RESTORATIVE URBAN DESIGN: TOWARD A DESIGN METHOD FOR MITIGATING HUMAN IMPACTS ON THE NATURAL ENVIRONMENT THROUGH URBAN RE/DEVELOPMENT

by

TULU TOROS

Bachelor of Architecture, Middle East Technical University, 1991
Master of Science in Architecture, Kansas State University, 2011

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Environmental Design & Planning
College of Architecture, Planning & Design

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2015

Abstract

The Restorative Urban Design (RUD) calls for a new urban design and planning approach targeting environmentally responsible re/development of urbanized areas through ecologically responsive impact mitigations. If implemented in a systematic manner, such re/developments can help move urban areas toward the successful restoration of the natural environment of which they are an inseparable part.

The RUD model advocates more rigorous assessment and mitigation of urban impacts by carefully evaluating the environmental performance of urban re/developments within five primary dimensions: Atmosphere (emissions, pollutants, ozone depletion); Hydrosphere (stormwater, domestic water, wastewater); Lithosphere (land use, land cover, food and wastes); Ecology (habitat resilience, biodiversity, population and resources); and Energy (renewability, reduction and efficiency, transportation). The model relies on a scenario-comparison process in order to evaluate and optimize the performance of urban re/development projections through four critical scenarios, which are respectively: 1) Natural Baseline (NBASE); 2) Historic Progression (HPROG); 3) Trajectory Forecast (TFORE); and 4) Restorative Projection (RPROJ).

The RUD Case Study illustrates how the principles and strategies of Restorative Urban Design can be applied specifically to a typical (densely developed) urban area, namely River North District in Chicago Metropolitan Area. The case study focuses exclusively on mitigation of a single critical human impact on the natural environment: Anthropogenic CO_2 Emissions. The case study focuses on the design assumptions by which the restorative urban re/development scenarios might exceed beyond the full mitigation of emissions into the global remediation by 2040. The restorative projections illustrate that only a certain portion of emissions can be effectively mitigated onsite (5 to 55%), and that the remainder of projected emissions (45 to 95%) need to be mitigated offsite in order to achieve the necessary sequestration and storage.

The restorative research suggests that the mitigation of major human impacts on the natural environment – not only CO_2 emissions but also other major impacts – are likely to require significant urban transformations. Moving beyond the strategies of preservation and/or conservation, the restorative approach asserts that comprehensive environmental restoration is achievable if urban impacts are adequately estimated and then entirely mitigated onsite as well as offsite through a systematic process of urban re/development.

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Biographical Sketch

Mr. Tulu Toros received his Bachelor of Architecture degree from one of the most prestigious schools of architecture in Turkey i.e. Middle East Technical University in Ankara. He graduated as the valedictorian student of the class in 1991. Same year, he migrated to the United States and started practicing professionally. After successfully satisfying the internship and examination requirements, Mr. Toros earned the distinguished privilege of becoming an "architect" nationally certified by the National Council of Architectural Registration Boards (NCARB) in 1998. Over the course of years that followed, he secured architectural board registrations in the states of OH, KY, NC, CO, WY, NE and KS, and collaborated on hundreds of multi-disciplinary, urban re/development projects throughout the U.S. and abroad.

In 2009, Mr. Toros returned to graduate school in order to deepen his research and academic background in sustainable design. In 2011, he received his Master of Science in Architecture degree with a specialization in "sustainable and ecological design" from the College of Architecture, Planning & Design (CAPD) at Kansas State University (KSU) in Manhattan, KS. Later in 2011, Mr. Toros entered the Master of Regional and Community Planning program at CAPD where he continued to broaden his research and understanding of the principles and strategies of sustainable urban design and planning toward the restoration of natural environment. In 2012, he was admitted to the doctoral program in Environmental Design and Planning at KSU specializing in "sustainability," which was completed in late 2014.

Mr. Toros continues to render professional design services on varying size and scale mixed-use, urban infill as well as re/development projects with a particular focus on ecologically responsive and environmentally responsible design practices. His professional expertise includes environmental analyses, master planning, architectural programming, code compliance, value management, construction documentation as well as contract administration.

In addition to NCARB, Mr. Toros is a member of the Union Internationale des Architectes (UIA), American Institute of Architects (AIA), American Planning Association (APA), Urban Land Institute (ULI), as well as a certified LEED-GA professional. He continues to collaborate on various planning and design projects for urban re/development not only in the United States but also in Turkey, Saudi Arabia, Russia, Kazakhstan, and China.

Dedication

The restorative research belongs
To those environmental designers and planners
Who sincerely and diligently work to restore the natural environment
...
And
…
To all fellow planetizens
Who sincerely support, strengthen, and implement the restorations,
Gradually transforming the human-made environments
To realign with Nature

Preface

In his Master's report on "Restorative Design: Toward Environmental Restoration," completed in 2011, Tulu Toros reviewed the literature on the many ways by which the current pattern of human settlements and architectural design contributes to the degradation of the natural world. But he did more than that: he summarized the vast and burgeoning literature on current movements to create a more sustainable society, with a special focus on comparing the major international rating systems for green architecture and sustainable urban design. His conclusion was that none of the existing systems are adequate to the crisis of sustainability. Rather than destroying the earth more slowly using current best practices, Mr. Toros concluded that what was needed was an inherently ecological approach to design that aimed at the restoration of the fabric of life, including the human ecology as an integral and living part of it. He called for a radically new paradigm for design and planning in the age ecology, and closed his report with an elucidation of the guiding principles of restorative design (Toros, 2011).

In this dissertation Mr. Toros has fleshed out an operational design model for this new paradigm for "Restorative Urban Design." He demonstrates how it is possible to assess and improve the performance and reduce the impacts of design and urban development along all five dimensions that define healthy ecosystem functioning: atmosphere, hydrosphere, lithosphere, ecology and energy. He has applied his model in one critical area of concern, anthropogenic carbon dioxide emissions, and he has tested his method in the redesign of the River North District of Chicago. His conclusion, not surprisingly, is that only a portion of the negative impacts even of a robust and comprehensive green redesign for this district can be mitigated with onsite measures. Mr. Toros' case study thus demonstrates that to truly heal the earth, even along this one dimension of healthy ecosystem functioning, it is necessary to offset negative environmental impacts with major efforts at environmental restoration offsite. Our task is to re-make the human footprint on earth.

In the end, this dissertation makes it clear that to fully apply the Restorative Urban Design model will require a comprehensive societal commitment to living in harmony with the natural world. Toward that end, Mr. Toros has outlined and tested a comprehensive and systemic strategy for truly sustainable and restorative urban design. It can only be hoped that Mr. Toros' radically visionary, and yet demonstrably practical, model for an environmentally restorative approach to architectural and urban design will fire the imagination and inform the collective efforts of a new generation of policy makers, planners, architects and designers who are as committed as he is to creating a sustainable society worth sustaining. The first step has been taken.

Gary J. Coates
Professor of Architecture
ACSA Distinguished Professor
Manhattan, KS
September 14, 2014

Chapter 1 - Introduction

The research behind Restorative Urban Design (RUD) is both an academic and a professional response of the author to an ever-expanding body of evidence showing that human impacts on the natural environment are overwhelming the innate ability of nature to regenerate, rehabilitate, and repair itself effectively. Rapidly expanding human population, production, consumption, and wastes within a finite environment increasingly necessitate responsible assessment and mitigation of undesirable impacts at their sources. As the degradation, deterioration, and depletion in the natural environment continue to accumulate, the responsibility to repair past and present damages weighs heavier on each passing generation on this good Earth.

Increasing numbers of perceptive theoreticians and practitioners realize that the contemporary agenda of urban design and planning will soon have to transcend sustainability of human subsistence, and shift toward the comprehensive restoration of the natural environment:

> The basic premise of sustainable…design is to allow the ongoing processes that sustain all life to remain intact and to continue to function along with development. While the first tenet of sustainable…design, and one that is actually often overlooked, is 'don't destroy the site,' in reality we have already destroyed too much and we can no longer measure the sustainability of design by its minimal impact on the natural systems of a site. Today, almost every site…has been abused. Sustainable design must go beyond the modest goal of minimizing site destruction to one of facilitating site recovery by reestablishing the processes necessary to sustain natural systems. (Franklin, 1997, p. 264)

Beyond the concerns of sustainability, can the human impacts actually be neutralized or reversed at this point in time? How can the comprehensive restoration of natural environment be successfully planned for? If comprehensive environmental restoration is not specifically aimed for, is it ever likely to arrive on its own anytime in the future?

If there were an urban design method aiming at comprehensive environmental restoration what would it look like?

The "Restorative Research," as coined by this dissertation, advocates that the comprehensive restoration of the natural environment is not only theoretically possible but also practically feasible if responsibly planned and designed for. Currently, too little attention, importance, energy, and resources are being devoted to implementing restorations within the natural environment. However, with passing time, it is becoming increasingly clear that many more integrated and comprehensive restorative mitigations are needed to assist the regeneration of the natural fabric and to insure that healthy and thriving life exists on this planet for the foreseeable future. As such, this restorative research offers a viable approach to ecologically responsive and environmentally responsible urban design and planning practices, where the ultimate comprehensive restoration is targeted and achieved through systematic and incremental re/developments in urbanized areas.

A. Overview of Restorative Research

The existing literature on the degradation and deterioration of the natural environment encompasses a wide range of interconnected concerns and issues. The body of evidence establishes that the most significant environmental concerns and issues are closely associated with the growth of human population as well as the expansion and sprawl of urban areas (Chiras, 1992; Goudie, 2006). The increasing human consumption of products and related urban demands are inextricably linked to the habitat loss and degradation, species extinction, depletion of natural resources (e.g. fossil fuels like petroleum and natural gas), depletion of ozone layer, and climate change.

A diligent review of sources of degradation, deterioration and depletion in the natural environment promptly reveals that the growth of human population, production, consumption, and urbanization are repeatedly cited among the primary causes (WCED, 1987; Brown, 1981; Hawken, Lovins, & Lovins, 1999; McDonough & Braungart, 2002; Orr, 2002; Brown, 2003; Heinberg, 2003; Sassi, 2006; Friedman, 2008; Calthorpe, 2011). Reducing the growth of human population and consumption are seen by many as critical in reducing the human impact on natural resources, and in creating regenerative systems that are able to endure over the long term. Credible research, like the Wildlife Fund’s Living Planet Report in 2008, indicate that “we are already operating 25 percent above the planet’s biological capacity to support life. And that is before we add another billion people by the early 2020” (Friedman, 2009, p. 25).

As a direct result of persistent growth in human population and consumption, increasing degradation, deterioration, and depletion of natural systems triggered the first phase of environmental concerns as preservation and conservation of natural assets and resources. Brown (1981), Berger (1985), Beatley (2000) and Oliver (2006) are among those discussing important strategies of preserving and conserving natural resources in addition to increasing efficiencies and reducing wastes, which are all vitally important to ensuring global health.

Brainerd (1973) insightfully observes that the consumption demands generated by the projected growth of human population would simply fall short of the supply by natural or synthetic means of production in the not-too-distant future. Brown (1981) examines a wide range of categories of deterioration in the natural environment such as losses of forests, and farmlands, and steadily reducing qualities of air, water, and soil. He cautions about the expanding consumption, gradually shrinking natural resources, and the increasing need for more preservation and conservation to avoid an ecological collapse. Berger (1985) advocates widespread application of ecological restoration projects to repair and rehabilitate the degraded areas of the natural landscape, which could become a national program. Berger (1990) elaborates on the rehabilitation of non-urban environments such as forests, wetlands, drylands, rivers, lakes, fisheries, as well as agricultural lands, advocating for federal legislation. Orr (1992) links food, energy, and climate warming problems to post-industrial re/development patterns, advocating a new post-modern world to be born. Chiras (1992) details the deteriorating quality of air, water, and soils, pointing out at the urgency of managing human population growth and or restoring the damage (p. 87). Baldwin, De Luce, and Pletsch (1994) specifically focus on the need to use ecological restoration as a basis for improving human harmony with nature through large-scale landscape design (p. 264). Similarly, Hawken, Lovins, and Lovins (1999) summarize the major areas of deterioration in the natural environment due to wasteful human consumption, calling for a new system of values to invest in the natural capital to order to increase use efficiency and regeneration. Brown (2001) lays out the important environmental stresses brought about by the human consumption in the biological base. He asserts that these stresses necessitate more preservation of resources as well as restructuring major cycles and processes of human environments simultaneously in order to sustain global health. Schmidt and Wolfe (2009) examine the symptoms of major deterioration in the natural environment, diagnose the progressing ailments, and offer possible cures as well as preventative planetary care.

While the awareness and knowledge on deterioration has been widening many theoreticians and professionals have been developing plans and designs in order to improve parts and pieces of the giant mosaic of environmental issues since the 1950s. In the last few decades, the research, experimentation, and developments in environmental design and planning practices have helped establish a wide range of core principles and strategies for more sustainable urban lifestyles and environments. Among these ideas are Sustainable Communities (Van der Ryn & Calthorpe, 1986), Regenerative Design (Lyle, 1994), Eco-Cities (Todd & Todd, 1994), New Urbanism (CNU, 1999), Green Urbanism (Beatley, 2000), Smart Growth (Porter, 2002; SGA, 2004), Living Buildings (ILBI, 2010), and Resilient Cities (Newman et al., 2009), to name a few. No doubt, each one of these approaches to ecologically responsive and environmentally responsible design have been instrumental in lessening the negative impacts of urban development patterns. Some of these approaches have clearly set higher standards than others toward achieving "ecologically-sound" or "environmentally-friendly" developments and communities.

McHarg and Steiner (1998) identify the fundamental traits of "harmony of man-nature" that is achievable in urban areas (p. 31), calling for future development practices that mimic functional and aesthetic characteristics found in nature (p. 37), and specifying the baseline design factors to be considered in ecological planning (p. 76). McHarg offers a methodological approach to sound ecological design and planning practices by understanding and following "nature's processes, interactions, and values as the basis for allocating human uses in the landscape" (Ndubisi, 2002, p. 45). McHarg's method calls for setting clear re/development goals, objectives, needs, and boundaries where the ecological inventory of physical and biological processes can be mapped and modeled to achieve optimum suitability.

Likewise, Thompson and Steiner (1997) summarize a range of mainstream ecological design and planning considerations with the goal of achieving responsible and appropriate human re/developments in harmony with natural systems and environments. The authors elaborate on the importance of planning principles and design strategies to complement the local, native, domestic and natural landscape (p. 183). Along similar lines, Barton (2000) and Barton et al. (2003) offer a series of basic principles for creating more sustainable communities and ecologically responsive neighborhoods taking natural ecosystems and processes as models for planning and design (p. 88).

There are numerous other kinds of studies exploring the sustainable and ecologically integrated environmental design possibilities for human settlements. Jackson and Svensson (2002) examine the key social, economic and environmental dimensions related to such settlements, which are conceived to be in tune with the natural ecosystems they are located in (p.

40). Their report shows that small villages nested in natural settings can offer critical design, implementational, and operational principles that may be applied in urban areas as well. Bang (2005) and Dawson (2006) focus on a series of similar communities throughout the globe, summarizing the vital characteristics that make each community ecologically versatile as well as resilient. Yeang (2006b) offers an ecological design manual for effective integration of natural air, water, food, and energy recycles (p. 58), which is very much in parallel with the five dimensions that make up the RUD model proposed in this dissertation. Environmental design precepts supporting these theories and applications have also helped to shape a number of other prominent methodologies such as: regenerative design (Melby & Cathcart, 2002); sustainable urbanism (Farr, 2008); resilient society (Edwards, 2010); and integrated design (DeKay, 2010).

