platinum" as its current highest level of performance achievement. Similarly, the UK BREEAM and Australian GreenStar systems offer "Outstanding" and "6-Stars" respectively as their highest performance designations. As such, building developers, designers and other stakeholders within these countries would presumably consider Platinum, Outstanding and 6-Stars as their respective environmental performance aspirations.

Today, however, many North American architectural practices have a wealth of accumulated experience in green design and, indeed, are consistently producing buildings achieving LEED 'Platinum'. This maturing of green building practice has meant that leading-edge 'green' practitioners and clients who have operated at this level are increasingly seeking to push much further than the performance aspirations embedded in current assessment methods. (Cole, 2012) So while the goal of net zero impact is implicit within green building performance and assessment methods, concurrent with the aspiration of achieving high recognition within LEED or BREEAM, the notions of net zero energy and carbon neutrality have become explicit performance goals. Indeed, such aspirations are increasingly embedded in national energy policies with many countries declaring that all new buildings must conform to net zero-energy and/or carbon neutral emission standards by a certain date (Dyrbøl *et al*., 2010; Rovas *et al.*, 2011).

As has been argued in many publications (McDonough and Braungart, 2002; Reed, 2007), green design is primarily directed at "doing less harm" or, more generally, reducing the degenerative consequences of human activity on the health and integrity of ecological systems. This is also embedded in the language and performance criteria in the building environmental assessment methods. Recently, however, the notion of buildings potentially offering a net positive performance is garnering greater interest – driven largely by the increasing literature calling for a fundamental reframing of design. (Birkeland, 2008; du Plessis, 2012; Mang and Reed, 2012) Birkeland (2012), for example, suggests that the necessary "paradigm shift to net positive design will not occur until the legacy of the negative institutional and intellectual infrastructure of [Ecological Sustainable Development] is challenged." (p.165)

This paper is directed at clarifying the notion of net positive design with particular focus on constitutes appropriate boundaries, baseline conditions and timeframes associated with Net Energy Positive Buildings. It begins first by identifying the conceptual underpinnings of net positive, then it summarizes the key definitions and characteristics of Net Zero Energy Buildings before finally exploring the additional considerations, distinctions and implications related to the emerging notion of Net Energy Positive Buildings.

## 2. NET POSITIVE

Mang and Reed (2012) and du Plessis (2012) present the key attributes of regenerative design and development that promote a co-evolutionary, partnered relationship between humans and natural systems rather than a managerial one and, in doing so, builds, rather than diminishes, social and natural capitals. It is not the building that is 'regenerated' in the same sense as the self-healing and self-organizing attributes of a living system, but by the ways that the act of building can be a catalyst for positive change within the unique 'place' in which it is situated. Within regenerative development, built projects, stakeholder processes and inhabitation are collectively focused on enhancing life in all its manifestations – human, other species, ecological systems – through an enduring responsibility of stewardship. (Cole, 2012) Of relevance to this paper is that the notion of regenerative design raises the promise that buildings can "add value" and be designed and operated to generate more than they need to fulfill their own needs. A key issue in net positive design is, therefore, not simply one of generating more energy but identifying the purpose and designing how the excess resources will be deployed.

Consistent with the fundamental tenets of regenerative design and development, Birkeland presents the idea of net Positive-Development as "physical development that achieves net positive impacts during its life-cycle over pre-development conditions by increasing economic, social *and* ecological capital." Positive Development, she argues, would not only "generate clean energy, air and water"….but would "leave the ecology better than before development." (Birkeland, 2008, p.xv) Embedded within this position is that the renewable energy generated by a building not only offsets that associated with the construction of the building – its embodied energy – but also that of the native landscape prior to development. A similar argument has been presented by Olgyay and Herdt (2004) and Bendewald and Olgyay (2010).

A more prevalent concept of net energy positive design generally relates to:

- Managing energy resources, carbon and other emissions (Torcellini and Crawley, 2006);
- Producing more energy than is needed by a building or system, and exporting this to other systems, i.e., "energy storage management or feeding the extra energy produced to the grid" (Koutroulis, 2006).

