ECOLOGICALLY ENGINEERING CITIES THROUGH INTEGRATED SUSTAINABLE SYSTEMS PLANNING

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INTRODUCTION

Every day more evidence surfaces about the dire state of the environment. More and more, sustainable development is fundamentally about meeting human needs while restoring balance to the global ecosystem that is failing. Greenhouse gas emissions reductions targets and other new environmental performance targets are rapidly being adopted across the globe to try to shore up this degradation.

We are finally entering the era of broad scale environmental accountability. Achieving sustainability performance targets across complex and integrated social, ecological, and economic systems requires new ways of engineering the way we interact with the environment. In turn, ecologically engineering the built environment requires new quantitative performance approaches to planning. It requires understanding and analyzing the complex systematic relationships between the built and natural environment and capitalizing on the efficiencies that can be found through integrated design.

The sustainability movement is currently focused on reducing greenhouse gas emissions, but the threats to sustainability run much deeper than that. Climate change is driving changes to nearly all ecosystem services upon which we rely. Reducing carbon emissions has taken a front seat in sustainability programming, but typically through a somewhat focused lens of energy and transportation systems.

This paper will discuss an approach to sustainability that is more holistic and ecosystem based. One that optimizes the ecological opportunities of a site and technology to make the built environment more sustainably integrated with the natural environment at the site, region, and global scale.

A NEW SUSTAINABLE PARADIGM

Traditionally, much interest has been given to certain regulated aspects of ecology such as sensitive and endangered species or water quality, with the result being a lack of focus on other related components of what makes an ecological landscape. We have found that by integrating ecologists' principles into design, a new paradigm for sustainable development is emerging.

Comprehensive ecosystem services planning for the built environment is the framework we must consider to optimize what we build. It is time to pull this all together so large complex development projects can take a 360 degree view of sustainability and capture the benefits of manmade and natural systems interaction.

Balanced sustainability also requires solving the challenges of implementation: how to coordinate the development process so that sustainability goals addressing finer scale components are effectively integrated into broader scale strategies and vice versa. In many respects, town and ecological planners are on the cusp of the next generation of sustainability planning.

Being fueled by the emerging necessity of meeting targets for reducing and adapting to climate

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change coupled with advances in knowledge and information technology, the next generation of sustainability planning is about bringing quantitative, scalable, and systems-integrated sustainability performance analysis to every project at every scale. City and regional land use and conservation systems will require optimization to collectively achieve a high level of global ecosystem function that can sustain us for the long term.

A quantitative systems approach to engineering cities and communities may also bring fringe concepts such as nano-technology, biomimicry, and other next generation technologies into urban planning and city operations. This essay will explore this issue by describing several leading edge approaches and tools employed by EDAW, Inc., to integrate ecological aspects of urban planning with other sustainability strategies, while allowing a realistic cost/benefit assessment of the multiple choices a developer or public agency confront.

THE DEVELOPMENT CLIMATE

A number of highly promising sustainable city proposals have surfaced over the last few years in China and the Middle East, but none yet has shown the ability to deliver on the promise of truly sustainable development. Whether these projects failed due to economics, the planning approach, imprudent goals, or a combination thereof, the sustainable development world has yet to deliver on this promise.

The emergence of regulations mandating reductions in greenhouse gas (GHG) emissions and climate change adaptation planning, coupled with the growing mainstream concern and awareness about climate change and sustainability, have lead to increased pressure for developers and governmental entities to plan and design new communities (and retrofit existing ones) that achieve higher levels of environmental performance. Consequently, the fundamental strategies for urban form, transportation, energy, and policy development are being rethought, reconsidered, and redefined across the globe.

The dire straits of the current economy add additional stress to achieving meaningful increases in balanced sustainability. The recovering market will most likely demand extremely cost sensitive product solutions. Energy, water, and other measures will need to be carefully designed to provide strong economic incentives to be acceptable to the building community. New tools are needed that allow a fine honing of strategies that allow real increases in energy, water, and mobility efficiencies while maintaining "good fit" in developers' pro forma procedures.

CREATING AN ECOLOGICAL COMMUNITY

It is becoming increasingly evident that reducing only carbon and water footprint without creating a healthy and robust ecological context results in an incomplete sustainability picture. And at a more pragmatic level, it foregoes the opportunity to gain synergies and benefits (both environmental and economic) from other related *ecosystem services*.

Whether for a new project or an existing community, sustainability planning must begin with an understanding of the site ecology. Through the multiple lenses of ecology, sustainability, and urban design, each site offers diverse ecological capabilities to enhance the built and natural environment. The first step is to evaluate the various natural systems it contains and the ecosystem services it provides.

An *ecosystem services analysis* of a site is a measure and inventory of the various contributions that the natural systems of a site make to the man-made and natural world. These contributions include cleansing water, absorbing or processing carbon dioxide and other pollutants, producing oxygen and other beneficial compounds, controlling erosion, creating food, storing water, providing recreation, maintaining balance between competing systems, and others. In contemporary times, such an analysis typically reveals a degraded landscape with levels of ecological function drastically reduced from their historic character.

For example, many sites that were once net carbon sinks, annually storing vast amounts of carbon from the atmosphere in soils and vegetation, now are the site of CO_2 emissions from fossil fuel burning and land clearing at levels hundreds or thousands of times their historic rates of uptake. Sites that recharged millions of gallons of water annually to aquifers, now remove more water than they recharge. Often sites contain some biodiversity, but only as small populations in a disconnected pattern across the landscape. On nearly every site, the ecosystem services analysis clearly exemplifies why our cumulative land use practices have resulted in a global ecosystem far out of sustainable balance.

While most of the sustainability movement is fixated on trying to reduce greenhouse gases, in the long run, our inefficient use of land and the degrading of ecosystem services such as water supply, flood protection, biodiversity, and/or agricultural systems are at least equally critical to sustainability. To achieve true sustainability, we must find new ways for land use to take advantage of the full range of ecosystem services, enhance them if damaged and restore balance to their declining ecosystem functions and biodiversity, maintain natural hydrologic cycles, and minimize input of energy and water and generation of waste. Additionally, the impacts of the carbon cycle.

Traditionally, such factors as recreation, aesthetics, sensitive species protection, and management of residual undevelopable land were addressed by landscape and open space programming in community development plans. While this approach often resulted in immediate economic and social benefits and entitlement relative to compliance with today's basic environmental regulation, it overlooked ecological opportunities to minimize impact, add value, and enhance the environment through win/win (environment/development) design strategies.

More ecologically integrated development approaches seek to reduce impacts on the ecological footprint, tap into a site's natural sustainable resources, and even to maximize the value of open space, landscape, and built features as resources to regenerate ecological degradation.

Integrated systems approaches also recognize that overall biodiversity has a place within the community fabric and should be planned for, rather than treated as just a residual feature in leftover areas. Local climate, wind patterns, renewable water and energy resources, agricultural soils, and biodiversity are all features of sites that can become organizing, sustaining, and identity-building resources for a community.

These resources can be used to support community agriculture, modify site climate for a more energy efficient and pedestrian friendly community, leverage higher densities and transit-oriented development to create more robust and sustainable biodiversity networks, and enhance landscape carbon storage to mitigate climate change.

BIOMIMICRY AT THE COMMUNITY SCALE

Considering the ecology of every site in the context of spatial context, temporal scales, and ecosystem processes is key to understanding the site's true design potential while ensuring that the highest and best use of the land is achieved. At the smallest scale, species can be evaluated for how they naturally adapt to the site (and similar sites) in order to identify ways to possibly mimic their beneficial characteristics and adaptability in community and building design. This idea of mimicking nature in design has been dubbed "biomimicry" and is beginning to be applied in building design and technology.