When critically analyzed from the viewpoint of environmental rehabilitation or restoration most of these sustainable and ecological design methodologies assist in the incremental recovery and rejuvenation of the natural systems and environments over a period of time. However, it is gradually becoming apparent that these strategies alone are not sufficient in preventing – or reversing – the overall deterioration being caused by the human environments and activities within the biosphere. No matter how well designed, ultimately, the health and longevity of urban re/developments depend on the health and longevity of natural resources and systems that sustain them. That is why urban re/developments cannot afford to incessantly degrade life-sustaining natural cycles and balances.

1. Background & Context

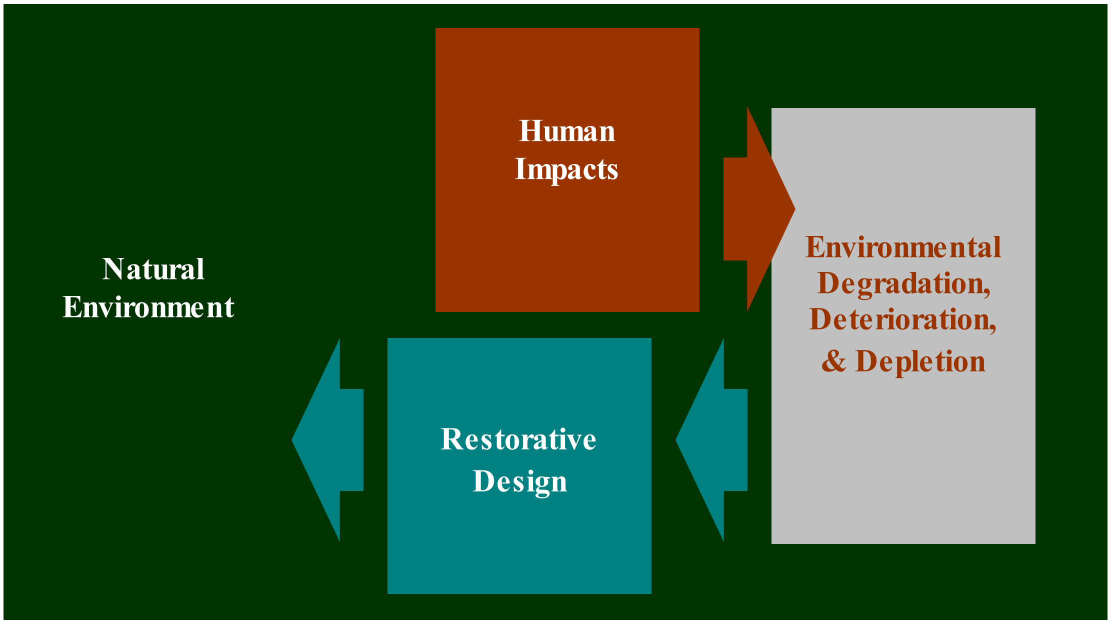
While major sources of environmental degradation, deterioration, and depletion on Earth are embedded in urban areas there appears to be an unjustifiable absence of research and development aiming for the comprehensive restoration of natural environment through improved urban design and planning. The Restorative Urban Design (RUD) is perhaps the first to propose an urban design methodology toward a comprehensive restoration, which can – and in fact should – be adopted by public or private entities for implementation, and realized at any scale in any community where social, economic, and political values are driven by mitigation of human impacts on environment.

At this point, a significant number of mitigations need to be implemented in a number of different dimensions of the natural environment simultaneously. Such large-scale undertakings are actually reasonably attainable when the sources of multidimensional environmental problems are correctly identified and mitigated promptly at the source.

Some of the primary requirements of restoration have been highlighted by many authors in the sustainable and ecological design literature. Brown (2003), for instance, points out that at a minimum restoring the tree and grass cover alone would protect soils, reduce floods, and sequester carbon, which is one of the simplest ways "we can restore the earth so that it can support not only us, but our children and grandchildren as well" (p. 150).

From a purely restorative perspective, it is important to note that a significant amount of research, development, and implementation in current urban design and planning espouses lessening of human or urban impacts while increasing sustainability and environmentally-friendliness. Yet, the environmental conditions reportedly continue to get worse with each passing each year. Only a relatively small fraction of individuals and organizations focus their work on the comprehensive restoration of the natural environment (see Figure 1.1).

Figure 1.1 Restorative approach aims to restore the state of natural environment

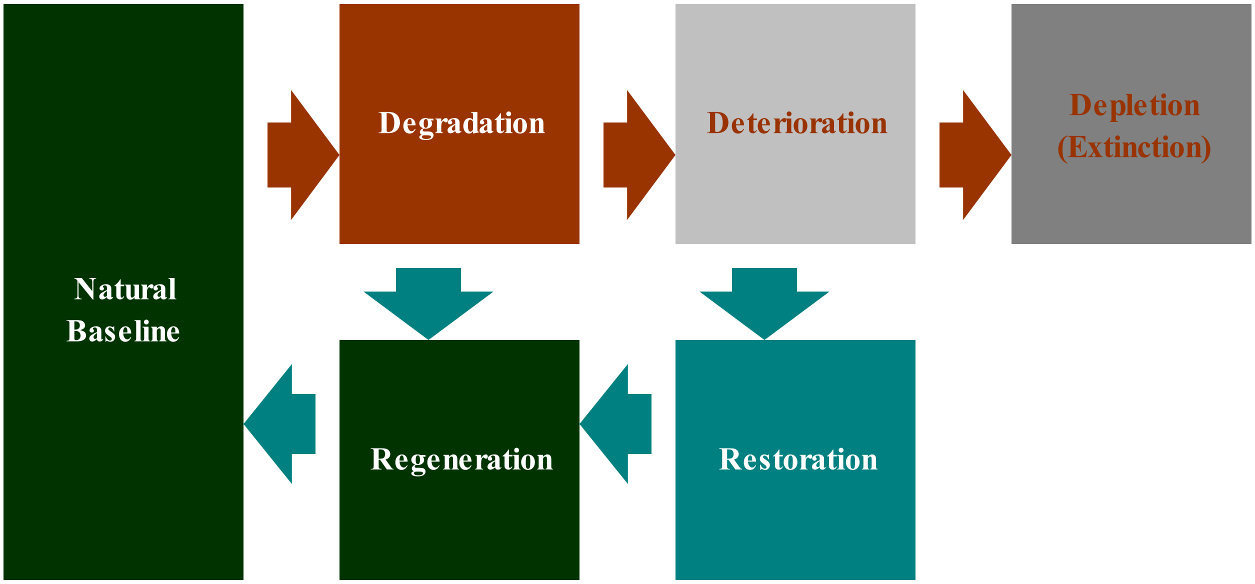


The literature on degradation, deterioration, and depletion clearly points to the mid twenty-first century as the timeframe for likely irreversible and potentially catastrophic environmental changes on Earth (Meadows, Meadows, & Randers, 1992; Heinberg, 2003; Diamond, 2005; Kunstler, 2005; Homer-Dixon, 2006; Hansen, 2009; Homer-Dixon & Garrison, 2009; Orr, 2009; Brown, 2011) (see Figure 1.1). The mainstream urban re/development principles and strategies in many industrialized nations – including the United States and Canada – lack a concentrated focus on restoration of the natural environment. There is a definite and urgent need for employing urban design and planning methods that focus on the comprehensive restoration of the natural environment through rigorous urban re/development as promptly as humanly possible.

2. Purpose of Restorative Research

While some proximate and short-term disturbance in the natural environment is inherent during urban development, excessive amounts of disturbance or degradation may easily give way to deterioration, which is a more vulnerable state of degradation (see Figure 1.2). Deteriorated environments or cycles in nature become more susceptible to becoming depleted and even extinct if rate of degradation is more than regeneration. As shown in Figure 1.2, the state of deterioration leads to depletion if appropriate amount of restorative intervention is not provided. While the degraded cycles and balances can be regenerated, the deterioration may be restored, the depletion or extinction may be neither regenerated nor restored easily.

Figure 1.2 Degradation beyond deterioration should be prevented by restorative efforts



Within this context, this restorative research aims to fill an important gap in the sustainable urban design literature by: 1) shifting the focus to the restoration of the natural environment rather than single-minded and widespread anxiety about human sustenance; 2) advancing a methodological scientific restorative approach to urban re/development; and 3) explicating possible environmental impact mitigation strategies within urbanized areas.

It must be clearly understood that there is no single, absolute or perfect way that will lead to a comprehensive restoration of the natural environment, just as there is no single source or dimension of deterioration. Undoubtedly, a comprehensive environmental restoration can only be achieved through application of a myriad of correlated, multi-disciplinary, and collaborative efforts that are in alignment with restorative principles. Springing from that awareness, this research focuses on identifying strategies and developing a practical method toward achieving restoration at the scale of urban design and planning. It is recognized that given many current institutional practices this will not be easy and will take persistent effort and time.

While the primary research questions behind restorative approach are deceptively simplistic, finding solutions to adequately address them requires much higher levels of sophistication. Leaving aside many other possible venues to restore the natural environment, this research focuses exclusively on the principles and strategies related to urban design and planning. The central questions that drive the research are:

i. If the comprehensive restoration of natural environment is not aimed for, is it likely to ever arrive on its own?

   The answer is 'no,' which enables this research to move forward.

ii. Can the principles and strategies of environmental design and planning for urbanized areas effectively facilitate the comprehensive restoration of natural environment?

   Absolutely. A rational, reasonable, and methodological approach to urban design and planning can facilitate large-scale rehabilitation and restoration. In fact, it may be the only viable way to do so, given the persistent growth of urban areas.

iii. If so, how should the principles and strategies of Restorative Design be formulated?

iv. If there were an urban design model of comprehensive environmental restoration, what would it look like? What would the goals, objectives, and actions of such a method be?

Many sources of on-going environmental degradation and deterioration are traceable back to developmental and operational patterns within urban areas (Orr, 1992; Goudie, 2006; Calthorpe & Fulton, 2001; GEO3, 2002). As a result, the design and planning of urbanized areas have critically important roles to play, not only in minimizing the impacts of human-made environments and systems but also in restoring the damages caused by these impacts on natural environment (Van der Ryn & Calthorpe, 1986).

Adequate investigation to answer the central questions above quickly produces a series of secondary and tertiary level questions integral to restorative urban re/developments, which need to be answered along the process:

i. What are the pristine natural cycles and balances that are being disturbed by human-made environments and activities?
ii. What are the most significant types and areas of degradation, deterioration and depletion caused in the natural environment by humans?
iii. What are the significant sources of these impacts?
iv. What are the primary indicators? What specific roles do the urbanized areas play in the degradation, deterioration and depletion of natural resources?
v. Which indicators or sources of urban impacts are currently monitored?
vi. What exactly should the restorative goals, objectives, and actions be?

The kinds of questions that follow are much more specific to design, methodology, and implementation of environmental restoration measures. The impetus behind the restorative research also aims at developing not only a conceptual framework and a theoretical foundation but also an implementation-oriented method for urban design and planning practices. Hence, some of the secondary and tertiary questions that need to follow are:

i. Are there any precedents to such restorations anywhere in the world?
ii. Are there any existing methods or models in place for achieving a comprehensive restoration of the natural environment?
iii. How, then, should the environmental restoration through urban design and planning be defined and measured?
iv. How should such restoration be designed and implemented within urban areas?
v. Which factors or indicators are most relevant to such a restorative agenda?

vi. Which existing methodologies present relevant and effective remedies toward restoration of the natural environment?
vii. What are the primary elements of environmental restoration within the urban areas?
viii. How can restoration be effectively measured and monitored relative to atmosphere, hydrosphere, lithosphere, ecology, and energy?
ix. What would be the major components of a Restorative Urban Design model to tackle so numerous and complex environmental problems?
x. Is there a more effective approach to evaluate the restorativeness of future re/development scenarios other than hypothetical estimation, examination, and optimization?
xi. Is there an urban design method more suited for restorative purposes than scenario-comparison?
xii. Can all of the required restoration be achieved on urban sites alone?
xiii. What kind of urban impact mitigations would be necessary offsite?

3. Approach, Framework, & Model of Restorative Research

The restorative approach acknowledges that a significant amount of degradation, deterioration, and depletion has already taken place in the natural environment. It acknowledges that the intrinsic pace of reconstitution and rehabilitation of natural resources and environment is simply not able to keep up with the escalating mass production and consumption demands, driven by human populations. Without significant changes in how we plan, design, develop, and operate landscapes, structures, and built infrastructure there is little or no hope for seeing any meaningful improvements in the current course of environmental degradation, deterioration, and depletion. The human-made environments and systems often disrupt natural cycles and balances in air, water, land, ecology, displacing the native and benign ecosystems with those designed to be indestructible by natural forces.

The framework of restorative research stems from “restoration” i.e. recovering the conditions or returning to a state that existed prior to a certain intervention or disturbance (SERI, 2004). In the context of sustainable planning and ecological design, that intervention or disturbance would be the human activities and systems introduced into the natural environment following the human settlements and/or industrial revolution. The premise is not to abolish current human activities and systems or to return urban systems literally back to any particular time in the past but rather to recover the attributes of the environmental functions that existed prior to the human interventions and disturbances.

The RUD model supports a multidimensional interdisciplinary environmental design and planning process by focusing on the scenario-based performance assessment toward environmental restoration. Hence, the central aim is not to prove or disprove a single set of relationships through hypothesis-testing, rather scenario building and geospatial visualization for decision-making purposes. Yet, there are many implicit presumptions upon which the method is constructed. Perhaps the most significant underlying presumptions are:

i. Planning principles and design strategies for urbanized areas can effectively facilitate the comprehensive restoration of natural environment, if and when, they are appropriately formulated to mitigate negative environmental impacts of urban developments.

ii. In fact, what has so effectively brought the human impacts on nature to the brink of an environmental catastrophe today is the application of principles and strategies that culminated in the current state of environmental quandaries. Just like problems, the solutions are also in the formulation of environmental design, development and operation patterns.

iii. Restorative Urban Design can utilize the techniques of building and comparing future scenarios (Nassauer & Corry, 2004) similar to the ecological restoration models (Berger, 1990; Urban, 2006; Clewell & Aronson, 2007) and the urban growth projections (Campagna, 2000; Cheng, 2003; Yang & Lo, 2003; Mani et al., 2005; Al-Kheder, 2006; Oguz et al., 2007; Lemp et al., 2008; Wang & Mountrakis, 2011).

iv. Scenario-comparison process can be used to evaluate and analyze the differences that restorative interventions are likely to make in the future course of urban re/developments.

v. Once the restorative interventions are implemented the balance and harmony in the natural environment can be on its way to be restored.

The RUD model proposes to develop an integrated urban design and planning approach to evaluate design assumptions and to optimize mitigation strategies using a series of critical analyses under primary dimensions of environmental assessment. The method is based on comparing various possible re/development scenarios toward an optimized restorative projection.