The notion of Net-Positive Energy buildings, while following many of the same principles as Net Zero building, introduces several new requirements and possibilities. This paper is primarily interested in the consequences of viewing the role of a building in adding value to a system in which it is part to make it more resilient to future stresses such as "climate change, the change towards a multifunctional and diverse society, the increasing individualization and the observed change in the type of end-users wishes and demands." (Bluyssen, 2010)

## 3. ENERGY EXCHANGE

Conventional building energy performance derives from the efficiency with which the supply of energy from utilities meet a building's various requirements for comfort provisioning, equipment and various operational processes. It is a one-way flow of energy from the utility to the building that, after fulfilling the various services, finally ends in dissipated heat/carbon emissions. By contrast, the issues explored in this paper involve a much more complex set of potential energy exchanges associated with both Net Zero Energy and Net Energy Positive buildings:

- *Grid-connected:* Two way electrical energy exchange with the utility grid wherein onsite electrical energy is sent to the grid when in excess of needs or drawn from the grid when the onsite electricity generation is insufficient. Grid connection is a necessary and core requirement of net zero energy buildings. Dirks (2010) argues that, '[d]epending on the timing of net demand or net generation and the variability of hourly electricity rates, a net zero-energy facility with "net-metering" may have a net electricity cost or credit.'
- *District heating:* As above, depending on a building's need, thermal energy is drawn from or deposited in a common thermal energy distribution loop.
- *Energy scavenging:* Using waste heat from processes in an adjacent building through dedicated local infrastructure.

The importing of energy to a Net Energy Positive building comes from the electricity and natural gas supply distribution networks. However, the exporting of excess energy to adjacent buildings or those within neighbourhood is in form of 'electricity' (generated from the building's renewable energy sources) and waste heat (heat collected from building services or processes).

### 3.1 *Net Expectation Benefit*

All the above approaches require a clear link between buildings and infrastructure and associated partnership agreements between agencies/stakeholders engaged in the energy exchange. The most typical agreement relates to the selling and purchasing cost of the energy involved in the exchange.
The notion of "Net Expectation Benefit (NEB)" has been proposed as a key factor in the discussion and definition of net positive energy assessments (Bojić *et al.*, 2011, Kolokotsa *et al.*, 2011). NEB is understood as the generation–consumption difference between the exporting and importing buildings weighted appropriately by the price that energy is sold or purchased, and thereby represents the anticipated monetary gain from the exchange. Here, Kolokotsa *et al.*, (2011) emphasise that the maximization of the Net Energy Benefit is not equivalent to the maximization of the "Net Energy Produced." The former represents the target set by the building operator to "minimize operational costs or, equivalently, maximize return on the energy

efficiency measures investment", while the maximization of the Net Energy Produced is considered the "most environmentally-friendly approach since it maximizes the energy produced from the building." (Kolokotsa *et al*., 2011, p. 3077)

### 3.2 *Net Energy Expectation and Indoor Comfort*

The notion of a Net Positive Energy building is premised on the generation of more energy by a building than is needed to meet its own requirements. The excess energy can be placed into the electrical grid or exported to adjacent buildings to offset their energy requirements. In technical terms, the potential exchange between buildings depends on their relative energy use – how much, what quality (exergy) and when it is required – and their ability to generate energy – again, how much, what quality and when it is produced. The former of these is, to a large extent, related to the expectation for energy services required by buildings which, in the majority of cases is dominated by comfort provisioning. This relationship between energy expectations and comfort requirements associated with the importing and exporting buildings is captured in the notions of "Net Energy Expectation" and 'Comfort index' (Kolokotsa *et al*., 2005, Doukas *et al.,* 2007, Dalamagkidis *et al.,* 2007).

## 4. NET ZERO ENERGY BUILDINGS

Torcellini *et al*. (2006) argue that "[t]he way the zero energy goal is defined affects the choices designers make to achieve this goal and whether they can claim success" and proceed to offer a clear definition of Net Zero Energy. A central notion within Net Zero Energy, they suggest, is that a building can meet all of its "energy requirements from low-cost, locally available, nonpolluting, renewable sources" or, more specifically a buildings that "generates enough renewable energy on site to equal or exceed its annual energy use." A key part of their definition relate to:

- Distinguishing between renewable energy sources located on the building, on the site or off-site;
- Distinguishing between primary (or source) energy and site (or delivered) energy;
- Distinguishing between electrical and natural gas energy sources and accounting for this distinction through their respective Resource Utilization Factors.[1]

More recently, Sartori *et al*., (2012) have provided further clarifications:

- The inherent interaction between buildings and energy grids means that every country or region faces different challenges with respect to the energy infrastructure in addition to other regional considerations such climate and building traditions;
- The physical boundary for defining net zero energy may be a single building or a cluster of buildings with the latter implying that an overall net zero condition may be attained through the synergy between several buildings which individually may not necessarily be Net ZEB;
- Two-way grids must be available at the physical boundary to define a Net ZEB. A two-way grid - the power grid or local thermal networks, such as district heating/cooling networks - can deliver energy to and also receive energy back from the building(s).