By expanding this idea to include larger landscape-scale disciplines such as ecosystem ecology, watershed ecology, landscape ecology, and conservation biology, we can apply biomimicry or ecomimicry to the creation of broad-scale land use patterns that function more like natural ecosystems and biological communities. It is at these broad scales that ecological degradation and climate change adaptation issues might be more effectively confronted.

Issues such as securing water supply; carbon storage across soil districts, rising seas, and changing hydrologies; feeding a growing planet; balancing nutrient loading of watersheds, or migration of biodiversity to new ranges with climate change, all require coordinated, broad scale application of biomimicry and ecosystem integration principles. At all scales, planning approaches should seek solutions that promote climate change resilience, a reduced on- and off-site ecological footprint, a flourishing and equitable community, and economic success.

CLIMATE CHANGE ADAPTATION

Changes in water and temperature regimes on land are the two primary drivers of climate change adaptation. While the basics of these changes are reasonably understood, the great challenge lies in understanding the diverse ripple effect of ecosystem change that will follow. Ecosystem services such as agricultural productivity, flood protection, urban heat island control, energy and water supplies, and biodiversity are all threatened by climate-driven ecosystem change.

Changes in ecosystems are so complex, interrelated, and difficult to model that a recent report by the United States Climate Change Science Program suggested that, "A primary premise for [climate change] adaptive approaches is that uncertainty, change, novelty and uniqueness of individual situations are expected to define the planning backdrop of the future." (Joyce et al. 2008). The old environmental planning paradigm, which assumed that ecosystems were at some equilibrium state, must be retooled to account for substantial and highly complex ecosystem change (Millar and Woolfenden 1999). New, dynamic planning approaches will be fundamentally different from today's strategies and must be highly adaptive, multidisciplinary, and accommodate a high level of uncertainty.

Accommodating climate change will require new development designed for change, transformation of inappropriate existing land uses, and reducing current stressors on ecosystems (e.g., improving ecosystem resilience and resistance to climate change through repairing degraded watersheds, habitat fragmentation, or other degraded natural processes and services, etc.).

Sustainable planning approaches must foster regenerative strategies that rapidly transform landscapes to support regional adaptation of both built and natural systems. Although most adaptation decisions will be at jurisdictional units, the eco-region is the preferred context in which to evaluate and plan for climate change impacts. Improving potential for effective adaptation strategies should include a process of modeling impacts, identifying vulnerabilities, establishing appropriate infrastructure, and integrated regional planning.

The following climate change adaptation concepts are examples of those being increasingly integrated into master planning:

- Changing water regimes to accept shifts in precipitation patterns, flooding, and rising seas.
- Enhanced conservation networks to allow biodiversity migration patterns and niches to adjust to shifting climates.
- Carbon sequestration to help reduce atmospheric carbon dioxide and the rate of climate change.
- Urban heat islands and local temperature change modification to reduce the impact of temperature shifts.
- Analyzing the people connection to create an understanding of the climate change processes at work on the site, and shift the behavior of both as appropriate.

INTEGRATED PLANNING AND DESIGN

To achieve balance and efficiency when confronting the complexity in, and interaction between, the various natural and man-made systems, the concept of *integrated design* helps link together what conventional planning and engineering methods deal with separately. Integrated design is about interrelationships; how natural systems, infrastructure, and building design affect each other so that high levels of performance in one system can be leveraged to reduce the costs or improve the performance of other systems. What has been termed *whole systems thinking* allows projects to achieve and exploit as many of these linkages as possible, which is the goal of integrated design.

Integrated design is unattainable without a shift in how the key participants in a development project (client, design team, and subsequent builders) think and collaborate. The Rocky Mountain Institute (RMI) was an early definer and advocate of this approach. In leading sustainability projects, RMI has successfully identified a project's potential to "tunnel through the cost barrier" by identifying system interactions that can result in net cost reductions by innovatively achieving high sustainability targets in multiple systems.

Developing the right team is the first step toward integrated design. Half the battle of achieving integrated systems sustainability planning is creating a teamwork process that seamlessly allows communication and feedback between experts of various systems. It is essential to follow a collaborative approach that integrates: 1) best sustainability practices, 2) research driven market parameters, 3) cost/benefit driven implementation strategies, and 4) a dynamic urban design and placemaking framework.

The team must have the capacity to articulate a sustainability framework at every level of scale: regional, city, district, neighborhood, block, building, and place. This holistic, organic view of sustainability distinguishes a whole systems approach from those more traditional static models often used by planning, architectural, and engineering firms.

SUSTAINABLE SYSTEMS INTEGRATION MODEL™

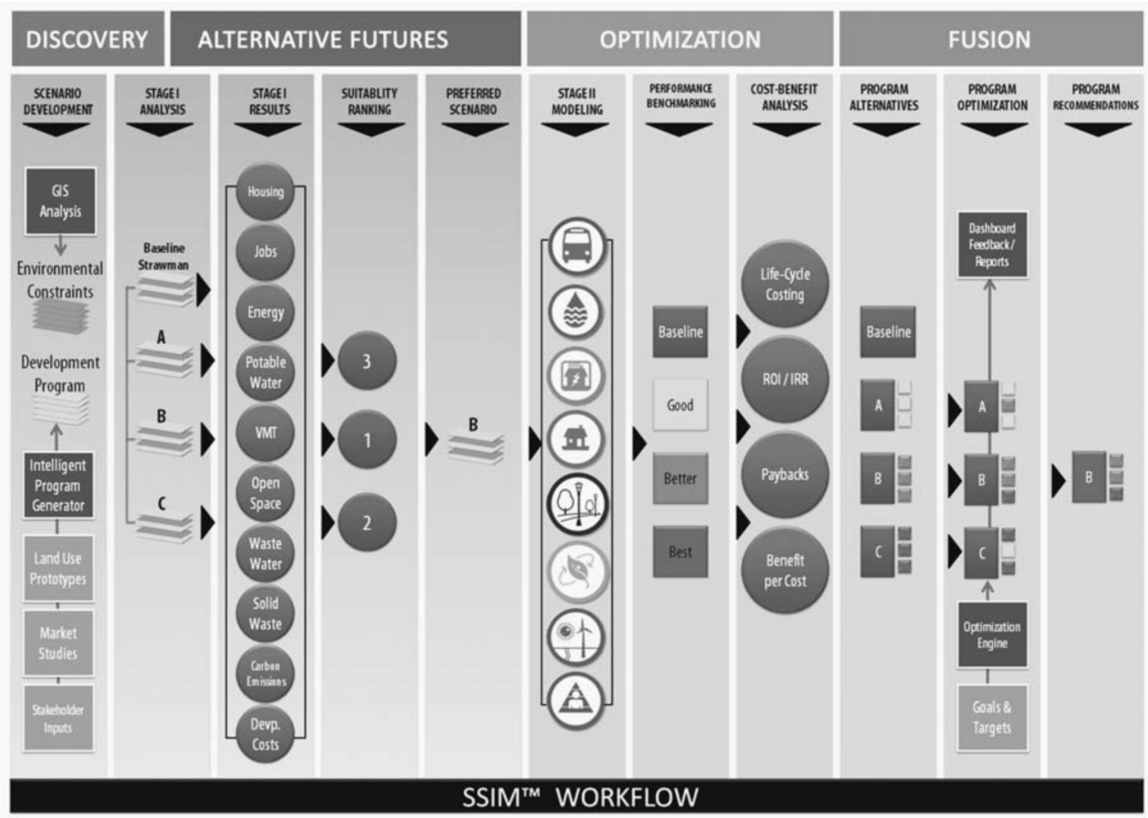
Developing a balanced sustainability strategy for a large complex project is a daunting task. The permutation of combinations of efficiency measures, technologies, and products over multiple land uses, building types, and densities is unlimited and overwhelming for any developer or city staff. Often financial resources are placed in areas that are easiest to understand and trendy rather than where they provide the best cost/benefit or add to an overall balanced approach. Ecological components often are the hardest to quantify and weigh against other hardware oriented elements.