4. A Case Study in Restorative Urban Design

To complement the RUD model, a case study is carried out to examine a single aspect of restorative urban re/developments. The case study illustrates in detail how urban impacts associated with this single indicator of the model can be applied in a given study area. The RUD Case Study is intended to demonstrate the process of determining a natural or ideal baseline for restorative design, estimating historical and present conditions, forecasting a future trajectory of historical trends, as well as examining possible restorative projection scenario alternatives that optimize the onsite as well as offsite impact mitigations.

At this point in history, it is widely recognized that one of the single greatest challenges facing the comprehensive environmental restoration is the mitigation of anthropogenic CO_2 emissions generated by human activities primarily happening in and around the urban areas. Within the larger framework of restorative research, the RUD Case Study is intended to take an in-depth look at the issues related to the estimation, evaluation, optimization, and mitigation of anthropogenic CO_2 emissions through restorative re/development strategies. In the case study, the estimated emissions generated in the study area are fully mitigated by reiteratively balancing different design assumptions in order to approximate the conditions to natural baseline in the most effective and practical manner possible.

The study area is purposely chosen to be an average size mixed-use urban neighborhood located adjacent to a downtown of a typical major metropolitan area in the United States: River North District in Chicago, IL. The River North District appropriately represents the common urban characteristics that dominate most contemporary metropolitan cities of the Western Europe and North America today. The population growth, distribution, density, mixture of land uses, modes and networks of transportation, infrastructure as well as supporting industries in the Chicago Metropolitan area are typical of most major urban areas. Largely fossil-fuel dependent private and public transportation, as well as electricity generation are common to most similar size districts and subregions in North America and Europe. The district is neither the most intensely developed in the Chicago area, nor the least. While the River North District is less densely populated than the urban core it has a higher density than many other suburban or exurban areas. The second highest skyscraper in Chicago – fourth highest in North America – i.e. Trump International Hotel and Tower is located within the boundaries of River North.

The RUD Case Study is designed to focus specifically on a single indicator of the RUD model with the presumption that the other indicators can be modeled, estimated, and analyzed with using similar approach and procedures. While certain adjustments for different indicators in each dimension may be necessary to apply the RUD model to a given study area the underlying processes of scenario-comparison and optimization for determining onsite as well as offsite mitigations remain constant.

5. Research Questions & Expected Results

In order to effectively address the challenge of environmental restoration from only the anthropogenic CO_2 emissions perspective, a number of key research questions were posed during the application of RUD model to the study area:

a) Question 1: Current Conditions – Anthropogenic CO_2 Emissions

What is the total estimated annual amount of current anthropogenic CO_2 emissions in the study area (tons/yr) as of year 2014?

For restorative research purposes, the amount of anthropogenic CO_2 emissions of any given urban area is estimated by using four main sources of CO_2 generation: private transportation, public transportation, heating (natural gas and fuel oil), and electricity consumption (Glaeser, 2008). There are other kinds and sources of anthropogenic carbon dioxide emissions such as from production and transportation of goods, services, materials, and foods, which happen outside but support the daily life within the study area. If included in estimations, these excluded emissions would result in even larger mitigation requirements. The current anthropogenic CO_2 emissions in the study area (tons/yr) as of year 2014 is likely to range:

a) High: 498,500 tons/yr, assuming 25% lower efficiency and/or more reliance on fossil fuels usage than regional averages.

b) Median: 398,800 tons/yr, assuming about 20 tons/yr per person on average (Rowntree & Nowak, 1991, p. 273; TLGDB, 2001, p. 219).

c) Low: 299,100 tons/yr, 25% higher efficiency and less reliance on fossil fuels.

b) Question 2: Trajectory Forecast – Anthropogenic CO_2 Emissions

What is the total annual amount of anthropogenic CO_2 emissions (tons/yr) to be restoratively mitigated by year 2040 in the study area?

It is expected that the total annual amount of anthropogenic CO_2 emissions in the study area (tons/yr) as of year 2040 depends largely on population and consumption patterns but is likely to be within a range of:

a) High: 579,300 tons/yr, 25% above historical patterns.

b) Median: 463,500 tons/yr, based on historical population growth patterns.

c) Low: 347,600 tons/yr, 25% below historical patterns.

c) Question 3: Restorative Projection – Onsite Mitigations

In an optimized restorative projection scenario, what percentage of the estimated annual amount of anthropogenic CO_2 emissions is likely to be mitigated through strategies implemented onsite by 2040?

The percentage range of projected restorative mitigations within the study area as of year 2040 is influenced by a series of factors such as population, growth, and design assumptions. However, possible scenarios could be grouped into the following categories:

a) High: 55%. This restoration projection scenario assumes a relatively lower level of future growth and development in the study area than Central Chicago Area Action Plan (CCAAP, 2009) projection, with relatively high level of mitigation measures for anthropogenic CO_2 emissions by the year 2040.

b) Median: 30%. This projection scenario assumes an average level of growth and development in the study area as compared to CCAAP (2009) by the year 2040, as well as moderate mitigation measures.

c) Low: 5%. This projection scenario assumes a much higher level of growth and development in the study area by the year 2040, with the least amount of onsite mitigations.

d) Question 4: Restorative Projection – Offsite Mitigations

In an optimized restorative projection scenario, what percentage of the estimated annual amount of anthropogenic CO_2 emissions is likely to be offset by mitigation strategies implemented offsite by 2040?

In most parcels of the RUD Case Study area, it is expected that the estimated range of anthropogenic CO_2 emissions cannot be sufficiently mitigated onsite, and therefore, significant offsite mitigations are likely to be implemented offsite. The percentage of offsite mitigated emissions could potentially be in the range of:

a) High: 95%. This projection assumes a relatively high level of growth and development in the area with relatively low level of onsite mitigation measures for emissions.

b) Median: 70%. This projection scenario assumes an average level of growth and development in the study area as compared to CCAAP (2009) by the year 2040, as well as a moderate level of onsite mitigation measures.

c) Low: 45%. This projection scenario assumes a lower level of growth and development in the study area by the year 2040, with the most amount of onsite mitigations.

6. Reliability, Validity & Generalizability

The process of information modeling is not immune from inherent technical constraints and potential limitations associated with issues such as data availability, reliability, validity, and generalizability. Whenever possible, reasonable efforts have been made to circumvent some of these issues by using alternative methods, however, as any other academic study the restorative research is as reliable, valid, and generalizable as the methods and data it utilizes.

In order to increase the reliability of results, the restorative research relies solely on data and information from governmental, institutional, and peer-reviewed literary resources. There are a number of critical areas where the reliability of results would be directly influenced by the accuracy of available existing information and design assumptions integrated in the information modeling. Especially within the process of establishing the existing conditions, gaps in the available information are inherent and unavoidable. While rigorous efforts are made to locate and utilize the fullest extent of recorded data through multiple sources, in some instances, missing data or conditions need to be interpolated or extrapolated to represent the situation based on the similar data or conditions.

Likewise, the processes of forecasting the future trajectory as well as projecting restorative scenarios as part of the RUD model rely largely on a series of necessary predictions based on historical trends and possible future tendencies. The reliability and validity of these predictions are circumstantial and subject to change based on the specific location and timeline under research. While the specific results may vary the overall conclusions from each case are likely to exhibit generalizable conditions. For instance, while the specific amount of offsite mitigations varies for each case the necessity to provide substantial offsite mitigations in each case is likely to be a general rule.

7. Limitations, Delimitations, & Assumptions

By its very nature, environmental information modeling relies on constructing mathematical abstractions and simplifications in order to represent, analyze and evaluate complex real-world phenomena taking place simultaneously. Perhaps the single greatest limitation for restorative research is brought about by the difficulties of meaningful simplification of causes and effects related environmental impacts.

A significant area of limitations for conducting a comprehensive research on a topic like environmental restoration emerges from the difficulties in defining measurable problems and conceptualizing the methods to appropriately quantify and analyze them. Due to complex interrelated nature of environmental design and planning issues involved maintaining a clear focus and a well-defined scope for research becomes a formidable challenge where certain assumptions have to be made in order to move forward. The RUD model makes certain exclusions and exemptions as noted, and focuses on major impacts due to temporal as well as spatial constraints.

A prominent delimitation on the restorative research is that the social, cultural, political and economic considerations related to the environmental design and planning issues are excluded from the scope of study. For clarity, this research focuses exclusively on environmental aspects of issues at hand seeking practical and viable solutions for them.

The limited time and resources available for the restorative research have been prominent delimitations defining the final form of this dissertation. While the RUD model starts to advocate a larger set of urban design principles and strategies based on a complex estimations and projections toward comprehensive environmental restoration, the RUD Case Study offers detailed analyses and application on only a single indicator. The Case Study serves as a precedent demonstrating how the method is to be implemented by the other indicators.

Some overlaps and redundancies are inherent to the RUD model as well as the RUD Case Study. An example of such overlaps and redundancies, for instance, exists between the calculation of annual anthropogenic carbon dioxide generation and the estimation of total carbon dioxide per capita. Even though these are seemingly similar calculations with seemingly similar purposes drastically different findings are attained depending on the assumptions made in their valuation.

B. Intellectual & Scientific Significance

Despite its overwhelming volume and complexity, the vast majority of current methods (i.e. sustainable, green, smart, eco-friendly, integrated, resilient, or regenerative approaches) for environmental design and planning offer little guidance specifically directed toward a comprehensive restoration of the natural environment. Contemporary modus operandi continues to be that the human impacts on nature can be considered relatively insignificant when compared to meeting economic needs and wants, and that the naturally rehabilitative processes in nature are presumably sufficient to neutralize these impacts in the long run. Evidence continues to mount, unfortunately, that this in fact is not the case anymore. The human civilization is slowly awakening to the fact that the view of nature as a vast, infinitely abundant, regenerating, self-rehabilitating, and self-repairing system at the service of humans now requires serious revisions. Meadows et al. (1972), Meadows et al. (1992), Meadows (2004), Diamond (2005), and Heinberg (2011) concur that there is in fact an end to growth, and that irresponsible growth patterns will lead society to a rather unpleasant and/or unfavorable ending.

Only a small portion of planners and designers are beginning to exclusively focus on the dire need to contemplate and implement ecologically and environmentally restorative strategies beyond sustainability. The current literature on the global, ecological, and environmental restoration is fairly narrow and limited to authors who concentrate on different aspects of necessary repairs and rehabilitation. McHarg (1969) provides a framework through which urban re/developments need to be designed in harmony with naturally living systems. Berger (1985) and Berger (1990) illustrate the range of restorations that are required in natural as well as urban areas of the environment. Lyle (1994) lays out the principles and strategies for designing systems and environments that rely primarily on the thriving and regenerating natural resources. ILBI (2010) builds on the living building and regenerative principles laid out by Lyle (1994), and provides a framework for designing buildings and environments integrated into the naturally self-sustaining systems. As Aronson et al. (2006) points out the restoration is, indeed, “the acknowledgement by humans that we have used too much natural capital and that – for our own good – it is now time to 'give back' to nature and to nature's functions on which we depend" (p. 137). Key impetus behind the Restorative Design research is the conviction that the best practices of future planning and design for urban areas must aim at the comprehensive restoration of natural systems, cycles, and balances to the furthest extent possible.

This research is perhaps a first to propose and develop an integrated method of urban design for comprehensive environmental restoration, which is – at least in principle – implementable by public or private entities in any community whose social, economic, and political values are driven by correction of environment damages. The restorative principles and strategies that shape the RUD model hold enormous potential to provide feedback for policy- and decision-making processes based on scientific analyses and – perhaps more importantly – to bring large-scale transformation in urbanized areas toward facilitating the recovery and the rehabilitation of natural balances within the living biosphere of the Earth. Urban design and planning, in particular, are among the most potent collaborative disciplines for facilitating future transformations within the urbanized areas. Integrated developments and coordinated redevelopments of the built environment are vitally important and perhaps the only viable venues leading to the comprehensive restoration of the natural environment.

C. Organization of Restorative Research

The restorative research is driven by the theory of environmental restoration, and organized around the Restorative Urban Design model, which is operationalized by the RUD Case Study illustrating how the method is to be implemented.

Chapter 1 (Introduction) has provided an overview, background, context, purpose, framework, and application of restorative research including research questions, expected results, limitations, significance, terms and definitions.

Chapter 2 (A Theory of Environmental Restoration) offers a review of specific literature related to restorative research including urban impacts, ecologically responsive, environmentally responsible design, and absence of environmentally restorative focus. This chapter builds the bases of environmental restoration, which is firmly embedded in mitigating impacts on natural ecosystems and ecologies within urban areas and beyond. Here, the theoretical framework and principles of Restorative Urban Design are discussed within urban ecology.

Chapter 3 (Toward A Method of Restorative Urban Design) explains the core principles and strategies of restorative research and design. The chapter elaborates on the framework, operational, and conceptual models of restorative research, which are used to establish indicators and indicators of restorative analyses. Restorative indicators, measurements, analyses, and scenario-comparison process are discussed in detail.

Chapter 4 (Case Study on A Restorative Indicator) illustrates the application of the conceptual model to a single indicator, i.e. anthropogenic CO_2 emissions, exemplifying how the measurements and analyses for the other indicators in the RUD model are to be estimated, analyzed, evaluated, and optimized for implementation of restorative mitigations.

Chapter 5 (Conclusions) provides an overview of restorative research, expected outcomes, research findings, as well as conclusions arrived at the end of this study. This chapter offers a series of discussions on opportunities and challenges on the path to comprehensive environmental restoration. It outlines some of the broader impacts and implications related to application of restorative principles and strategies. The final chapter also offers few recommendations related to the future research on environmental restoration.

D. Terms, Definitions, & Abbreviations

Some of the key terms and definitions that are extensively used in the restorative research are summarized on the list below. For the abbreviations frequently used in this document refer to Appendix A.