## 5. NET ENERGY POSITIVE BUILDINGS

The majority of the emerging literature on the notion of Net Energy Positive buildings typically place it alongside Net Zero Energy and consider it to be guided by the same key concepts/principles. (Kolokotsa *et al*., 2011, Wang *et al*., 2009) In this way, a simple definition of a Net Energy Positive building could be one that generates more energy than it uses over a declared period of time, e.g., over a year. Several issues relate to this definition, but those of particular interest to this paper are:

- *Partnering:* As with net zero energy, net positive energy is a systems approach linking the performance of a building with that of others through energy infrastructure that involves a series of negotiations, partnerships and agreements with the associated stakeholders. Certainly a net zero energy building involves an energy and economic exchange with the power utilities, but net positive opens up a host of different exchanges, negotiations and partnerships.
- *Building Types:* Different building types offer different potentials for being Net Zero Energy or Net Energy Positive. Griffith et al. (2007) identify that achieving the ZEB goal on a given building project depends on four characteristics: (1) number of stories; (2) plug and process loads; (3) principal building activity; and (4) location. The issue is one of the extent to which energy demand can be reduced and the ability of the building to accommodate renewable energy systems such as Photovoltaics. Their US-based study indicated that offices need 67% energy savings, warehouses 6%, educational facilities 43%, and retail 44% before PV systems could provide sufficient energy to achieve Net Zero. By extension, greater reductions in energy demand would be required to achieve Net Energy Positive as well as greater potential to accommodate onsite renewable energy systems.

The current emphasis of building energy efficiency or Net Zero Energy relates to the performance and energy/economic benefits accrued by an individual building. Such is the case for the simple definition of Net Energy Positive defined above. However, if a broader framing of net positive is considered, then the benefit gained by the larger system within in which the building sits assumes importance. Since the notion of Net Energy Positive sets buildings as part of a system/neighborhood and explicitly linking them with infrastructure, a number of broader potential benefits emerge, e.g., by exploiting onsite renewable energy sources and exporting surplus energy to the utility grid increases the share of renewable energy within the grid (Sartori *et al*., 2012).

5.1 *Net Energy Positive Buildings & the Grid*

Dirks (2010) examines the significantly different demand profile that a net zero-energy project has compared to that of a conventional building. He argues that the "wide-spread implementation of net zero-energy facilities would significantly change the load profiles that the grid must serve" such that:

- While the absolute energy demand levels would decrease compared to continued development of conventional facilities, the shape of the demand profile (i.e., the extent and timing of peak demand) could change significantly.
- Existing peaks may be flattened and new peaks may be created as a result of the onsite renewable energy generation.

The current number of net Zero Energy buildings is small and the number claiming to be net energy positive is negligible compared to conventional or even low energy buildings. Dirks (2012) raises questions regarding the relationship between the buildings and the utility grids should the number of Net Zero Energy buildings significantly increase. He offers several conclusions of relevance to this paper:

- Without consideration of their impact beyond the building, the widespread adoption of ZEBs will almost certainly lead to suboptimal outcomes when viewed within a broader energy context.
- The value of the energy being produced is as important as the amount in formulating

appropriate design strategies for ZEB buildings.

- Disruptions to the grid associated with a significant level of PV generated electricity from increased ZEBs can be minimized by matching energy loads to the time of peak PV generation.
- Preventing generation peaks of PV systems in ZEBs from flowing back to the grid by directing to some onsite a combination of thermal storage, thermal mass and possibly pre-cooling, phase change materials, chilled water or ice storage and some form of electrical energy storage, "would allow for nearly unlimited penetration of ZEHs."

While many of the above issues are clearly equally applicable to Net Energy Positive buildings, the potential energy exchanges between buildings in addition to the grid connections create a host of new possibilities to minimize peak flows to the grid.

5.2 *Expanding the Range of Energy Services*

Studies examining the potential for buildings to achieve net zero energy (Griffith *et al.,* 2006; Torcellini and Crawley, 2006) suggest that the percentage of commercial floor area able to reach this goal decreases with the increase in number of floors. This derives from the combinations of results from a decrease in daylighting and solar energy potential and an increase plug loads relative to heating and cooling. Goldstein *et al.,* (2010) raise a host of concerns regarding a possible interpretation here that low-rise development less three story buildings is necessary to meet net zero energy goals and argue that:

- It is directly at counter to the goal of reducing transportation energy through high-density development.
- If the definition of Net Zero Energy requires on-site energy generation, this could result in density limits that would create higher transportation and infrastructure emissions than is reduced as a result of improved building performance and onsite energy generation.
- The "on-site" requirement inherent in the zero energy definition could also eliminate the use of rooftop area for personal open space, urban food production, or water collection.