The Sustainable Systems Integration Model (SSIM)™ was developed by EDAW, Inc. as a platform for rationally evaluating, balancing, and costing a wide variety of sustainability strategies to determine the combination best suited for the economic, social, and business objectives of the project. SSIM places ecological enhancement and service components side by side with energy, water, mobility, green building, and socio-cultural strategies so that a truly integrated, balanced sustainability program can be measured and conceived.

SSIM's analytical platform can evaluate multiple building, ecological, and infrastructure systems to determine the highest cost/benefit ratio amongst sustainability strategies. The platform's approach to the planning and design process is organized into four stages:

- Discovery
- Alternative futures
- Optimization
- Fusion

FIGURE 1.



The four stages are repeated throughout the various phases of development from conceptual planning to detailed implementation, e.g., Phase One—Master Plan Concept Design and then repeat them in greater detail in the Phase Two—Detailed Master Plan, and so on. These stages allow the core principles of integrated design and whole systems thinking to be expressed in the planning process while maintaining high levels of creativity and innovation through each cycle of refinement.

Following is a detailed explanation of the four stages:

STAGE 1—DISCOVERY

> *"The voyage of discovery is not in seeking new landscapes but in having new eyes."*
> *—Marcel Proust, author*

This first stage of the SSIM process focuses on discovering the multitude of characteristics, resources, and systems within and surrounding the site. Physical, social, cultural, ecological, and economic aspects are researched and processed so that as many constraints and opportunities as possible are identified. All team disciplines are engaged to explore the many interactions and relationships of site resources, climate, ecology, energy, market context, transportation, and culture to identify opportunities for innovation and the redefinition of how a sustainable community/project relates to its site and context.

Analysis and study of site conditions are the first task of planning team members and are often presented to the project's multidisciplinary team during a kick-off charette held proximate to the site. Aerial photographic interpretation, topographic evaluation, ecosystem mapping, and other land resource evaluations in some form, whether conceptual or detailed, are essential to inform the process at the outset.

On the development front, existing source energy and water characteristics, delivery systems, conventional development practices, building typologies, and emerging sustainability trends and regulations are also reviewed. An opportunities and constraints matrix is frequently developed to help track site issues and design implications during the charette and throughout the planning process.

Sustainable City/District Visioning

A visioning process is recommended during the charette that allows the sponsor and other stakeholders to share preconceptions and priorities with the larger team. This is important so that initial alternatives and strategies developed by the team are in sync with the client's and the community's overall goals and objectives. Identifying initial sustainability strategies and impressions is extremely valuable at this stage when design possibilities are still relatively unbound by known constraints. The most relevant outcome may be a set of guiding principles; these principles assist in keeping the project on track during the months and years that follow in refining and implementing the project.

Sustainability Targets

Another key product of the charette should be a set of sustainability targets for primary systems, such as: energy, water, transportation, green building, site works, ecology, education, and implementation. A "base case" (business-as-usual) level of sustainability performance is defined and then at least three alternative targets, each at an increasing level of green practice. Conceptual cost, feasibility, and implementation issues are also discussed early on for each primary system. Prior to leaving the charette, the group identifies, within the bounds of the information gathered at this point, a preliminary set of base case, "good, better, or best" targets. The initial workshop will not generate a complete sustainability program but will identify major themes, components, additional areas for research, and an approach to development of a sustainability program. This initial set of strategies will support the sponsor's goals, any relevant approval process, local and market expectations for green building, emerging greenhouse gas (GHG) regulations, and the framing of the project as a model sustainable community, city, or region.

Establishing Ecological Variables

At an early point in the Discovery stage, a set of ecological parameters are developed that identify various levels of ecological sensitivities, system interactions, healthy and degraded resources, and opportunities for preservation, enhancement, and regeneration. The potential levels of integration of urban system and ecosystem begin with a thorough inventory of the site ecosystems, considering climate, geology, biota, topography, hydrology, landscape pattern, and ecosystem services provided. This inventory is also organized around various temporal benchmarks (e.g., historic pre-European condition, 1990 condition, 2009 condition, 2030 anticipated condition, 2100 anticipated condition, etc.).

These benchmarks help to establish ecological performance goals and targets and are the starting point for the community design process. Once this inventory is completed, strategies are developed that focus on reducing impacts to site resources and ecosystems, as well as identifying how site resources/ecosystem services and urban design can be leveraged to improve project sustainability and mitigate global climate change.

To effectively implement this process, it is important to include biologists, ecologists, engineers, and designers who have a solid understanding of each other's goals. When working at such large scales with the goal of maximizing overall biodiversity and ecosystem function, it is beneficial to include ecologists who are knowledgeable in such disciplines as landscape ecology, ecosystem ecology, watershed ecology, macroecology, climate change ecology, conservation biology, and biomimicry, and to emphasize that the process focuses on overall biodiversity and ecosystem services rather than the traditional sensitive species/resources approach. With the uncertain future we face due to climate change, most species and resources should be considered as sensitive.

The framework analysis typically results in the following products: 1) development of open space configuration and ecosystem services alternatives, 2) evaluation of ecological performance of alternatives using GIS-based spatial analysis tools and approaches, and 3) analysis of costs and benefits of alternative programming. Following are the primary steps in developing an initial set of alternatives and then a preferred open space/ecological framework.

- The ecological team identifies key habitat, species, ecosystem, watershed, climate change vulnerability, and biomimicry opportunities for urban design and other environment issues based on photogrammetry, existing studies/inventories, research, and on-site verification.
- The team creates an ecological summary map of key findings, including baseline landscape ecological features delineation.
- Two ecological design prioritization maps are then developed. The first uses a weighted overlay method to identify areas most suitable for development and avoidance (e.g., sensitive species, protecting ecosystem patterns and processes through corridor networks, minimizing removal of natural carbon sinks, prime agricultural soils, climate change vulnerabilities, etc.). The second will identify areas suitable for design treatments to utilize or enhance ecosystem services (e.g.,

FIGURE 2. Site landforms, biodiversity, ecosystem services and sensitive resources are mapped and overlaid with development footprint alternatives in gray. The resulting ecological frameworks are then analyzed for ecosystem services potential and sensitivity to biodiversity and regulated resources.

storm water management configuration, buffer treatments, habitat corridor configurations, greenways and park configurations, native landscape zones, land use preferences, etc.), and will include key planning recommendations and diagrams.
- Based on these two sets of priorities, 2–3 open space/ecological frameworks are developed for consideration in developing the initial master plan alternatives. Key ecological values and GIS-based performance analysis techniques are incorporated into the overall SSIM Stage One performance analysis to assist the team in selecting a preferred alternative to carry into concept plan refinement. GIS analysis tools may include weighted overlay analysis, Fragstats landscape ecology analysis tool, or other GIS-based pattern analysis approaches.

It is key that an ecological framework precede and guide the urban form of the city or community. Only by letting the land tell us which areas are suitable and unsuitable for development will a valid groundwork for sustainable development be determined. This is done prior to and during the initial charette at the conceptual level as noted above. Following the definition of a preferred master plan concept, the ecology team continues to evaluate the ecological framework and provide a variety of choices on how the plan can be optimized for ecosystem services.