Terms	Definitions
Degradation (Regeneration^{-1})	State of decline to a lower grade, level, quality, or condition
Deterioration (Restoration^{-1})	Diminishing or impaired quality or value; Decay; Disintegration
Depletion (Extinction)	Process of becoming depleted or nonextant; Becoming extinct
Ecological Restoration	Process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER, 2002; Clewell & Aronson, 2007)

Environmental Restoration	Act of restoring a defined segment of environment to a former, original, or satisfactory condition
Evaluation	Assessing, comparing, and considering the advantages and disadvantages of the amount or intensity of the restorative design assumptions
Historic Progression Scenario (HPROG)	Temporal progression of human or urban impacts on the natural environment, which lead up to the current conditions of degradation and/or deterioration
Method	Study of the process, rather than the product, of inquiry (Groat & Wang, 2002, p. 9)
Methodology	Aspects of the research processes of inquiry that are common to a broad range of disciplines (Groat & Wang, 2002, p. 9)
Nature	A dynamic self-sustaining system containing representatives of all forms of life (Laurie, 1979, p. 23)
Natural Baseline Scenario (NBASE)	A natural or ideal functional set of conditions, which form the design baseline in the restorative research; the natural baseline would be the assumed preferred alternative or restoration target
Offsite Mitigations	Environmental restoration activity that is located outside the confines of the project site or study area
Onsite Mitigations	Environmental restoration activity that is located within the confines of the project site or study area
Optimization	Process of reiteratively refining a final scenario (RPROJ) in the RUD model, where an optimal, most effective, or best possible combination among the design assumptions is reached
Restorative Indicators	Environmental performance assessment indicators that assist in the assessment of environmental restoration
Restorative Projection Scenario (RPROJ)	A set of projected scenario conditions to be achieved by strategies and mitigations proposed by the RUD model,

	which are reiteratively refined and specifically optimized to deliver restorative results
Restorative Significance (Restorativeness)	Degree to which a certain system, process, or activity is assisting in regeneration and restoration or preventing further degradation and deterioration of nature
RUD model	The Restorative Urban Design model is comprised of a specific set of elements and procedures developed for a conceptual model outlined in this dissertation, which include restorative dimensions, indicators, scenario-comparison, optimization, and visualization
Urban Ecology	Study of relationships between human and natural environments within urban areas (Fitter, 1945; Breuste et al., 1998; Douglas et al., 2011); Ecological make up of an urban area
Urban Metabolism	An accounting of material inputs into and waste outputs out of a city (Wolman, 1965; Douglas et al., 2011)
Scenario-Comparison	In restorative research, this term defines a specific process of building and evaluating scenarios of urban impact generation and mitigation i.e. Natural Baseline (NBASE), Historic Progression (HPROG), Trajectory Forecast (TFORE), and Restorative Projection (RPROJ)
Trajectory Forecast Scenario (TFORE)	A particular future forecast scenario in the RUD model that is based on the historic and present conditions and that is most likely to take place in time, assuming the historic and current trends do not change significantly

Chapter 2 - A Theory of Environmental Restoration

This chapter presents important ideas and principles that ground environmental restoration primarily in urban areas. A summary of the literature review behind the theory is laid out in greater detail. In short, the theoretical bases of environmental restoration are introduced and explained. In addition to the main principles of restorative urban design, the spectrum of environmental scales for restoration is discussed within the geospatial context. The chapter also offers the theoretical framework of environmental restoration within the context of urban ecology. Some of the key concepts such as Natural Ecosystems, Urban Ecology, Urban Metabolism, Urban Ecosystems, and Ecological Resilience are reviewed, and the methods of ecological restoration are related back to the restorations in urban ecology.

A. Literature Review

The theoretical foundation of environmental restoration draws from the experience, knowledge and expertise of a wide range of disciplines including agriculture, architecture, biology, city planning, ecology, ecological engineering, geography, landscape architecture, and urban design, all of which provide feedback to refine our understanding of restoration-focused environmental design and planning. The following literature review attempts to define the core design challenges and central importance to the environmental restoration theory.

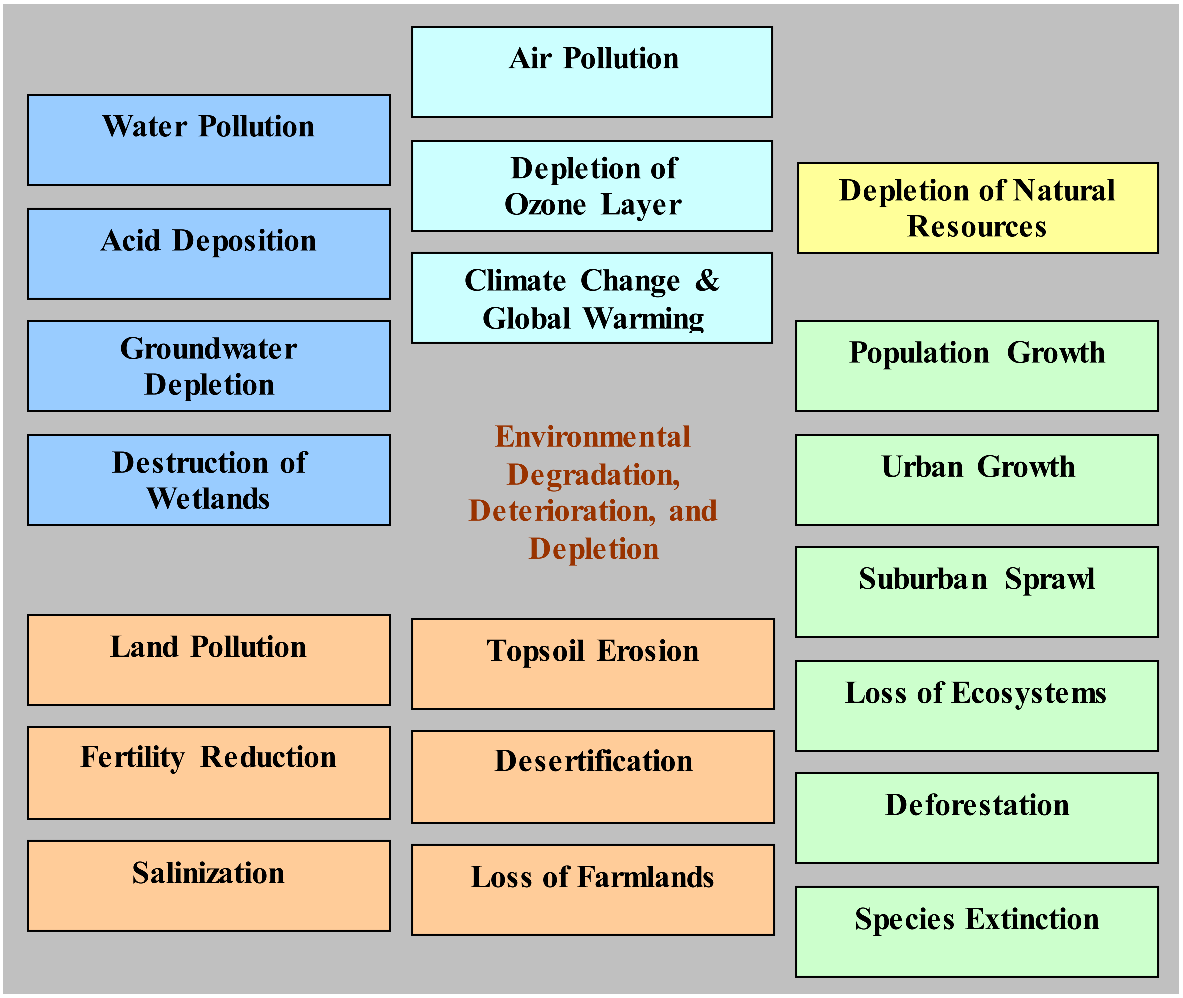
To begin with, an in-depth review of primary sources of degradation, deterioration, and depletion in the natural environment establishes the key issues to be addressed through restorative efforts. Considering that the root causes of these issues are often directly attributable to urban developments, operations, and activities this review lays out a strong foundation.

In the following the review of the principal sources of degradation, deterioration, and depletion, the restorative research closely examines some of the most prominent urban design and planning methods already developed to address these issues. The review of existing methods helps establish a holistic agenda for ecologically sustainable and environmentally restorative urban design and planning. The review of emerging study areas such as urban ecology, urban metabolism, ecosystem resilience, and urban ecological restoration makes the development of a theoretical framework for restorative urban design and planning possible.

1. Environmental Degradation, Deterioration, & Depletion

While this literature review is not exhaustive or complete by any means it does give a clear and in-depth representation of the major categories of degradation, deterioration, and depletion in the natural environment and resources (see Figure 2.1).

Figure 2.1 Major sources of degradation, deterioration, and depletion are in urban areas



The key issues of environmental degradation, deterioration, and depletion can be grouped into categories related to air, water, land, ecology and energy including air, water, and land pollution; acid deposition; destruction of wetlands; topsoil erosion, fertility reduction, salinization, and groundwater depletion; loss of farmlands; desertification; deforestation; species extinction; population growth; urban growth, suburban sprawl, and loss of ecosystems; depletion of natural resources; depletion of the ozone layer; climate change and global warming. In response to these issues many urban design and planning methods have been developed in the last few decades, which have started to establish patterns of ecologically responsive and environmentally responsible design.

a) Air, Water, & Land Pollution

The built-environment in the industrialized societies of the "developed" world continues to be the leading source of pollution and resource depletion within the natural environment thanks in large part to wide-spread, intensive, and energy-and-resource-hungry industrial processes. There is a wide selection of relatively recent literary sources such as GEO3 (2002), MEA (2003), MEA (2005), and GEO4 (2007) on the specific extents and magnitude of air, water, and land pollution measured in the natural environment.

A number of sources compile and summarize the vast amounts of data into a concise form in order for planners and designers to use more effectively. Chiras (1992), Orr (1994), Hawken et al. (1999), Brown (2003), Orr (2006), Goudie (2006), and Brown (2011) explicate the severity and implications of air, water, and land pollution as they relate to wellbeing and longevity of urban dwellers from national and regional scale perspectives. In response to degraded ecological systems, Van der Ryn and Calthorpe (1986), Calthorpe (1993), ILBI (2010), Calthorpe (2011), Douglas at al. (2011), Haapio (2012) and many others elaborate on the roles and responsibilities of urban planning and design as it relates to improving the quality of air, water and land in and around the urbanized areas.

The common theme evidencing from these resources is that despite improvements brought about by the rigorous regulations on the quality of air, water, and soil in and the urban developments since 1970, the overall environmental quality has been on the path of impoverishment and decline, not of rehabilitation and recovery.

The evidence in the literature makes it clear that the contemporary practices of urban design and planning aiming specifically at the comprehensive restoration of natural environment need to do much more than lessening the human impacts at local scales. Global rehabilitation of air, water and land pollution are possible to achieve only by requiring and enforcing onsite as well as offsite mitigations of all known and likely impacts that are generated by the human activities. While there are some local regulations on acceptable levels of impacts to the quality of air, water, and land the cumulative results of seemingly small individual impacts become overwhelming.

b) Acid Deposition

Another significant outcome of industrial civilization has been the unnatural increase of acidic emissions and wastes in the natural environment. From industrial processes and combustion of fossil fuels, many chemical byproducts and waste materials such as sulfuric and nitric acids have long been disposed directly into the atmosphere, streams, and water bodies (Brown, 1981; Calthorpe, 1993; Hawken, Lovins, & Lovins, 1999).

There are currently limited restrictions and almost no restorative mitigation requirements for majority of these sources of degradation. The evidences of increased acidity in air, water and land (Berger, 1990; Orr, 1994; IPCC, 2007; Schiermeier, 2007, p. 580; McKibben, 2010) makes it clear that urban design and planning practices aiming at comprehensive restoration of natural environment need to go beyond lessening urban impacts. The urban re/developments need to achieve incremental mitigations beyond their direct impacts not only onsite but also offsite so that meaningful rehabilitation at global scale can be achieved.

c) Destruction of Wetlands

Another environmental tragedy, the destruction of wetlands typically involves expansion of urban areas and infrastructure developments, sometimes in conjunction with other human-caused or naturally occurring environmental factors such as drought or salinization. MEA (2003 & 2005) illustrate the steadily expanding nature of this problem which not only diminishes wildlife habitats for many native species but also contributes to decreasing capacity of the natural ecosystems to regenerate and rehabilitate human impacts. Berger (1990) estimates the amount of wetland area already lost to urbanization at about 50% (p. xv). McHarg and Steiner (1998) explain the phenomenon of surface hydrology and the important part that wetlands have in that process (p. 85). While authors such as Brown (1981), Chiras (1992) and Goudie (2006) explain the regional and global roles that healthy wetland systems play in the natural environment, other authors such as Lyle (1994), Todd and Todd (1994), Forman (1995), Beatley (2000), Kemp (2008), Porter (2008) and Edwards (2010) outline the specific planning and design strategies to integrate them within and around urban areas.

While conservation and preservation of existing wetlands is clearly an important principle for restorative design purposes it is simply not enough because there has been a tremendous amount of loss already. Depending on the underlying reason behind the losses, some wetlands may never return. Wherever possible the restoration of degraded or lost wetlands as well as creation of new ones to replace extinct habitats need to remain a local and global priority (Spirn, 1984; Berger, 1990; Forman, 1995; Diamond, 2005). The urban re/developments need to be required, as appropriate, to achieve incremental mitigations onsite and beyond so that timely rehabilitation at global scale can be achieved. In most cases, rehabilitation and/or recreation of wetlands would need to be initiated by the local governance and supported by the local and regional community at large.

d) Topsoil Erosion, Fertility Reduction, Salinization, & Groundwater Depletion

The environmental issues of topsoil erosion, fertility reduction, salinization, and groundwater depletion are primarily related to farmlands, grazelands, and other agricultural lands, which often remain adjacent to and/or outside urban areas. However, they are still relevant environmental issues that affect the quality of air, water, and soil which in turn effects the wellbeing and longevity of productive lands sustaining the urbanized areas.

Brown (1981), Chiras (1992), Hawken et al. (1999), Brown (2003), Orr (2006), Goudie (2006), and GEO4 (2007) explain how and why these interlinked problems are potential extraordinary threats to food production and supply for urbanites. Naturally, the literature and practices of urban agriculture, community gardens, and urban gardening have been gaining prominence (Lyle, 1994; Viljoen et al., 2005; Coyle, 2011; Gorgolewski et al., 2011; Girardet, 2008; ILBI, 2010; Philips, 2013). While no replacement for industrialized food production at large the urban food production need to be designed as a naturally integrated part of urban areas.

e) Loss of Farmlands

The loss of valuable farmland to urban developments is one of the most debated issues of the literature at odds with urban growth and expansion tendencies. Gradual but steady conversion of food producing lands to asphalt, concrete, and glass appears naturally to be a step in the wrong direction.

Degradation and loss of farmland soils is perhaps one of the most illustrious manifestations of how urban re/development often works against the very environments and systems that enable it to exist in the first place. However, the process typically happens rather subtly and under considerable pressures. Chiras (1992), Orr (2006), Goudie (2006), and GEO4 (2007) dwell on causes, effects, current extents, and magnitude of this modern phenomenon. From a historical perspective, Brown (2003) and Diamond (2005) point out that the loss of farmlands and topsoil acts as one of the main ingredients of eventual collapse for the urbanized societies. Dubos (1976) explores the ecological symbiosis between earth and man and highlights many different ways the balance can be kept (p. 461).

From an urban planning, growth management, sustainable, and ecological design perspective, Brown (1981), Calthorpe (1993), Orr (1994), Todd and Todd (1994), Van der Ryn and Cowan (1996), Hawken et al. (1999), Beatley (2000), McDonough and Braungart (2002), and Brown (2011) not only discuss the ill-effects of losing valuable farmlands but also different ways to preserve and enrich the existing ones that are still available. Many environmental performance rating systems such as LEED (2009) and ILBI (2010) strongly discourage or prohibit any urban developments to replace productive farmlands.

Loss of natural open spaces, farmlands, and grazelands is a primary driver behind environmental conservation and urban growth management literature where authors like Williams (2000), Kelly (2004), Burchell et al. (2005), McElfish (2007), Kemp (2008), Porter (2008), and Calthorpe (2011) explain the effective principles and strategies to prevent further degradation and deterioration of life-supporting soils and vegetation.

Conservation and preservation of existing farmlands at all costs need to be a clear priority for restorative urban design purposes. Whenever possible the degraded or potentially threatened farmlands need to be protected and new opportunities for community assisted agriculture and urban gardening need to be cultivated (Diamond, 2005; Brown, 2011). Typically, the rehabilitation and/or recreation of farmlands prove to be extremely difficult if not impossible to accomplish. The efforts would need to be initiated by the local governance and supported by the local and regional community at large.

f) Desertification

Desertification is a major phenomenon that progresses slowly but contributes greatly to the large-scale degradation and deterioration of the natural environment. GEO4 (2007) defines it as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (p. 104). The incremental losses of wetlands, marshlands, natural meadows, grasslands, grazelands, farmlands and other sensitive areas play significant roles in the increase of desert-like qualities and accumulating decline in the natural environment as reported by MEA (2003), Goudie (2006), and GEO4 (2007).