A significant conclusion from Goldstein *et al.'s* paper is that the exclusion of transportation energy from the discussion and framing of net Zero Energy projects, can ultimately lead to sub-optimization in the use of energy at the larger scale. Interestingly, the California Public Utilities Commission (2007) offered a significant shift in the definition of net zero buildings: "Zero Net Energy is herein defined as the implementation of a combination of building energy efficiency design features and on-site clean distributed generation that result in no net purchases from the electricity or gas grid, at the level of a single "project" seeking development entitlements and building code permits. Definition of zero net energy at this scale enables a wider range of technologies to be considered and deployed, including district heating and cooling systems and/or small-scale renewable energy projects that serve more than one home or business." (California Public Utilities Commission, 2007, p.38). Rohloff *et al.,* (2010) suggest that since a "project" within this definition can range from a single building to an entire development, "effectively sets the stage for ZNE "communities" and further deepens the nexus between building and transportation energy use."

It is anticipated that the number of Plug-in Hybrid Electric Vehicles (PHEVs) in California and other locations will increase over the next few decades and that their owners will recharge them at home. Rohloff *et al.,* (2010) suggest that while PHEVs electric charging loads are expected to remain relatively constant over the next 20 years in California, home energy loads will likely to be reduced as energy prices and building energy codes become more stringent. They show that, by 2030, PHEV charging in California will "account for 20% of a typical home's total energy use and will surpass its electricity use." The added charging electricity required PHEVs will need to be met by an increase in the area of onsite photovoltaics and, as such, invariably affect the ability of a home to achieve a net zero energy performance.

## 6. TIME-FRAME

In net Zero Energy buildings, the time-frame is defined as the period of time over which the building calculation is performed to establish when a balance is met between energy demand and renewable energy supply. This is typically one year but, given year-to-year variations in climate and energy use, a balance may clearly not always be achieved over this time period. Although one year could be selected to designate if a building generates more energy than it uses to be designated as net positive, this would significantly limit the potentials of a net energy positive approach.

Current discussions and definitions of net-zero energy relate only to the operational energy – that is, the onsite generation of energy required to offset a building' annual operating energy (heating, cooling, etc). Hernandez and Kenny (2010) acknowledge that a building's full life cycle would be a more appropriate period for the energy balance, and by implication a discussion of net energy positive. By using the life-cycle, it is possible to include not only the operating energy use, but also the energy embodied in the building materials, construction and demolition and/or technical installations. Within the notion of "life cycle zero energy buildings" the excess energy production is therefore considered to offset all the energy associated with the construction and operation of a building. The expectation, therefore, would be the highest quality of net energy positive system that results from the highest energy performance of the system operation combined with the lowest embodied energy in materials used for system infrastructures associated with the on-site or off-site energy production and transmission services.

## 7. CONCLUSION

A considerable amount is known about net Zero Energy buildings and, indeed, their definition has been subject to considerable scrutiny and clarification. While net Energy Positive buildings share several of same characteristics, the primary ambition of this paper was to identify those that are unique to a net energy positive system. Three key distinctions are:

1. Rather than a two-way energy exchange between an individual building and the grid and where the benefits are primarily financial and accrued by the building owner, a net positive approach involves a more complex set of energy exchanges and partnerships.

2. Rather than only considering operating energy, the broader spatial framing of net positive potentially captures building energy and transportation energy relationships.

3. Rather than defining the balance period between demand and energy generation over one year, the notion of net positive potentially extends this timeframe to the full-lifecycle and thereby captures operating energy and embodied energy relationships.

Other potential issues/outcomes from the paper are:

- Rather than considering only the generation of more exporting energy versus its importation rate to individual buildings or the grid, net positive energy design should seek the maximization of energy performance in a system-based approach. As such, buildings, landscape, infrastructure and services must be considered as elements of a system/neighborhood collectively as being directed at providing the highest import-export and generation-consumption performance. This extends beyond technical systems and considers inhabitant behaviour and engagement critical to achieving successful performance;

- Rather than focusing solely on the quantity of energy use and exchange, a net positive approach is equally concerned with energy quality, i.e., striving for the lowest waste of energy during the processes of export-import and the lowest transformation of a part of energy to its lower quality forms. To achieve this goal, it will be necessary to improve how, when and where energy is exchanged within the system.
- Improvements will invariably be required in the management and controlling systems associated with energy importation-exportation. The higher demand of energy import in an uncontrolled approach calls for the energy-exporting building/s to provide more infrastructures and utilities to generate more renewable energy, e.g., more PV capacity, wind generators, etc. This in turn, may translate into an increase in a building's embodied energy for the production, installation and maintenances of such systems.

In summary, the paper highlights the importance of striving for 'high-quality net positive' rather than simply responding to higher Net Energy Expectation Benefit demands in a financial-driven approach.

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ENDNOTES

[1] Multiplier applied to the quantity of fuel or energy delivered to a building site, which provides a quantitative estimate of the energy resources consumed in providing that fuel or energy. Variant multipliers account for the burden of processing, transporting, converting, and delivering fuel or energy from the point of extraction to the building site. (http://wiki.ashrae.org/index.php)