STAGE 2—ALTERNATIVE FUTURES

"The future isn't what it used to be."
—Yogi Berra

The Discovery stage has developed for the study area a set of ecological parameters that can be used to develop an urban footprint that will protect resources and lead to an optimal level of ecosystem services. A set of Alternative Futures will now be developed and compared against each other in search of an urban form, land use mix, transportation system, and internal open space network that achieve the highest level of inherent sustainability. These take the form of various master plan schemes and integrated strategies related to sustainability, transportation, ecological framework, land use, and energy systems. These alternatives are driven by the guiding principles developed at the charette and evaluate various configurations of:

- Land-use mix and balance.
- Ecological framework—internal and external.
- Urban design forms and organization.
- Transportation networks.
- Backbone infrastructure networks and strategies.

Alternative Evaluation and Selection—SSIM Stage One

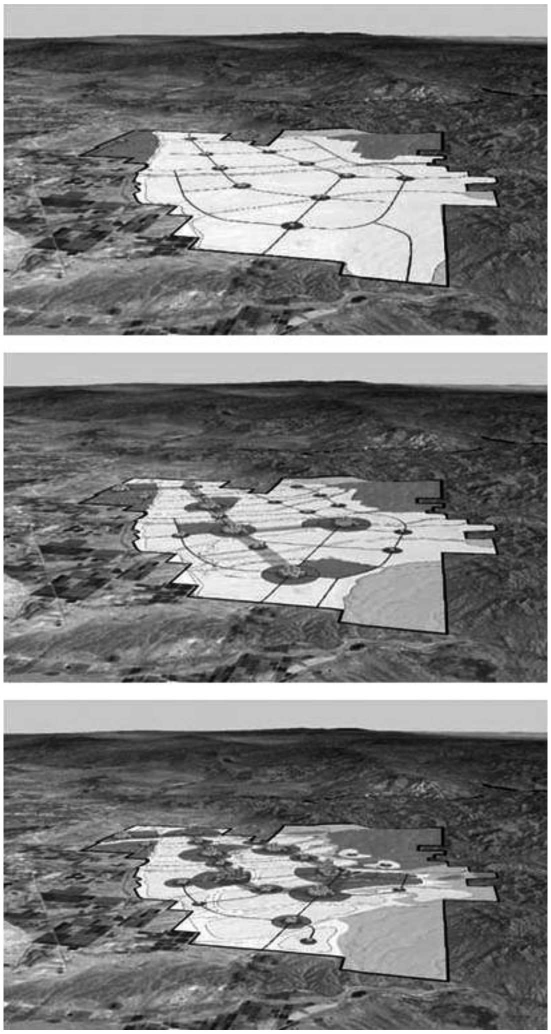
The SSIM process starts by utilizing a proprietary GIS-based modeling tool to compare the sustainability merits of alternative master plan solutions. This tool can be used in real time during a workshop to assist in evaluating urban form performance.

The urban form of each scheme is evaluated through a variety of indicators to ascertain which has the lowest inherent carbon footprint, highest trip capture, connectivity, land-use balance, etc. This is done using a BAU (business-as-usual) scheme as a straw man (or base case) and then calibrating the simulation model with alternative plans until ultimately a preferred plan evolves. Based on the outputs, modifications and improvements to both the master plan framework and land-use program can be gained.

SSIM Stage 1 utilizes an ArcGIS Server 9.3 based platform that, after initial calibration, allows immediate evaluation of key sustainability indicators calculated from preliminary land-use concepts. Using a customized palette of land-use types, street types, pathways and bikeways, open space and landscape types, community facilities, and amenities, a conceptual sketch is drawn for each scheme and converted to GIS. Each palette item is a prototype with relevant assumptions such as density, building types and mix, and spatial dimensions built into its definition. The spatial analysis model is used to measure an elementary level of sustainability through a limited set of indicators, including:

- Jobs/housing ratio.
- % overall ecological preservation.
- Natural lands connectivity index.
- % ecosystem pattern/process preservation.
- % jobs walkable from transit.
- Orientation for local climate
- Carbon sequestration.
- Parks per 1000 population.
- % land with impervious surface.
- Total storm water runoff.

FIGURE 3. Alternative development frameworks consider all aspects of the site from urban to natural. In this conceptual diagram from Superstition Vistas, Arizona, the business as usual framework (top) depicts a low density, land intensive framework least optimized for sustainable systems potential. The bottom scenario seeks to maximize ecosystem services and sustainable systems opportunities through reduced development footprint and increased open space.



- Energy use per person.
- Water use per acre per person.
- Gasoline consumption per person.
- Vehicle kilometers per person.
- Solid waste generated.
- CO_2 Eq MT total.
- CO_2 Eq MT per person.

These outputs are compared across the multiple alternatives and provide input for the sponsor to further refine or select a preferred alternative. Carbon footprint per capita is utilized as well as total emissions since several urban form-related mitigation strategies require higher densities that may result in higher total emissions quantity, but lower emissions per capita or dwelling unit.

A primary tool in this step is the "7-Ds" local trip capture calculator developed by Fehr & Peers, a Walnut Creek, California-based transportation planning firm. Fehr & Peers has participated in a research study that resulted in a validated trip-generation calculation model that directly estimates trips by mode for mixed-use developments. The model takes into account the 7-Ds: density, diversity, design, destination accessibility, distance to transit, demographics, and development scale.

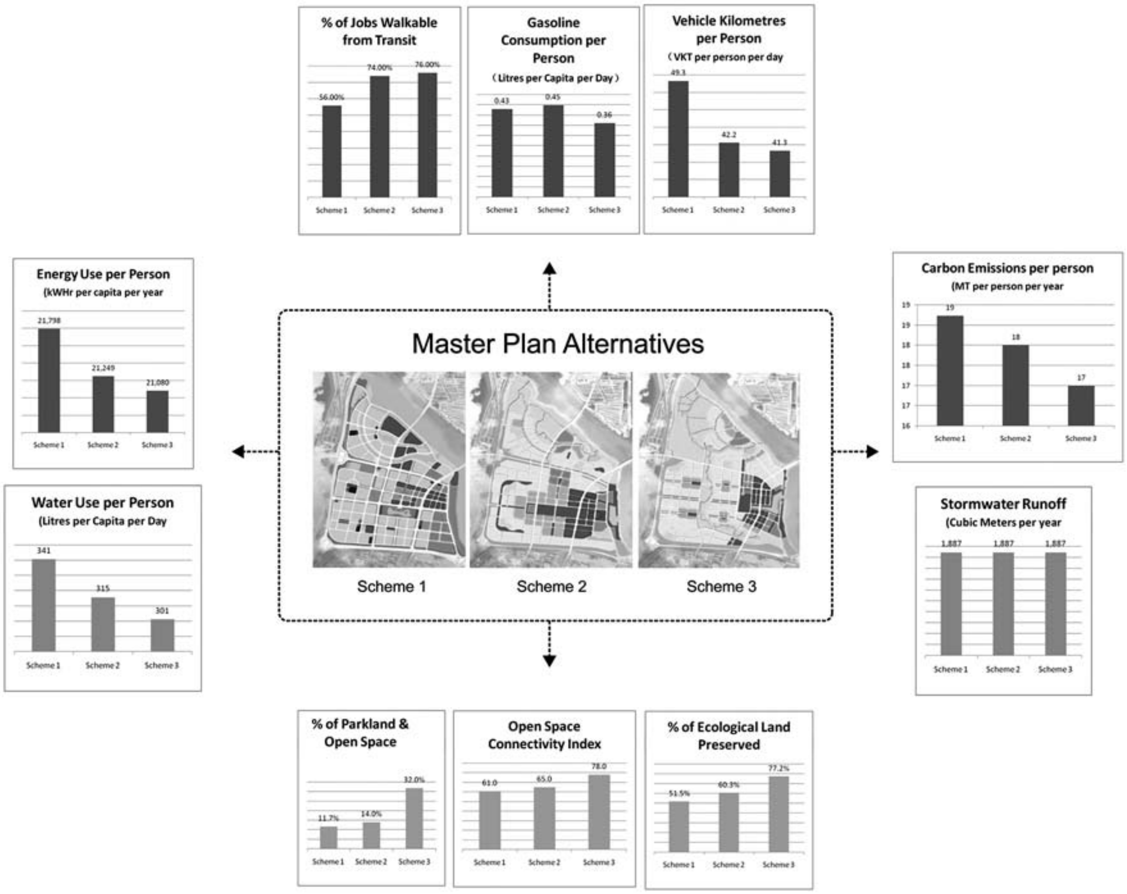
The ecological indicators measure the amount of ecosystem services preserved or leveraged in design, access to those resources from the population, connectivity of the network pattern, and the characteristics of the storm water runoff.