From a planning and urban design standpoint Hawken et al. (1999) and Edwards (2010) describe the steadily increasing spread of deserts and desertified lands in nearly every continent. Lyle (1994) identifies this process as a degenerative system that is devouring the sources of sustenance (p. 5). Brown (2011) cites a 2010 U.N. report estimating about one quarter of world's lands – where more than a billion people reside – to be affected by desertification (p. 37).

In order for urban re/developments to be truly restorative, not only the degenerative and degrading effects need to be controlled but also slow and steady gains for positive improvements in the spread of the natural habitats and living ecosystems need to be accomplished. The increase of ecological water flow as well as green cover is the prerequisite for healthier ecosystems (McHarg & Steiner, 1998; SSI, 2009) and positive environmental change (Allison, 2012).

g) Deforestation

Deforestation is another critically important environmental issue that constitutes an early step toward desertification. The demolition or loss of forested areas is a commonly irreversible occurrence that cannot be undone quickly or easily. The cumulative impacts of deforestation cause extremely adverse effects through the natural environment affecting many species. When all the rehabilitating and healing effects of green cover and forests as the base of natural ecosystems are considered the loss and/or absence of these areas create voids that cannot be filled by anything else. When the air filtering and conditioning, water purifying and regulating, soil moisturizing and protecting, energy and food producing, shade and shelter providing living members of the natural environment are eliminated there are no equivalent replacements to take their stead.

Environmental reports such as GEO4 (2007) and UNEP (2011) estimate that the majority of forests are lost to the pressures to create more urban lands and farmland more than other causes such as fire, disease and climatic change. Brown (1981), WCED (1987), Berger (1990), Chiras (1992) are among the literary sources that point out to the extent of deforestation globally, and most notably in South America, North Africa, Himalayas, and West Asia where rapid population growth and urban expansion have been on the rise.

In some countries, the pain and pressures of substantial losses of national forest areas have resulted in the initiation of notable reforestation programs. Among these are China with 2.9 billion, Ethiopia with 1.5 billion, Kenya with 1 billion, Turkey with 700+ million trees replanted, and India with their 600,000 trees a day campaign (Brown, 2011, p. 142).

The natural baseline scenario of the RUD model starts with the qualities of pristine or well-functioning natural ecosystems where all forms of life are supported and nurtured. In parallel with the measures against desertification, the restorative urban design principles are built around the restoration of life-supporting natural habitats and/or the restoration of environmental qualities of life-supporting natural habitats to counterbalance the incumbent human impacts.

h) Species Extinction

Included in the list of prominent environmental issues is species extinction, which is a consequence of overall degradation, deterioration, deforestation, desertification, and destruction in the natural environment. Like few of the other crises in the global environment the extinction phenomenon is irreversible. Once a certain kind of fish, bird or mammal is extinct it is lost and gone forever. Since the natural environment is an interconnected web of natural balances between diverse species and habitats each lost species takes away from the richness, diversity, resilience, health and longevity of the natural environment. The survival of humans, in turn, depends on the healthy existence of these supporting biological pools (Chiras, 1992; Van der Ryn & Cowan, 1996; Orr, 2006). Of course, extinction is inevitably proceeded by incremental losses of habitats and local populations.

Restorative mitigations within the urban ecology and beyond need to aim at the increased richness and diversity of other species living in the rehabilitated and/or natural ecosystems. Creation and maintenance of habitats that are conducive to nurturing of other non-threatening species of animals and plants need to be a priority for ecologically restorative mitigations. While some portion of these mitigations can be achieved onsite, the offsite mitigations need to be orchestrated and regulated by local governments or regional authorities.

i) Population Growth

The current human population growth and accompanying expansion of consumption appear to be at the crux of all subsequent environmental issues and problems. A number of scientists and experts on human population growth and associated environmental impacts argue that there are simply too many humans living on earth today in increasing numbers with increasing needs and demands. “The human population did not reach one billion until about 1820; in less than two centuries since then, it has increased nearly six-fold. This is a rate of growth unprecedented in human history” (Heinberg, 2003, p. 30).

> In the language of ecologists, humans have exceeded the Earth's carrying capacity. The environmental problems we face are signs that we have transgressed critical ecological thresholds. Unfortunately, few people in positions of power understand the meaning of carrying capacity and limits it places on human endeavor. Even fewer understand how far we have overstepped ecological boundaries and the long-term consequences of continuing to do so. An understanding of carrying capacity is therefore vital to solving our problems. (Chiras, 1992, p. 9)

> Humankind is now using natural resources more rapidly than natural systems can replace them and has been doing so for approximately two and one half decades. Moreover, both natural capital and the ecosystem services it provides are being diminished at an unprecedented rate. Finally, the human population is expected to increase by 3 billion by 2050. (Cairns, 2006, p. 77)

Heinberg (2003) estimates earth's natural carrying capacity to be at 2.0 million people, which is perhaps too conservative of an estimate (p. 192). Brown (1981) reports that the estimates in 1970 indicated diminishing resources and a collapse of earth's major ecosystems at 3.6 billion (p. 143). Brown (2011) indicates the carrying capacity to be at about 4 billion people:

> By 1999, global demands on the Earth's natural systems exceeded sustainable yields by 20 percent. On-going calculations show it at 50 percent in 2007. Stated otherwise, it would take 1.5 Earths to sustain our current consumption. Environmentally, the world is in overshoot mode (Brown, 2011, p. 7).

Friedman (2008) writes "it's the total number of Americans on the planet" (p. 74) and describes in detail the overburdening demands of energy-intensive lifestyles on the earth's limited resources. Authors like Meadows et al. (1972), Brown (1981), Meadows et al. (1992), Meadows et al. (2004), and Girardet (2008) analyze the earth's natural carrying capacity in detail and point to the increasing stresses on natural resources. Wilson (2008) recognizes the earth's limitations as a natural bottleneck that is likely to restrain the human population growth in the very near future and notes that for every person in the world to reach present U.S. levels of consumption with existing technology would require four or more planet Earths (p. 82).

While the largest expansion is happening in the less-developed countries today the exponential growth pattern in the world's overall population is perhaps in part attributable to the advances in modern sciences like agriculture, physics, biology, chemistry, and medicine. The accumulating advances in these sciences altogether help evolve various technologies that create artificial foods, synthetic clothing, sanitized infrastructure, non-biodegradable construction materials, quickening electronics, multiplying mechanization, wondrous drugs medications, and medical procedures (Friedman, 2008; Heinberg, 2003). As a direct consequence, more and more people are fed, clothed, sheltered and comforted relatively better today, enjoying much more nourished, healthier, and inherently longer lives.

There is arguably little that the restorative urban design could or should offer to counter the expanding human population. However, there is a lot that restorative urban design strategies could and should do to ensure the responsible expansion of urbanized areas. Growth will more than likely continue to happen but it needs to happen in an ecologically and environmentally appropriate manner. The types of re/developments that cause disruption in the natural environment need to by-and-large be confined and limited to contiguous urban in-fills where their estimated total impacts need to be mitigated onsite as well as offsite. Whereas the types of re/developments that foster the natural systems and flows need to be incentivized to spread not only within the urban areas but also beyond their borders. McDonough and Braungart (1998) as well as Hawken et al. (1999) insightfully illustrate that growth and fecundity are both beneficial and natural as long as their support systems are well planned, designed, and implemented to be regenerative, renewing, and positive for the environment. It is hoped that offsite mitigations advocated by the restorative research would facilitate rehabilitation and reclamation of lands that have already been lost to deforestation and desertification of previous decades.

j) Urban Growth, Suburban Sprawl, & Loss of Ecosystems

Environmentally irresponsive and/or irresponsible expansion of urban areas is a key area of concern in the contemporary battle between human-made and natural environments. The natural ecosystems appear to be defenseless against the invasive challenges of urbanization. However, ill-conceived urban re/developments often bring their own demise by undermining the naturally occurring ecosystems that support the longevity, health and welfare of urbanites in the long run.

The subject of ecologically responsive and environmentally responsible urbanization and urban expansion in the environmental design and planning literature is relatively extensive. Prominent theories and concepts related to the ecologically responsive and environmentally responsible design such as Smart Growth (SGA, 2004), Resilient Cities (Newman et al., 2009), Sustainable Communities (Condon, 2010), Green Urbanism (Beatley, 2000), and Urban Growth Management (Kelly, 2004; Kemp, 2008; Porter, 2008) are critically analyzed in the following section i.e. Ecologically Responsive and Environmentally Responsible Design.

Restorative efforts need to support and advocate the widespread use of many urban re/development principles and strategies proven to be beneficial to the rejuvenation and rehabilitation of natural cycles and balances in the environment as discussed in the Theory of Restorative Urban Design. The preservation and conservation of existing natural areas, open space reserves, wildlife habitats, wetlands, farmlands, and grazelands are as important as the restoration of degraded, deteriorated or depleted areas. Urban growth may happen but it needs to happen in an ecologically and environmentally sustainable manner. The RUD model establishes the use of offsite mitigations not only as part of assessing and remediating total environmental impacts but also as an instrument of environmental rehabilitation beyond the limits and borders of urbanized areas.

k) Depletion of Natural Resources

The undesirable end-results of environmentally irresponsible human consumption and urban growth patterns include the extinction and depletion of natural resources. Under the current human population and consumption growth patterns the finite natural resources of the Earth are subject to proportionally increasing pressures.

The literature on human impacts on nature, sustainability, sustainable urban design and planning is writ with the root causes and ill-effects of human activities upon the natural resources. Presence of clean air, access to clean water, availability of uncontaminated fertile soils, accessibility to non-engineered, unmodified or unaltered organic food sources, as well as availability of natural fabrics and materials are all compromised today in immensely significant ways. A multitude of natural products and foods have been effectively replaced with synthetic and artificial ones (Brown, 1954; Brown, 1981; McDonough & Braungart, 2002). In many cases, the substitutes are engineered to feel and taste like their originals. In some cases, the substitutes offer an even better – manicured and sanitized – feel and taste. It is ironic that there are many synthesized products and foods available today that never existed before in the history of the natural world while many natural resources are at the brink of depletion.

WCED (1987), GEO3 (2002), MEA (2005), GEO4 (2007) and secondary sources like Brown (1981), Chiras (1992), Hawken et al., (1999), Heinberg (2003), Friedman (2008), and Steiner (2009) provide numerous estimations of overall amount as well as annual rates of depletion and/or extinction in the natural environment. Brown (2011) provides a detailed summaries on changing climate, disintegrating ozone layer, record setting temperatures, expanding human population, deteriorating air quality, falling groundwater levels, disappearing freshwater supplies, melting mountain glaciers, evaporating lakes, dwindling rivers, melting polar ice, systematic losses of wildlife habitats, wetlands, grasslands, farmlands, desertification, deforestation, oceans fished out, millions of affected and displaced people. On the energy side, the irreversible depletion of fossil-based fuels such as coal, natural gas, and petroleum poses significant economic and environmental concerns as well.

Nearly all types of depletions and extinctions in natural resources are directly or indirectly linkable to the planning and design of urban activities and environments. To the furthest extent possible, the restorative mitigation principles and strategies predicated by the RUD model aim to not only minimize further degradation and deterioration but also maximize rehabilitation and regeneration in the natural environment through implementation of offsite measures.

l) Depletion of Ozone Layer

Indeed, the lack of understanding about the intricate balances of Earth's biosphere as well as the absence of genuine concern for the human impacts on nature, have clearly manifested themselves in the growing environmental problems being witnessed globally today. Bateson (1972) points out to the certainty of these "irreversibilities" surrounding "all around us; many, like global warming, the decay of the ozone layer, and movement of poisons through the global food chains, are set on courses it is too late to change". Bateson also affirms the prediction that "we have yet to suffer their full effect," which is probably still a true statement (p. xiv).

The detailed accounts of causes and effects of ozone layer depletion can be found in the writings of Bateson (1972), Coates (1981), Brown (1981), WCED (1987), McKibben (1989), Chiras (1992), Heinberg (2003), Sassi (2006), IPCC (2007), Friedman (2008), Steiner (2009), and Calthorpe (2011), which establishes the important roles that anthropogenic greenhouse gas emissions play on the depletion of ozone layer. The depleting layer is closely associated with the increasing global temperatures to be followed by permanent shifts and changes in the global climate patterns. Cairn (2010) quotes Myles Allen as stating:

> The world's carbon emissions must eventually stop – and stop completely. There is no sustainable per capita carbon emission level because it is the total amount of carbon emitted that counts. (p. 297)

The primary responsibility of global as well as local sustainable urban design practices is to focus on implementing a widespread transformation in the makeup and functions of human-made environments. The RUD model aims to contribute to this transformation by heightening the rehabilitative goals and expanding the restorative mitigations of urban re/developments to the furthest extents possible. The RUD Case Study has been chosen exclusively to illustrate the application of the RUD model in order to aim reduction and full mitigation of the anthropogenic CO_2 emission in a given urban area. Densely developed urban areas are among the most important areas where widespread environmentally restorative corrections are urgently needed.

m) Global Warming & Climate Change

Credible institutional, governmental and intergovernmental sources continue to signal the significant likelihood of shifts in political power structures in the near future due to environmentally induced crises such as flooding, food shortages, and so on, hopefully to translate into stricter minimums on key environmental performance requirements. A close review of literature available including the reports from Union of Concerned Scientists (UCS, 1997) as well as the Intergovernmental Panel on Climate Change (IPCC, 2007) suggests that the warming trends in the average land and ocean temperatures, desertification, food scarcities are very real and present threats, and are more likely to get worse unless intervened by counteractive measures globally.