STAGE 3—OPTIMIZATION

> *"Make no little plans; they have no magic to stir men's blood . . . Make big plans, aim high in hope and work."*
>
> — *Daniel H. Burnham*

After a preferred master plan and ecological framework are selected, a more intensive evaluation of sustainability practices and measures can now occur. This step will answer two questions: 1) "How aggressive can we realistically be in setting sustainability goals?" and 2) "What set of sustainability practices allows us to achieve these goals in the most cost-effective manner?" This is achieved by disaggregating the project or district into constituent

FIGURE 4.



SSIM Stage One Evaluates Base Sustainability Indicators Between Alternative Plan Forms

primary systems. Sub-models are developed for each system which "push" for increasingly higher levels of resource efficiency while tracking the conceptual cost and environmental benefit of each solution set.

First, a model and/or analytic method is established for each primary system. The good/better/best targets established in the initial charette will be modeled to identify which sets of measures achieve the prescribed efficiency targets. SSIM provides a platform for comparing the cost/benefit of the various packages and allowing optimal combinations to be selected in the SSIM synthesis step. In addition to indexing ecological framework alternatives, the systems being modeled for potential optimization include:

- Building Energy
- Public Realm Energy
- Renewable Energy
- District Energy
- Transportation/Mobility
- Potable Water
- Storm Water
- Waste Water
- Green Building

Building Energy

Energy conservation measures (ECMs) required to attain the four levels of targeted efficiency, e.g., base case (BaU), 25%, 50%, 80% reductions, are established with first costs and life cycle costs determined. Adjustment to the ECMs are made to best achieve the targets at the lowest respective cost. ECM sets typically combine passive, mechanical, and renewable strategies. Attempts are made to achieve net positive cash flows and return on investments acceptable to the marketplace.

Whole Systems Water Planning

By using the SSIM program, water engineers are able to effectively incorporate a knowledge of sustainable strategies related to the domestic water system into a comprehensive project water model. The process typically includes detailed modeling of site storm water generation, residential and nonresidential interior and exterior water use, wastewater generation, and explores opportunities for storm water collection, rain water harvesting, grey water use, and interior/exterior water use reduction. The water conservation team utilizes a whole systems water balance model to evaluate the water conservation and reuse strategies and help identify the combination of measures with the highest cost/benefit relationship. The team provides outputs in the form of alternative water reduction strategies, illustrates their effectiveness, and generates a cost/benefit analysis that identifies the percentage of water reduction per $1000 invested for each good/ better/best package. This information provides input into SSIM that allows synthesis into an optimized master energy/carbon/water reduction program.

Transportation and Sustainable Mobility

Whether the circulation system for a district or community is fixed or still in the planning stage, SSIM allows the benefits of various enhancements to be evaluated from a cost/benefit viewpoint. Internal measures such as improved connectivity and local transit, external transit linkages, and improved housing to jobs relationships are applied in the previously described good/better/best comparison. Modifications in density and land use mix can also be tested for potential increases in local trip capture, resulting in lower vehicle miles traveled and therefore reduced emissions.

Ecological Framework Refinement

Choices in the ecological framework are refined by separating the plan into open space areas and urban landscape areas, and evaluating opportunities for ecosystem service enhancement above a baseline condition. Enhancement opportunities might include aligning land use with local microclimate characteristics to reduce the urban heat island effect; community scale passive solar design; carbon sequestration potential in terms of tree planting, forestry, and ecological restoration; nature recreation and education; water quality; and community agriculture potential based on land suitability or alternative agricultural practices, anticipated population, and regional production precedents.

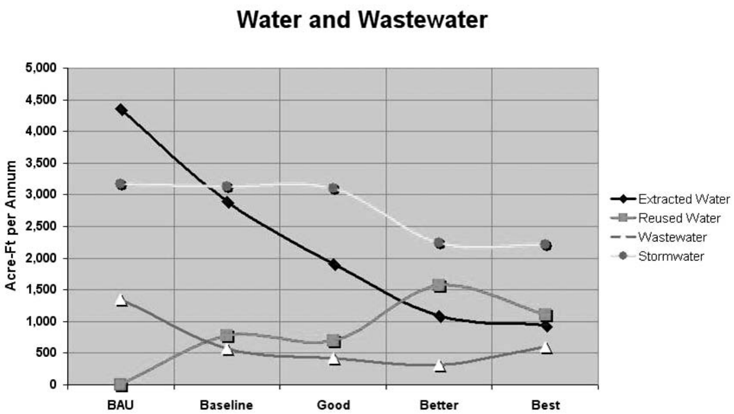
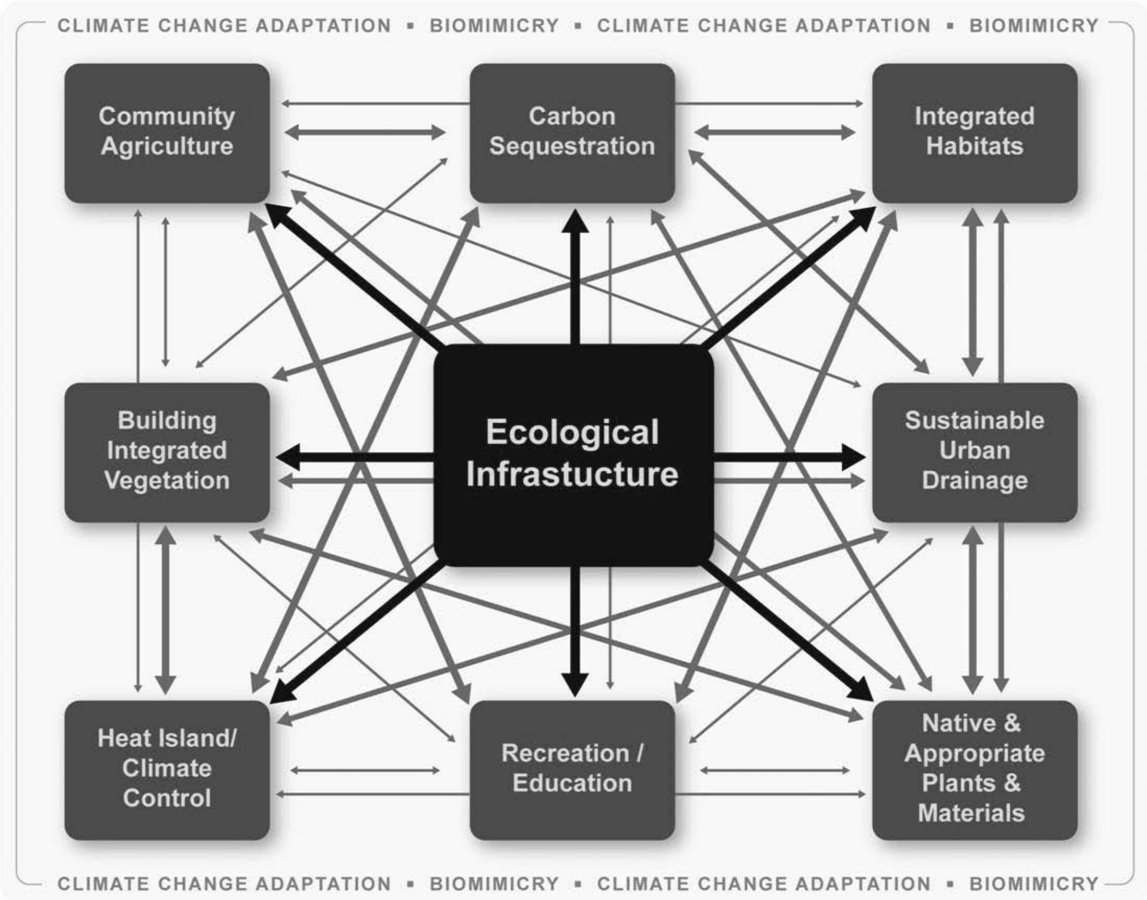


FIGURE 5. This output graph from the Whole Systems Water Model tracks the water supply from various systems in 5 alternative scenarios.