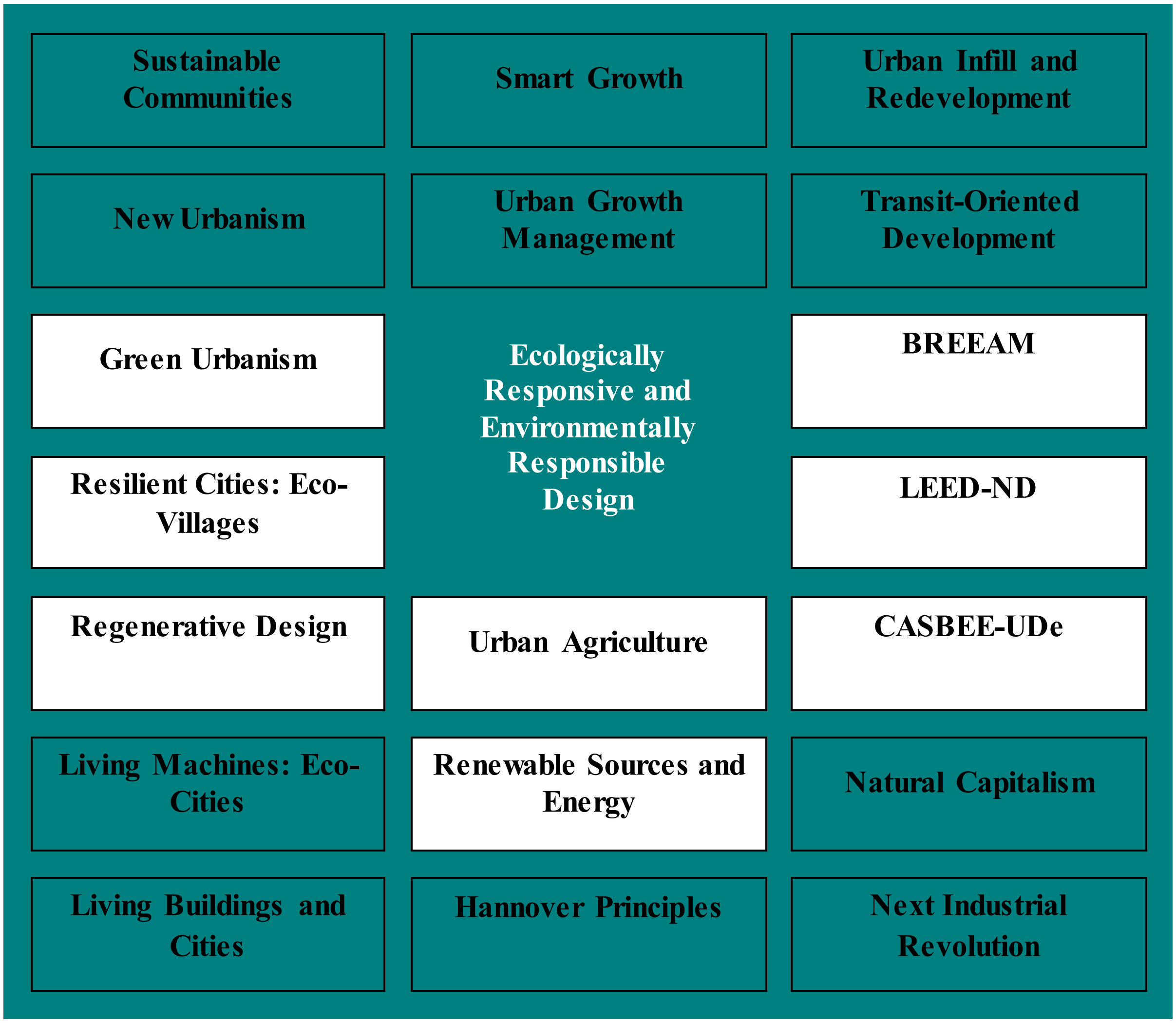
> No previous civilization has survived the ongoing destruction of its natural supports. Nor will ours. (Brown, 2011, p. 7)

Again, the central responsibility of ecologically responsive and environmentally responsible urban design is to focus on implementing an incremental but widespread transformation of human-made environments into where natural cycles and balances are nourished rather than disrupted. The RUD model seeks to improve on the rehabilitative goals and the restorative mitigations of urban re/developments onsite as well as offsite to the furthest extents possible.

2. Ecologically Responsive & Environmentally Responsible Design

Largely in response to the emerging environment degradation, deterioration, and depletion issues, numerous environmental design and planning approaches have already been developed since the early 1970s. The following is a summary of significant approaches that demonstrate the range and complexity of design methods in ecologically responsive and environmentally responsible practices (see Figure 2.2).

Figure 2.2 Ecologically responsive and responsible design already exists in literature



The design methods summarized in the figure above and discussed in the following sections are foundational in the transformation of existing best practices into restorative ones. Since the focus of restorative research is not sustainability, preservation or conservations alone, the planning principles and design strategies promoted by these methods appear to align more closely with the selected group. Consequently, the restorative research pays attention to all of these existing models in the literature and is inspired by them in creation of core principles. In the evolution process of restorative approach, even more methods are likely to get integrated.

a) Smart Growth

Smart Growth offers an extremely well-organized and orchestrated set of principles and strategies primarily for local governments, planning authorities and institutions as well as other public and private entities (SGA, 2004; EPA, 2010). SGA (2004) describes the main principles of Smart Growth to be used in the planning and design of cities and towns, which promote mixed-use and mixed-income neighborhoods that are relatively more compact and conveniently walkable. The Smart Growth principles specifically aim to advocate urban infill projects seeking higher urban densities which in time allow for better integration of transportation while preserving natural lands and open spaces, and conserving the identity as well as the quality of urban places. Over time the movement has also proven to be extremely effective in harnessing the power of multidisciplinary collaboration in public-private partnerships.

From a sustainable urban design perspective, there is some wisdom behind and merit in these principles in that the smart growth re/developments are compact, dense, contiguous, and well-connected, which at least theoretically helps prevent uncontrolled urban sprawl and expansion. The smart growth literature including authors like Porter (2002), Kelly (2004), Porter (2008) establishes that perhaps the biggest smarts in these principles are in the savings for costs and expenses related resources and services like infrastructure and public transportation that municipalities and governments are obligated to provide to their constituents.

Strictly from an environmental restoration standpoint, the “smart” principles are really geared toward lessening the enormous economic costs associated with the urban growth and expansions (Calthorpe & Fulton, 2001; Calthorpe, 2011). The principles appear to help with both social and environmental issues. However, there are not any significant provisions or requirements in these principles for integrating, rehabilitating, or fostering natural support systems such as food and energy generation within that well-planned network of urban uses and places.

In order to become truly restorative the Smart Growth principles need to move beyond lessening environmental impacts and need to adopt principles and strategies to closely regulate the quality of air, water, soil, and to integrate more enjoyable and productive natural systems to assist the infrastructure services, food and energy generation. The public-private partnership expertise within the Smart Growth Networks need to be fully exploited especially for the offsite mitigations necessitated by the full mitigation of urban impacts.

b) New Urbanism

The canonic principles put forth by the Congress of New Urbanism (CNU) are well-established and widely recognized by both public and private practices inside as well as outside of the United States (CNU, 1999; CSAU, 2008). Instituted as a responsible reaction to the global environmental problems created through urban planning and design practices, the principles continue to evolve, spread and infiltrate into many local regulations and zoning ordinances.

The New Urbanist planning and design principles start at the scale of region and encompass the metropolis, city, and town (Talen, 2005). They recognize the geographic boundaries in the local topography, considering the adjacent watersheds, coastlines, farmlands, regional parks, and river basins. They definite edges within basic environmental, economic, and cultural boundaries with unified governance and/or regulations for cooperation (Calthorpe, 1993; Katz, 1994). The New Urbanist public policies and planning principles allow for establishing multiple urban centers, aiming specifically to protect agrarian hinterlands, natural landscapes, and farmlands. The CNU favors urban infill re/developments over peripheral expansion, respecting historical patterns of development, encouraging proximity as well as mixture of public and private uses for all income levels (DPZ, 2008; Calthorpe, 2011).

From a sustainability perspective, the New Urbanist principles are much more conscious of protection and rehabilitation of the natural support systems and environments. However, there are well-reasoned criticisms against some of the strategies in the specific implementations. For example, the New Urbanist design approach and resultant neighborhoods are predominantly low density re/developments, dominated automobile-oriented, and somewhat limiting to mixture of land uses (Leung, 2003, p. 178). Even though sustainable features like public transportation, green infrastructure, and urban agriculture are seldom incorporated into the master plans, which are primarily driven by the market-based interests of developers and investors.

Through the lens of environmental restoration, the New Urbanist principles appear to achieve environments more conducive to fostering natural support systems such as food and energy generation within a tightly-knitted network of urban spaces. In order to become truly restorative, however, the New Urbanist principles need to advocate principles and strategies of improving the quality of air, water, soil, and of integrating pleasurable and well-functioning natural systems to assist generation and cycling of food, energy and wastes through onsite as well as offsite mitigations as necessitated by complete mitigation of human impacts.

c) Resilient Cities: Eco-Villages

The concept of resilience within the vocabulary of urban design and planning springs from the scientific theory of ecological resilience, which is simply defined as “the amount of disturbance that can be sustained before a change in system control and structure occurs” (Holling, 1996, p. 33). The increasing adaptation of ecological design principles in urban planning practices infuses the concept of ecologically and environmentally resilient urban areas where re/developments are designed to be self-reliant, autonomous, self-sustaining, and are therefore able to withstand many forms of possible environmental adversities.

Newman et al. (2009) examines different examples of resilient cities through history – using water power, railways, electricity, petrochemicals, and electronics – and arrives at today’s model as being dominated by bio-mimicry and resource reproduction. The authors point at Vauban in Freiburg, Germany as a visionary model for a resilient city in built form, which is inherently compact, walkable, inclusive, adaptable, diversified, redundant, regenerative, and life enriching environment not only for humans but also for many more species as well (p. 62).

The methodology behind the resilient model includes several strategies including the following: setting a vision (preparing an improvement strategy); learning on the job (setting strong goals, planning, and implementing); targeting public buildings, parking, and road structures; building TODs (Transit-Oriented Developments), PODs (Pedestrian-Oriented Developments), and GODs (Green-Oriented Developments); building resilient infrastructure; letting prices drive change; rethinking rural regions; regenerative household and neighborhoods; facilitating localism (businesses, food, enterprises, tourism, materials); and regulating post-oil transition.

From the standpoint of sustainable urban design, the principles of reliance on locally available material, food, and energy resources in an environment that nourishes and fosters the diversity of its own support systems have the potential to be more environmentally restorative. Strictly from a restoration perspective, the concept and principles of resilient cities appear to be very much in line with the intent and conduct of the RUD model. Perhaps the one of missing component is an explicit call for estimating the environmental impacts of resilient cities. While the urban principles of resilience offer integration, rehabilitation, and fostering of their natural support systems i.e. local food and energy generation, and waste recycling still some restorative mitigations onsite or offsite are highly likely.

d) Sustainable Communities

Over the last few decades, the evolution of sustainable architecture and sustainable urban design have given rise to many attempts to meaningfully define Sustainable Communities in planning as well. Van der Ryn and Calthorpe (1986) defines them in planning terms as denser, walkable, climate responsive, food and energy generating, water and waste recycling communities that rely on local employment and safe, integrated, and energy-efficient transportation systems.

Maser (1997) brings to forefront the building of a community that is conscious and responsive to local resources and ecological limitations, and that participates in the continual process of improving the landscape of forestlands and other habitats (p. 57). Barton (2000) breaks it down to smaller units called eco-neighborhoods, which aim to reduce the consumption of materials, water, food, and energy, and to reduce the generation of wastes, emissions, providing a safe, healthy and productive environment (p. 87). The definition of Bang (2005) features much smaller communities of 50 to 500 residents who are totally integrated into and dependent on their surroundings, fully enjoying the social, cultural, economic, and environmental benefits of communal life within nature. Babalis (2006) calls for master planned communities providing integration in natural ecology, mixed uses, highly efficient and quality buildings, well-serviced with infrastructure and transportation, creating social cohesion and employment (p. 26). Condon (2010) lays out “Seven Rules for Sustainable Communities” as follows: restore the streetcar city; design an interconnected street system; locate commercial services, frequent transit, and schools within a five-minute walk; locate good jobs close to affordable homes; provide a diversity of housing types; create a linked system of natural areas and parks; and invest in lighter, greener, cheaper, smarter infrastructure.

From an exclusive restorative perspective, many of these sets of principles and strategies are valid and need to be implemented, however, a central priority needs to be on the recovery and rehabilitation of the natural cycles and balances. The planning and design principles and strategies which do not make restoration of functional qualities of nature their priority in urban re/development unsurprisingly become secondary in the restorative rankings (Cairns, 2007). Sustainable Communities, no matter how they are defined and envisioned, cannot be truly restorative unless they contribute to rehabilitation and regeneration of natural supports providing purified air and water, healthy soil, habitats, species, as well as energy (Cairns, 2006).

e) Regenerative Design

In the natural cycles and balances, the degeneration or degradation is counterbalanced by the regeneration. Without regeneration and restoration of natural systems persistent deterioration and eventual depletion or extinction of natural systems are unavoidable. While degeneration or degradation can be regenerated, and deterioration may be restored the depletion or extinction is irreparable.

Lyle (1994) coins the term regenerative design within the vocabulary of ecologically responsive and environmentally responsible design. The Center for Regenerative Studies he instituted remains dedicated to the development, refinement and dissemination of regenerative principles and strategies. The regenerative theory asserts that only by successfully integrating human activities within the naturally regenerative systems and rehabilitating the natural habitat they depend on can urban re/development achieve long-lasting sustainability. The regenerative goals laid out by Lyle (1994) predicate: designing shelters without depleting resources or damaging natural systems; joining buildings with earth; giving visible and meaningful form to that relationship; and shaping building and urban form to foster community interactions.

Along the same lines, Melby and Cathcart (2002) expands on the practical techniques of applying regenerative design principles in order to achieve human settlements that blend into natural landscape where the generation of food, energy or wastes does not diminish the quality of air, water, or soil (p. 20). As part of natural ecology, in order for humans to successfully remain integrated within a healthy biosphere, their lifestyles, life support systems, production mechanisms, and consumption patterns need to conform to the laws of nature. Lyle’s visions of sustainability and regenerative design (Lyle, 1994) still hold true today, the widespread expansion of regenerative systems is still the fundamental way to solve cascading environmental problems and avoid pending crises to manifest in the very near future. The battle remains to be successfully waged within human communities. The battleground is the urban landscape.

From the standpoint of environmental restoration, the regenerative design principles and strategies are very much in line with the intent and conduct of the RUD model. One of the gaps filled by the restorative research is the disconnection between the low-density experiments of regenerative studies and the high-density urban environments common in many metropolitan areas throughout the world. The restorative method aims to bridge the gap through implementation of onsite and offsite mitigations.

f) Living Machines: Eco-Cities

The theoretical as well as practical studies of Todd and Todd (1994) are organized into a series of nine precepts for ecological design based on biological observations and inspirations, which are crucially relevant to the conception and manifestation of human settlements. Each of these precepts plays an important role in forming a cohesive environment.

The precepts of Biological (or Living) Design by Todd and Todd (1994) assert that: Living world is the matrix for all design; Design should follow, not oppose, the laws of life – biological equity must determine design; Design must reflect bioregionality; Projects should be based on renewable energy sources; Design should be sustainable through the integration of living systems – design should be coevolutionary with the natural world; Building and design should help to heal the planet; Design should follow a "sacred ecology," which the authors define to be "the undifferentiated interconnectedness of the human and nature worlds in an unknowable 'metapattern which connects'" …"the foundation and the summation of all the preceding precepts of design" (Todd & Todd, 1994, p. 79).

Many other notable studies and movements in the sustainable urban design evolution spring forth from the principles of living machines and biological design such as Living Buildings (McLennan, 2009; ILBI, 2010) and Eco-Cities (Register, 2006). In much the same way, these methodologies make note of biological and ecological qualities of the natural environment as the baseline for design and attempt to develop strategies whereby the human settlements can conform to and foster these qualities.

From a sustainable urban design standpoint, the principles behind living machines and eco-cities are beneficial in thinking human activities as an integral part of natural living systems that rely on provisions of local available material, food, and energy resources. The difficulty comes in the adaptation of these principles to the entire range of contemporary urban environments already developed and functioning in drastically contrasting patterns.