FIGURE 6. The core elements of the ecological framework and interrelationships between elements are outlined above. Principles of biomimicry and the potential impacts of climate driven ecosystem change are important considerations for developing the ecological infrastructure program.

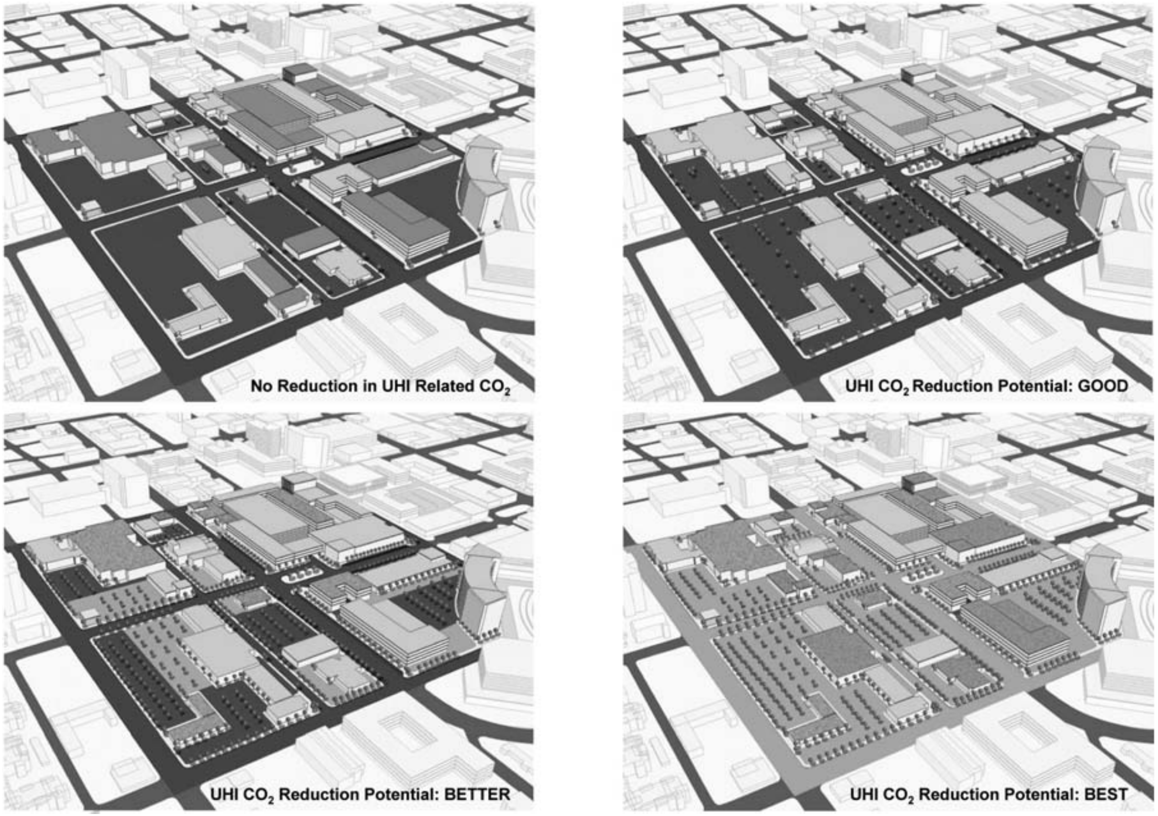


Key items include:

- Findings are integrated into good, better, and best alternatives for open space ecosystem services programming and urban landscape services programming and are evaluated for cost and environmental benefit.
- Ecological performance of several design alternatives are quantified using SSIM ecosystem integration analysis methodologies that take into account conservation area design, carbon sequestration, urban heat island reduction, and microclimate design at the community/city scale, as well as nature appreciation/interaction potential and community agriculture.
- Final ecological performance quantification is then performed on the preferred land-use alternative and strategies for further improvement at later stages and finer scales of plan refinement are suggested.

Findings and recommendations are regularly reviewed by the team and inputted into the model for the next stage of the process—synthesis with other sustainability measures into an optimal combined program for the project.

FIGURE 7. Performance potential of urban heat island mitigation alternatives is one aspect of overall urban ecological landscape services optimization.



This stage has defined a number of scenarios for each primary system that lead to a range of sustainability outcomes, some lower and some higher in performance; each with both initial and long-term cost implications. This information informs us as to what measures are optimal based on the project's goals, market, and economic parameters. But we have yet to combine those optimal measures from each primary system into a total sustainability program or understand the total cost and benefit impact for the project area.

STAGE 4—FUSION

"Synergy between disciplines creates a product that is greater than the sum of its parts"

—David Blau, EDAW principal

Fusion is defined as the melding of primary elements into a process of re-combination that result in the creation of a new compound or element. It is in the spirit of fusion that the various measures and strategies are now weighed, selected, and compounded in a synergistic manner so that efficiencies or regenerative levels of performance are gained within the economic envelope of the project.

In the previous task, the team defined and modeled good/better/best packages of measures for each primary system and provided outputs related to environmental benefit, first costs, life-cycle costs, monetized cost/benefit, and benefit per $1,000 invested for each package. The team can now use SSIM to combine the individual systems (i.e., water, energy, transportation, ecological framework, etc.) into a set of comprehensive, all-systems master program alterna-

FIGURE 8. The SSIM gaming board allows various combinations of sustainability measures to be compared in real time for cost effectiveness and environmental performance.