From a perspective of environmental restoration, the principles of biological or living design hold tremendous value as they establish a solid baseline for restorative design efforts. The RUD model considers the process of assessing urban impacts on natural cycles and balances as the initial starting point where incremental urban re/developments need to start mitigating all impacts. These mitigation efforts would include both onsite and offsite activities aimed at transforming the built environment, restoring a biological or living design baseline.

g) Living Buildings, Neighborhoods, & Cities

The Living Building Challenge (ILBI, 2010) establishes an orchestrated effort to transform the existing fabric of buildings and neighborhoods in be in tune with natural cycles and balances using the fundamental principles of biological or living design (Todd & Todd, 1994). The Challenge is structured to have four categories, under which all types of projects are classified and processed: Renovation; Landscape; Building; and Neighborhood. The Challenge establishes a "Living Transect," which essentially modifies the New Urbanist transect model for the purposes of living building and neighborhood design. The living transect is composed of six zones with varying design requirements. ILBI (2010) encourages "the transition of suburban zones either to grow into new urban areas with greater density, or be dismantled and repurposed as new rural zones for food production, habitat and ecosystem services" (p. 8).

The Living Challenge (ILBI, 2010) is made up of seven "petals" with different subsequent requirements as follows: Site (establishes limits on growth, encourages urban agriculture at varying densities, stimulates habitat exchange, and car free living); Water (urges net-zero water import on all sites, integrates ecological water flow); Energy (promotes net-zero energy practices on site); Health (values civilized environment, targets healthy air, propagates biophilia); Materials (features a "red list", considers embodied carbon footprint, partners with responsible Industry practices, seeks appropriate sourcing, supports conservation and reuse); Equity (celebrates human scale and human places, seeks democracy and social justice, assigns rights to nature); and Beauty (stimulates beauty and spirit, advocates inspiration and education).

From a sustainability standpoint, the petals of the challenge definitely go beyond the re/development strategies of most mainstream sustainable urban design trends and enter the territory of rehabilitating cycles and balances in the naturally living systems that humans rely on. Again, the difficulty comes from having to adapt and apply these principles to an entire range of urban environments already developed and functioning in drastically contrasting patterns.

From the environmental restoration perspective, the living building, neighborhood, or city principles are perhaps closest to those adopted by the restorative efforts where the design baseline is the natural environment. Similarly to the RUD model, the Living Challenge is based on the assessment and neutralization of environmental impacts onsite as much as possible. However, the challenge includes no offsite mitigation requirements, which limits the ability to fully mitigate all impacts or to rehabilitate degrading conditions beyond the boundaries of site.

h) Green Urbanism

The principles of Green Urbanism appropriately address a multitude of environmental issues ranging from land use, urban form, housing, urban ecology, car-free transportation, bike-friendly mobility to renewable energy generation, ecological governance and sustainable economy. Beatley's work forms a solid foundation and an inspirational framework for "green" urban re/development.

> Cities can be fundamentally greener and more natural. Indeed, in contrast to the historic opposition of things urban and things natural, cities are fundamentally embedded in a natural environment. They can, moreover, be reenvisioned to operate and function in natural ways – they can be restorative, renourishing, and replenishing of nature, and in short like natural ecosystems: cities like forests, like prairies, like wetlands. (Beatley, 2000, p. 198)

Beatley (2000) outlines a spectrum of existing patterns and conceivable future strategies primarily from the major metropolitan regions in Europe where cities are much more compact, dense, contiguous, walkable, bikeable, and reliant on public transportation than cars. They work rather effectively toward reducing the ecological and carbon footprint of larger populations. A significant portion of the Green Urbanist theories, is concentrated on the use and integration of solar powered technologies among other renewable resources and practices. Other strategies include: integrating natural areas, ecological waterways, tree corridors, parks and open spaces; green roofs, courtyards, green walls, streets, balconies; reduce hard surfaces; rainwater collection, graywater recycling, water conservation; and urban gardens (Beatley, 2004; Beatley, 2011).

From the perspective of sustainable urban design, the green urbanism scores very high toward enabling the urban re/development to assimilate the cycles and balances of nature. Once more, however, the difficulty lies in transforming the theoretical principles into physical reality through incremental urban re/developments.

From an environmental restoration standpoint, the green urbanist principles offer perhaps the most practical yet effective set of strategies toward restoration of the natural environment within densely populated areas. Like many other sustainable urbanist movements, when the total environmental impacts of urban re/developments are evaluated, no matter how rigorous they might be, the onsite mitigations proposed by green urbanism would probably not be sufficient to neutralize all estimated impacts onsite. Offsite mitigations would be needed for full remediation.

i) BREEAM

While primarily focused on the energy efficient building and urban design, the Building Research Establishment's Environmental Assessment Method (BREEAM) rating system administered by the British Research Establishment (BRE) is an extremely effective system that is widely used in the western hemisphere (Crawley & Aho, 1999; Haapio, 2002). The system offers tools to introduce and maintain sustainability practices for individuals, communities, organizations, materials, products, services, and wastes. BREEAM aims to "mitigate the life cycle impacts of new buildings on the environment in a robust and cost effective manner. This is achieved through integration and use of the scheme by clients and their project teams at key stages in the design and procurement process" (BREEAM, 2011, p. 13).

Originally initiated in order to assess the environmental impacts and to improve the efficiency of buildings, the rating system has been expanded over time to include community scale issues. BREEAM Communities address neighborhood and community scale inefficiencies that cannot be addressed solely by the material resources and buildings. Haapio (2012) summarizes the community-scale principles and strategies related to transportation, ecology and biodiversity, and critically analyzes their effectiveness in lessening the adverse effects on the natural environment and climate (p. 167).

Evaluated from a sustainable urban design perspective, the principles and strategies of BREEAM Communities accomplish a series of improvements toward minimizing the negative impacts of urban re/development on natural cycles and balances. The rating system really works effectively to reduce wasteful consumption of natural resources and to increase reliance on recycling and renewable energy types. At a community level, it stimulates compact, dense, walkable, and well-connected communities that are more dependent on local diversity of materials, foods, energy, and transportation, all of which helps the rehabilitation of the natural environment at large. The longer history and broader reach of BREEAM rating system are also other significant contributions it provides toward global healing.

However, from the perspective of environmental restoration, the full mitigation of environmental impacts cannot be reached through a system that does not estimate them. The RUD model aims to unveil or disclose the unmitigated portion of material resources, emissions, pollution, wastes, and other ecological impacts of urban re/developments on natural baseline so that they can be mitigated onsite as well as offsite.

j) LEED-Neighborhood Development

The sustainable design principles established and regulated by the USGBC's rating systems set the benchmark on current ecologically or environmentally friendly design practices in the United States and beyond. Since its inception LEED is reported to have "grown to encompass more than 14,000 projects in the U.S. and 30 countries covering 99 billion m² of development area" (Nguyen & Altan, 2011, p. 379). The LEED suite of industry standards and design guidelines aims to reduce the environmental impacts of planning, design, and construction in urban re/developments.

LEED-ND specifically focuses on the issues within the scope urban design and planning. The USGBC's plan of attack for mitigating the urban impacts on natural environment through LEED-ND includes three major sections: Smart Location & Linkage (considering ecological communities, habitats, species, wetland and water bodies, land uses and proximities, transportation networks); Green Infrastructure & Buildings (considering water and energy efficiency of buildings, pollution prevention, site water management and landscaping, passive solar and renewable energy, district heating and cooling, recycling and waste management); and Neighborhood Pattern & Design (considering compactness, walkability, connectedness, diversity of uses and incomes, reduced parking, increased transit, civic and public spaces or education and recreation, local food production) (LEED, 2009). The LEED-ND also places special emphasis on innovative and exemplary performance beyond base requirements, and values reliance on regional and local resources.

Targeting the reduction of car trips by encouraging the proximity of codependent land uses such as housing, work, and shopping places is one of the fundamental tenets of sustainable urban re/developments. The LEED-ND principles and strategies recognize this and favor mixed-use developments and walkable streets, which encourage walking, bicycling, and public transportation for daily errands and commuting. "Environmentally responsible buildings and infrastructure are an important component of any green neighborhood, further reducing greenhouse gas emissions by decreasing energy consumption. Green buildings and infrastructure also lessen negative consequences for water resources, air quality, and natural resource consumption" (LEED-ND, 2009, p. xi).

Haapio (2012) observes that the smart location and linkage requirements in LEED-ND celebrate the development of cities and suburban areas where protection of water bodies and the revitalization of natural areas and ecosystems are particularly important aspects. The design guidelines for neighborhood pattern and design value the importance of multimodal connectivity, the role of public transportation, and the reduction of auto dependency, simultaneously, while aiming to enrich neighborhoods by increasing social interaction (p. 168).

There is always room for improvement though, especially for systems that attempt to undertake the extremely diverse and complex subjects such as environmental performance assessment and improvement. There are certainly those who are critical and skeptical of some of the principles and practices propagated by LEED. For instance, Owen (2009) identifies the fundamental weakness of LEED as being "not a comprehensive, objective assessment of true environmental impact but, rather, a values-laden incentive system that encourages projects which achieve to a very particular view of high-end real estate development" (p. 188). There is certainly merit in criticisms like these, in that, even in the best examples of LEED Platinum certified projects one can find significant flaws from the perspective of urban design or building sustainability. There are examples of LEED Platinum public or private buildings collecting most available points on the checklist but still surrounded a sea of parking on a highway in the middle of greenfields where most users arrive by driving. Significant numbers of occupants of these buildings may in fact prefer artificial lighting and forced air conditioning during the day because they are not used to or comfortable with using natural lighting or ventilation.

From a perspective of sustainable urban design, the principles and strategies of LEED rating systems and LEED-ND in particular, effectively help achieve a series of improvements toward minimizing the negative impacts of urban re/development on natural cycles and balances particularly reducing inefficiencies and wastes in consumption of resources and increasing use of recycling and renewable energy technologies. From a planning standpoint, LEED-ND stimulates compact, dense, walkable, and well-connected urban re/developments that depend more on local diversity of materials, foods, energy, and transportation.

When one asks how much of this really works toward restoration of the natural environment, the application of most LEED strategies arguably fall short of estimating and mitigating full impacts of urban re/developments, where the unmitigated impacts simply get released and passed onto the global environment at large where they continue to accumulate. The RUD model aims to expose the unmitigated portion of material resources, emissions, pollution, wastes, and other ecological impacts and mitigate them totally onsite and/or offsite.

k) CASBEE-UDe

The Comprehensive Assessment System for Built Environmental Efficiency (CASBEE), a joint research and development project of Japanese government, industry and academia, offers a family of environmental performance assessment and rating systems. The CASBEE suite is set up in three hierarchical levels of environmental assessment: Home, Building, and Urban scales respectively. Each level is considered an individual yet interdependent part of larger scales, which may or may not be evaluated separately.

Initiated and published by the Institute for Building Environment and Energy Conservation (IBEC) "under the guidance of the Ministry of Land, Infrastructure and Transport", the CASBEE-UDe 2007 system primarily focuses on the issues related to urban design and considers: exterior spaces such as roads, plazas, and other public open spaces on district scale; and "effects of collectiveness," which occurs when a group of buildings come together to form a cluster and outdoor spaces (CASBEE-UDe, 2007, p. 3). Complementing the environmental assessment objectives and strategies at home and building scales, the CASBEE-UDe focuses on increasing environmental quality in urban development through increased ecosystem and microclimatic strategies, service functions, and local community contributions. This rating system also aims to reduce environmental impacts of urban developments through strategic design and management of building façades, site landscaping, social infrastructure, and local environment (Haapio, 2012, p. 166).

From the standpoint of environmental sustainability, the application of CASBEE-UDe assessment strategies result in a range of ratings where the decisions-makers are encouraged to choose ecologically more appropriate design options. So, the results seem to depend largely on the eagerness of decision-makers. There also seems to be a lack of regulation to conserve existing natural assets and resources, as well as to generate local food and renewable energy.

From an environmental restoration perspective, similar to other rating systems, the results delivered by CASBEE-UDe do not seem to go beyond reduction of urban re/development since there is no estimation of total impacts. In order to truly become environmentally restorative the principles and strategies put forth by CASBEE-UDe need to move beyond reduction of urban re/development impacts, and move into the territory of rehabilitating the natural surroundings and support systems to a baseline design. Once full impacts are calculated the need for onsite as well as offsite mitigations are necessary.

l) Sustainable Sites Initiative

The Sustainable Sites Initiative (SSI) is initiated and established by American Society of Landscape Architects – and other collaborators – taking the LEED rating systems as a guiding example. The initiative promotes the application of an environmental performance assessment and rating system, which is made up of over 50 credit points evaluating different aspects of sustainability in site planning and landscape designs.

Just as in LEED rating systems, the prerequisites of SSI (2009; 2014) are required and not part of available credit points. Available categories in the Sustainable Sites rating system are: Site selection (21 points – protection of farmlands, wetlands, sensitive habitats, brown/greyfield developments, contiguous land uses, multimodal and public transportation); Pre-design assessment and planning (4 points – suitability, integrated process, stakeholder engagement); Site design in water, soil, vegetation, materials selection, and human health and well-being (164 points); Construction (21 points – minimizing pollutants and emissions, restoring soil quality, material recycling); Operations and maintenance (23 points – reduce emissions, wastes, pollutants, recycle organic matter); and Monitoring and innovation (18 points). The SSI evaluation results in a basic level of certification (One Star) for achieving 100 points (40% of 250 total points available) whereas the highest rating is Four Stars for 200 points (80%).

From the sustainable urban design perspective, the principles and strategies contained in SSI rating system provide an excellent range of measures and controls that are exclusively focused on site design, installations, and operations. Design guidelines and requirements appear to provide a very good coverage on preservation, conservation, regeneration, as well as restoration of naturally living support systems, habitats, and species. Since the SSI does not address the performance of buildings located on or around the sites the emphasis on local generation of food and energy does not seem to be strong. In tandem with other programs, rating systems, and planning/design approaches, SSI could move us in the right direction.