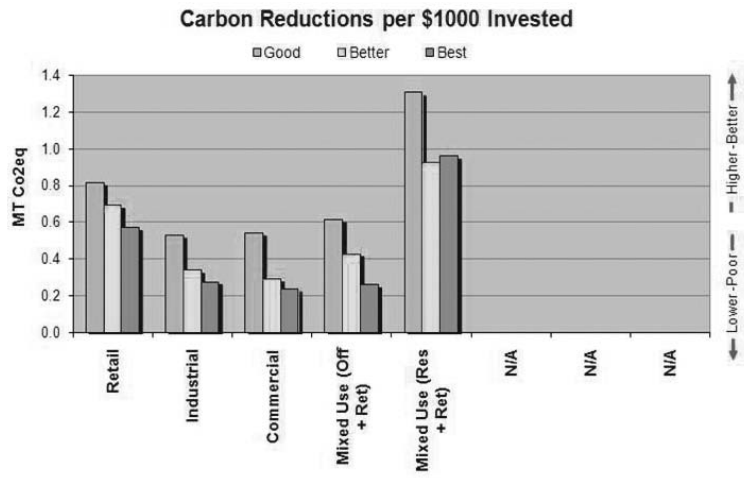
STAGE III PROGRAM SELECTION

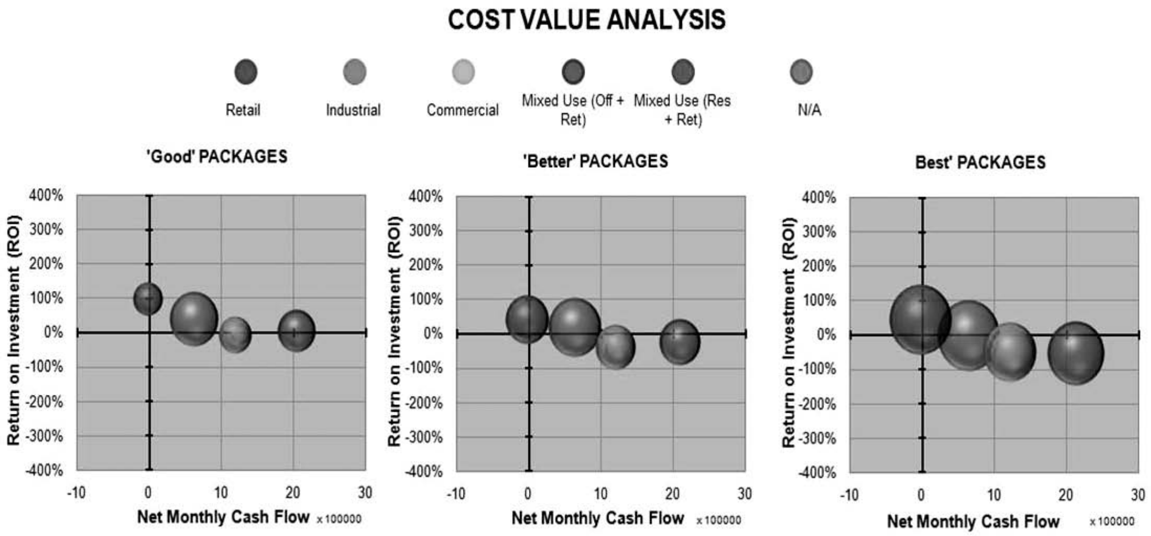
Themes	Selected Packages for Programs		
	A	B	C
Residential : Small SFD	Good	Best	Better
Residential : Med SFD	Good	Better	Better
Residential : Large SFD	Good	Better	Better
Residential : Large SFD Rural	Good	Better	Better
Residential : Townhomes	Good	Best	Best
Residential : Low Rise Condos	Good	Best	Best
Green Building - Residential	Baseline	Better	Baseline
Non-Residential : Retail	Good	Baseline	Baseline
Non-Residential : Industrial	Good	Good	Baseline
Non-Residential : Commercial	Good	Best	Better
Non-Residential : Mixed Use (Off + Ret)	Good	Better	Good
Non-Residential : Mixed Use (Res + Ret)	Good	Better	Best
Non-Residential : N/A			
Non-Residential : N/A			
Non-Residential : N/A			
Green Building Non-Residential	Baseline	Better	Baseline
District Heating / Cooling	Baseline	Baseline	Baseline
Water	Good	Better	Better
Sequestration - Public Landscaping	Good	Baseline	Best
Sequestration - Forestry	Baseline	Baseline	Best
Ecology - Farming	Good	Better	Best
Ecology - Biohabitat	Good	Best	Best
Urban Heat Island Mitigation	Baseline	Baseline	Baseline
Public Realm Energy	Best	Best	Best
Public Renewable Energy	Baseline	Baseline	Baseline
Transportation - Density + Diversity Measures	Best	Best	Best
Transportation - Internal Measures	Best	Baseline	Best
Transportation - Employee Based Housing	Best	Baseline	Best
Transportation - External Transit	Best	Best	Best
Renewable Energy - With Transportation	No Renewables		
Renewable Energy - Without Transportation	No Renewables		
Total Carbon Emission Reduction (%)	27.5%	33.9%	44.0%
Total Cost (% Increase)	1.5%	5.5%	5.4%
Total Master Developer Cost (% Increase)	0.5%	0.0%	1.8%
Total Building Energy Reduction (% Reduction)	16.2%	32.7%	26.1%
Total Cost Buildings (% Increase)	1.1%	5.4%	2.7%

tives. At least three master programs will be selected and the following outputs will be provided for each:

- Total domestic water savings.
- Total building energy savings.
- Total public realm energy savings.
- Total reduction in VMT.
- Total reduction in GHG emissions.
- Total ecological footprint.
- Total selected ecosystem services output.
- Total initial costs.
- Total ongoing monthly costs.

FIGURE 9. Various building types may have different sensitivities to energy measures. Comparative modeling tools assist in assigning appropriate cost effective measures to each typology.



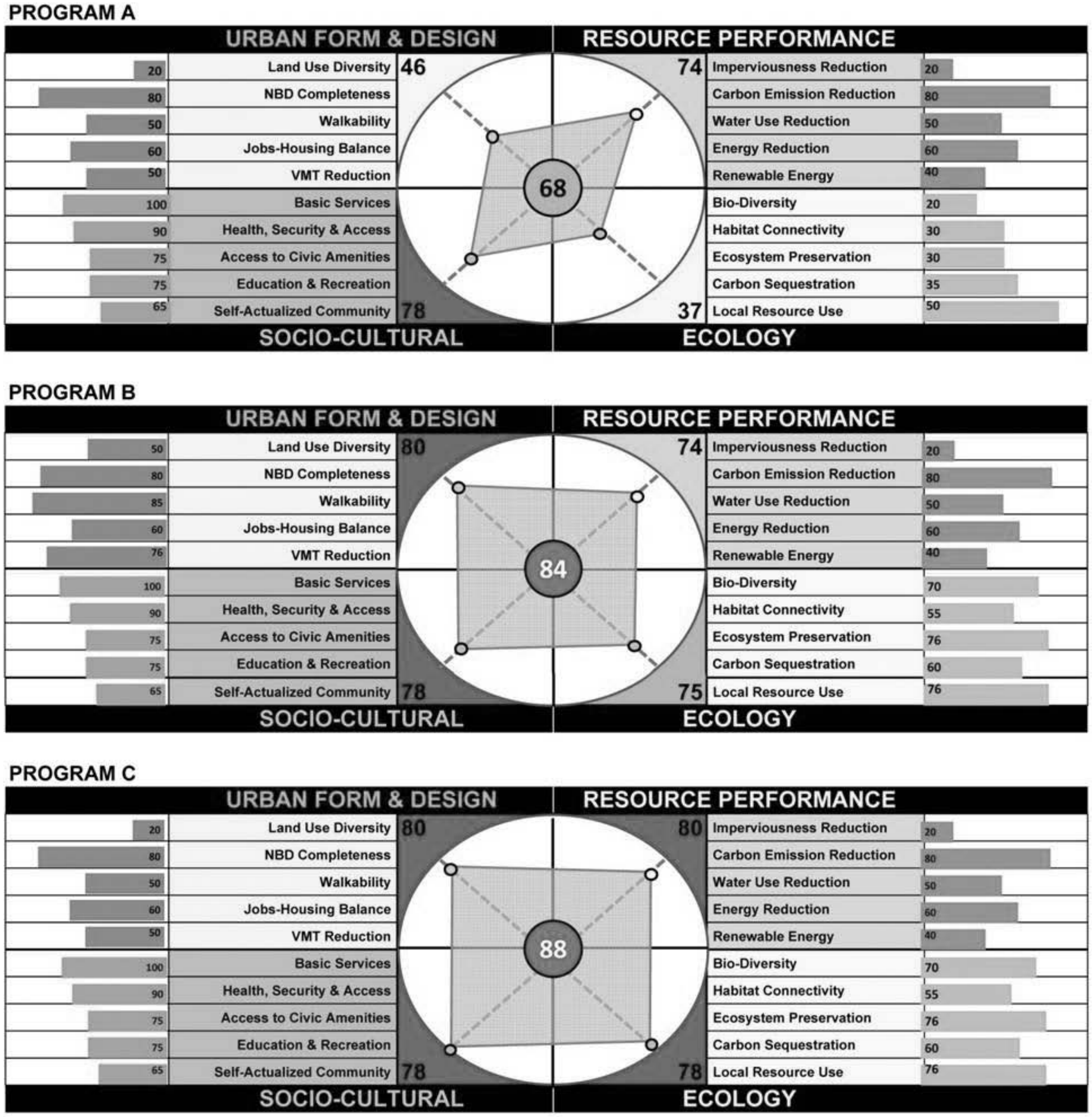


As a part of the evaluation of master program alternatives, various schemes for cost allocation are developed and reviewed with the team and sponsor. The following cost allocation categories are typically defined and incorporated into the analysis:

- Increased cost and/or savings to residential building construction in cost/sf and % over base costs.
- Increased cost and/or savings to non-residential buildings in cost/sf and % over base costs.
- Increased cost and/or savings to master developer.
- Increased cost and/or savings to third part energy or infrastructure entity.
- Increased cost and/or savings to master homeowners' association.

Goals related to carbon foot printing may be evaluated and modeled. Energy scenarios in this class may require the consideration of "backbone" large-scale renewable energy regimes such as photovoltaic farms, solar thermal plants, geothermal, wind turbines, etc. These renewable energy alternatives are independent of building systems and typically are freestanding facilities requiring separate modeling and financial analysis. The SSIM model is an excellent platform for evaluating alternative scenarios to achieve carbon footprint targets while identifying related costs and acreage.

FIGURE 10. The SSIM tool allows comparison of scenarios through an alternative valuation strategy to suggest total sustainability performance considering benefits that are difficult to quantify (i.e. socio-cultural or habitat benefits, etc).



Interaction with the Ecological Urban Landscape

The relevance of the SSIM methodology to enhancing the ecological urban landscape and its associated ecosystem service values lies in the interaction between the primary systems. Choices made in any of the primary systems have primary, secondary, or tertiary impacts on the site's internal and external ecology. Attempting to measure these impacts, whether positive or negative, helps us paint a more integrated total picture of the implications of our choices.

Key interactions that have been found relevant at a strategic level on various projects include:

Primary level ecosystem cause/effect interactions:

- Potable water reduction and reuse measures allow reallocation of water to community agricultural, forestry, and ecological restoration programs.
- Rainwater capture reduces GHG from long distance water delivery systems.
- Potable water reuse strategies that include intensive reuse of storm water at community infrastructure and at the building roof water harvesting level have allowed significant reductions in storm water volume impact on degraded downstream drainage systems, thereby improving potential for more natural ecological and biological regimes.
- Potable water reduction and reuse measures result in substantial reduction in water plant construction allowing savings to be reallocated to renewable energy or local transit measures.
- Increased on-site urban forestry programs increase carbon sequestration rates offsetting the need for more expensive renewable energy strategies.
- Slightly increased density curve reduces urban footprint allowing a larger percentage site for ecosystem services.
- Increased internal urban landscape program reduces Urban Heat Island (UHI) effect which reduces building energy demand.
- Integrated and strategically located water elements (stormwater/irrigation storage/storm water polishing) reduces UHI effect, which reduces building energy demand.
- Building integrated landscape, e.g., green roofs, reduce UHI effect, which reduces building energy demand.
- Reduced UHI reduces impact on temperature sensitive species in nearby conservation areas.
- Strategic tree planting increases shade on buildings reducing energy use.
- Increased urban biodiversity and open space improves community knowledge of nature leading to increased conservation behavior.
- Community farming program reduces off-site VMT and associated GHG emissions.

Secondary level ecosystem cause/effect interactions:

- Increased density curve and land use balance allows increase in local trip capture reducing vehicle miles traveled (VMT) which reduces total lane miles.
- Increased internal and external transit programming reduces VMT, which reduces total lane miles required.
- Reduced lane miles decreases runoff and pollutants reducing impact on downstream ecosystem services.
- Reduced lane miles allows either increase in landscape area for sequestration or land use

FIGURE 11. Through a process of integrated environmental performance based planning, ecologically engineered communities of the future may maximize their contribution toward restoring a sustainable global balance of ecosystem services.

efficiency both allowing larger percentage of site for ecosystem services.

- Increased biodiversity improves resiliency to long term impacts of climate change on species diversity.
- Wood generated from sequestration program is used in wood based products or if energy demand outweighs sequestration benefit, wood is used for energy generation.

Achieving a Zero Net or Reduced Carbon Benchmark

A key goal of integrated modeling is to determine the lowest cost pathway to a reduced carbon footprint. There are numerous opportunities for reducing greenhouse gas emissions from building and site operations through energy efficiency, renewable energy, and reduced VMT. The role that ecological systems can play in reducing carbon footprint through UHI reduction, carbon sequestration, and community agriculture is just becoming legitimized in certain jurisdictions with the accountable metrics starting to take form.

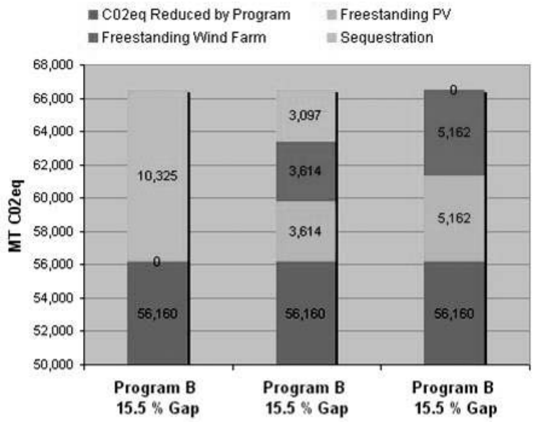
Early indications from SSIM modeling are that legitimate, on-site forestry, water absorption, and landscape intensification programs are one of the lowest cost measures for offsetting a project's CO_2 emissions. Having a tool to evaluate cost tradeoffs and ROI comparisons between passive, mechanical, high technology, mobility, and sequestration measures is key to maximum reduction with least impact to the bottom line.

SUMMARY

Complete, precise, and comprehensive modeling of man-made and natural systems on large projects is extremely difficult due to their complexity and our current elementary understanding of complex natural systems. However, acknowledging those we do understand and tracking obvious linkages between systems can give a more complete picture of the offsetting and compounding impacts of prospective sustainability strategies. Recent definitions of sustainability stress balance between its physical, social, and economic dimensions. Modeling approaches similar to SSIM allow ecosystem integrity and services aspects to stand side by side with conventional mechanical and operational sustainability strategies.

As our knowledge base expands, the SSIM program may be applicable for larger and larger projects including regional and national sustainability and carbon footprint planning. In the long term, programs similar to SSIM may be part of an ongoing community/city/region scale dynamic smart-monitoring system that can help city and regional land use and conservation infrastructure adapt over time to optimize performance across systems in a rapidly changing environment.

FIGURE 12. After carbon emissions reductions are quantified, further offset opportunities are evaluated including solar farms, wind farms or carbon sequestration through ecological restoration or plantation forestry.



% of Gap	0%	35%	50%
# Turbines	0	5	10
Acres	0	89	179
Cost $M	0	20	40

% of Gap	0%	35%	50%
# Panels	0	49,773	71,105
Acres	0	18	25
Cost $M	0	68	98

% of Gap	100%	30%	0%
Acres	1,414	127	0
Cost	4	0	0