When the SSI methodology is analyzed from a comprehensive environmental restoration standpoint, most strategies score very high in estimating development impacts on nature and mitigating them with respect to a design baseline. Yet, even when a 100 percent of SSI points were to be achieved there would still be some unmitigated impacts. The restorative approach recommends calculating and fully mitigating all impacts on resources, wastes, and other ecological services.

m) Transit-Oriented Development

One of the pioneers in the TOD arena, Calthorpe (1993), defines a Transit-Oriented Development as "a mixed-use community within an average 2,000 feet walking distance of a transit stop and core commercial area; mixing residential, retail, office, open space, and public space in a walkable environment; making it convenient for transit, bike and foot" (p. 56). Calthorpe (2011) expands on the TOD experience as "a cross-cutting approach to development that can do more than help diversify our transportation system, it also offers a new range of development patterns for households, businesses, towns, and cities" (p. 86) (Bernick & Cervero, 1997; Gilbert & Ginn, 2001; Cervero, Ferrell, & Murphy, 2002; Dunphy, Myerson & Pawlukiewicz, 2003; Dittmar & Ohland, 2004; Steiner, 2009).

n) Urban Growth Management

Urban growth management techniques are designed to regulate the timing, location, and rate of growth in any given location. Perhaps among the most effective techniques is Adequate Public Facilities (APF) requirements, which predicate the approval of developments contingent on the availability of adequate public facilities. Other techniques include Growth Phasing programs, Urban Growth Boundaries (UGB), Rate-of-Growth programs, and comprehensive programs which are simply combinations of any of these techniques (Juergensmeyer & Roberts, 1998; Calthorpe & Fulton, 2001; Kelly, 2004; Kemp, 2008; Porter, 2008).

o) Natural Capitalism

Another theory that is often used and extensively referenced in the sustainable urban design literature is that of 'Natural Capital' (or 'Natural Capitalism'). The originators of the theory, Hawken, Lovins, and Lovins (1999), record that "natural capital can be viewed as the sum total of the ecological systems that support life, different from human-made capital in that natural capital cannot be produced by human activity. It is easy to overlook because it is the pond in which we swim, like fish, we are not aware we're in the water" (p. 151) (Orr, 2002; Brown, 2003). The development of Natural Capitalism could create a different type of economy, taxation, and set of values, which could function as a widespread and effective mechanism working toward the restoration of natural environment. As exciting as this theory is, there are perhaps a large number of unknowns and uncertainties its path to evolution and fruition.

p) Renewable Sources and Energy

The design theories and practices on the renewable sources of energy and materials have been rapidly expanding in the environmental design literature over the last few decades. The approaching energy scarcities as well as the broadening environmental degradation and deterioration increasingly necessitate the appropriate use and integration of a spectrum of various renewables in the supply of human needs (Coates, 1978; Brown, 1981; McDonough, 1992; Beatley, 2000; Brown, 2003; Heinberg, 2003; Torcellini, Pless, Deru, & Crawley, 2006; Evans, 2007; Friedman, 2008; Friedman, 2009; ILBI, 2010; Calthorpe, 2011).

q) Urban Agriculture

With regards to the concept of urban agriculture, the New Urbanists at Duany Plater-Zyberk (DPZ) assert that Urbanism must be cohesively designed. In their approach by concentrating development, "land is liberated for agricultural use. Agricultural projects must be precise both in terms of the land cultivated, and in the management of it" (DPZ, 2009, p. 2) (Coates, 1981; Lyle, 1994; Todd & Todd, 1994; Viljoen et al., 2005; Yeang, 2006b; Newman & Jennings, 2007; LEED-ND, 2009; ILBI, 2010; Philips, 2013).

r) Hannover Principles

These principles call for environmentally sensitive expression "as part of the evolving matrix of nature," and environmentally responsible expression through design that enables us to "remain in the natural context" (McDonough, 1992, p. 3). The Hannover Principles can be grouped under nine maxims as follows: Insist on rights of humanity and nature to coexist; Recognize interdependence; Respect relationships between spirit and matter; Accept responsibility for the consequences of design; Create safe objects of long-term value; Eliminate the concept of waste; Rely on natural energy flows; Understand the limitations of design; and Seek constant improvement by the sharing of knowledge (McDonough, 1992; Todd & Todd, 1994).

s) Next Industrial Revolution

In formulating the precepts behind their approach to environmental design and planning, Hawken and McDonough (1993) develop "a plan to create a sustainable future" and determine "its objectives through practical, clearly stated goals and strategies" (p. 81). They record their core intentions as follows: Eliminate the concept of waste; Restore accountability; Make prices reflect true costs; Promote diversity; Make conservation profitable; Insist on the accountability of nations; Restore the guardian by getting the business out of government (McDonough & Braungart, 1998; Hawken, Lovins, & Lovins, 1999).

3. Absence of Environmentally Restorative Focus

The literature review of ecologically responsive design behind the restorative research finds mounting scientific data and projections on key environmental indicators, which strongly suggest that the current patterns of urban growth and expansion are likely to trigger significant catastrophes within the Earth's biosphere during the next few decades (Brown, 1981; Newman et al., 2009; Calthorpe, 2011). Experts voice grave concerns over an irreversible collapse of major life-supporting systems as early as the end of this century (Meadows, Meadows, & Randers, 1992; Heinberg, 2003; Diamond, 2005; Kunstler, 2005; Homer-Dixon, 2006; Hansen, 2009; Homer-Dixon & Garrison, 2009; Orr, 2009; Brown, 2011). Human impacts on nature are documented to be the leading sources that overwhelm the innate ability of natural systems to repair, rehabilitate, and regenerate themselves. As anthropogenically initiated degradation and deterioration in the natural environment continue to build up, the responsibilities to repair the associated damages of the past and the present weigh heavier on each passing generation of humans on Earth. Responsible assessment and effective mitigation of negative environmental impacts – at their sources – are on the way to become prerequisites for the urban design and planning practices, and will hopefully occur in the very near future.

Change and transformation in the urban areas materialize incrementally and slowly over time based on the evolution of circumstances made possible by gradually shifting awareness, knowledge, and technologies. First era in the postindustrial awareness of human impacts on the natural resources and environment had established the principles of preservation and conservation, which produced a wealth of literature on anthropogenic impacts (Marsh, 1864; Mumford, 1938; Carson, 1962; Leopold, 1966; McHarg, 1969; Lovelock, 1979). The environmental movement was a necessary natural response to the increasing pressures of advancing industrialized technologies and consumption, and remains vitally relevant to the increasing pressures of human population growth.

The following era in collective awareness was focused on the principles of sustainability, which resulted in a vast literature on how modern urban re/developments and activities can be made “more” environmentally friendly, resilient, and sustainable along with an appropriate level of preservation and conservation (Brown, 1981; Coates, 1981; Chiras, 1992; Orr, 1992; Calthorpe, 1993; Todd & Todd, 1994; Lyle, 1994; Beatley, 2000; UNEP, 2002; Condon, 2010). Sustainable urban design and planning strategies are and will continue to be necessary to reduce the increasing pressures of increasing human population and consumption within a resource limited biosphere.

However, the emerging era in human evolution must arguably address restoration, where the primary objectives in urban re/developments must transcend concerns of building, site, or neighborhood sustainability into the uncharted territory of comprehensive environmental repair and integrated rehabilitation. Moving beyond the sustainability frame of mind and entering into the paradigm of comprehensive environmental restoration requires a simple – but rather sobering – realization that significant degradation, deterioration, and depletion in natural environment have already occurred. Mitigation of past damages are now due along with prevention of future impacts (Beatley, 2011; Brown, 2011; Calthorpe, 2011).

The existing literature – focusing on a comprehensive approach to urban ecological restoration – is unsurprisingly scattered and limited to several dozen studies and initiatives in disciplines such as ecology planning and design, landscape architecture, ecological restoration design and related fields. McHarg (1969), Lyle (1994 & 1999), Van der Ryn (1996), Tamminga (1997), Orr (2002), Higgs (2003), Register (2006), Yeang (2006b), and Newman and Jennings (2007) are among many who have dealt with the ecological design strategies to varying degrees. The restorative literature focused specifically on urban ecology is even narrower and primarily concentrates on redevelopment of infrastructure, recreation facilities, parks, and natural spaces within urban areas (Laurie, 1979; Spirn, 1984; Hough, 1990; Hough, 1995; Sauer et al., 1998). Given that environmental degradation, deterioration, and depletion on Earth are strongly connected to conventional growth of urban areas, more focused research of developments aiming for the comprehensive restoration of natural systems through improved urban design and planning is necessary in multiple scales, building on applied works by Lewis (1996), Wilson et al. (1998), Throop (2001), Platt (2006), Beatley (2011), and Palazzo and Steiner (2011).

B. Theoretical Bases of Environmental Restoration

The concept of interdependence – or co-dependence – is well-established in the contemporary understanding of relationships between a habitat and its inhabitants. By definition those who depend on a certain habitat cannot be considered independent from their connections to that environment. Whether consciously or not these inhabitants function as integral elements of the system, no matter how active or passive their roles might be. Maintaining long-term health and longevity on either side of the ecological equation depends on the abilities of both habitat and its inhabitants to harmonize with one another.

The same principle holds true for the humans, which function collectively as an integral element of the natural environment, serving as agents of both constructive (regenerative) as well as destructive (degenerative) processes. The long-term health and longevity of humans within the natural environment is determined by the healthy and harmonious relationships they do or do not establish and maintain within the natural surroundings.

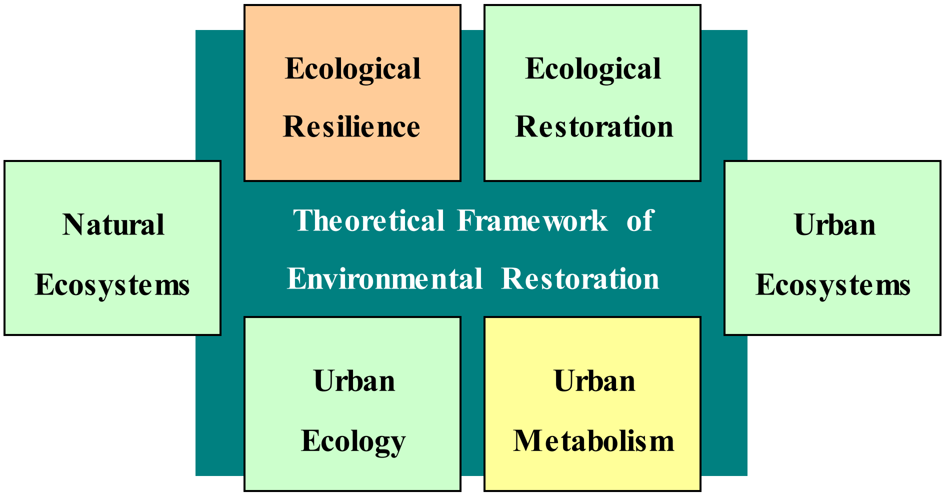
Health is generally defined as the state of optimum well-being, of being free from illness or injury, and of exhibiting lasting functional and metabolic efficiency. Inversely, disease is a state of disturbed health where the optimal functionalities degrade, the metabolic efficiency deteriorates, and eventually – if the disturbances persist and the healthy conditions are not restored – the living energy is eventually depleted.

McHarg and Steiner (1998) assert that the human settlements should be viewed as being subject to the same physical, biological, and cultural processes measured in terms of fitness and unfitness, health and pathology:

> This should become the basis for the morphology of man-nature and man-city. We must abandon the self-mutilation which has been our way, reject the title of planetary disease which is so richly deserved, and abandon the value system of our inheritance which has so grossly misled us. We must see nature as a process within which man exists, splendidly equipped to become the manager of the biosphere; and give form to that symbiosis which is his greatest role, man the world's steward. (McHarg & Steiner, 1998, p. 71)

This dissertation on restorative research seeks to arrive at an urban design and planning methodology that is integrated, multidisciplinary, multilayered, multidimensional, multi-faceted, and interconnected to work with the complex problems of comprehensive restoration in the natural environment, receiving feedback from and considering a wide range of aspects of the human impacts that area initiated within or by the urbanized areas. As summarized in Figure 2.3, it seeks to accomplish its restorative goals through adopting a theoretical framework firmly embedded in the key concepts, theories, and methodologies of ecological restoration that are inspired by the natural ecosystems. The restorative research seeks to operate primarily from within the realm of urban ecology, aiming to implement environmentally restorative mitigations through urban re/developments.

Figure 2.3 Theoretical framework of environmental restoration targets urban ecology



1. Natural Ecosystems & Resilience

The naturally-occurring ecosystems are generally considered to be the building blocks in nature. Ultimately, they function as experiment grounds where modeling, testing, trial and error continues in an on-going basis. The study of natural ecosystems reveals a wealth of insights into environmental traits such as diversity, harmony, health and longevity (Van der Ryn & Calthorpe, 1986; Beatley, 2000; Jackson & Svensson, 2002; Register, 2006; Newman & Jennings, 2007).

> The integrity of nature can guide us, for in the broadest sense, nature is the only thing that has proven adaptive and successful in the long run…I wonder if it would not be prudent to design human enterprises on blueprints from nature. (Todd, 1996, p. 141)

Recognizing ecosystems as naturally living metabolisms and observing the intricate interdependencies among their constituent parts disclose the principles behind how healthy ecosystems are created, developed, and maintained. An intimate understanding of these characteristics over time helps in diagnosing the symptoms of disharmony in natural habitats. Then, treatment of environmental stresses are possible with precise interventions where success rates generally depend on the accuracy of diagnosis for the observed symptoms. (Falk et al., 2006; Douglas et al., 2011).

> Our understanding is growing: we have added the four major elements, carbon, hydrogen, oxygen and nitrogen and one important minor element, phosphorus, to our company; we have recognized the fundamental importance of some hitherto obscure and unknown algae and bacteria, Nostoc and Azotobacter; we have recognized that volcanic action and lightning are allies rather than enemies; we have learned to fear losses of carbon and phosphorus to the depths of the ocean and to respect water and the ocean as a primary component of the fitness of the environment. (McHarg, 1969, p. 49)

The processes of healing and regeneration in the natural ecosystems require not only removal of ecological disturbances but also allocation of adequate recovery times. Lack of flexibility, adaptability, agility and rigor in any natural habitat may translate rapidly to disharmony and even extinction (Walker & Salt, 2006). Persistent long-term disturbances on the natural ecosystems from outside sources often bring about degradation and deterioration of inherent balances, which may simply become irreversible beyond certain thresholds (Holling, 1996, p. 37; Allen et al., 2010). In the context of restorative urban design and planning strategies, the fundamental characteristics of natural ecosystems are not only integral but also critical elements of the restoration process, and constitute a large part of what needs to be restored.

2. Urban Ecology

As the scale, complexity, and impacts of human-made environments continue to increase, the study of these environments give rise to new areas of knowledge and technology that were not even conceivable just a few decades ago. One of these exciting new areas is urban ecology, which typically approaches the study of urban areas as ecosystems (Fitter, 1945; Breuste et al., 1998; Beatley, 2000; Radovic, 2009; Palazzo & Steiner, 2011).

> In a sense, modern industrial culture has banished most of us from that essential connection with our environment, community, and our polis. Our future lies in reestablishing those links. (Van der Ryn & Calthorpe, 1986, p. 33)

An ecological approach to urban design and planning aims to learn from, mimic and create harmonious existence as well as interdependence with the natural processes and systems. The concepts of urban metabolism and urban ecosystems offer promising new possibilities for the holistic environmental design and planning of urbanized areas (Gill & Bonnett, 1973; Spirn, 1984; Douglas et al., 2011).

3. Urban Metabolism, Ecosystems, & Resilience

Based on the similarities between the human and other organismal metabolisms, Wolman (1965) first introduced the idea of urban metabolism, which was defined as "an accounting of the material input to a city and its outputs as wastes" (Douglas et al., 2011, p.513). Since then, there have been studies that tried to model the ecosystems that exist within urban areas. These studies aim to shed light on important concepts such as: ability to withstand disturbance and assimilate waste; Resilience: capacity to absorb change; stability of energy and materials ebb and flow; and growth, reproduction, and adaptation.

Spirn (1984) notes that the ecosystem concept provides "powerful tools for understanding the urban environment," which creates a framework of perceiving the effects of human activities and their interrelationships. The concept of urban ecosystems provides an effective way to evaluate relative costs and benefits of alternative actions. It also encompasses "all urban organisms, the city's physical structure, and the processes which flow within it; and it is appropriate in examining all levels of life, from an urban pond to megalopolis" (Spirn, 1984, p. 244).

On parallel terms, Barton (2000) as well as Barton and Tsourou (2000) discuss the urban ecosystem approach to design of sustainable communities and neighborhoods, which rely on local and regional economies, renewable energy generation through benign natural processes, and minimized eco-disruption while conserving nonrenewable resources (p. 157).

A step further in the same vein, Allen et al. (2010) and Hollings (2010) continue to refine ecological resilience, considering the challenges in measurement of resilience and disturbances to document the shifts in alternative states.

4. Ecological Restoration

Initially, the scientific knowledge and methodologies developed for restoring natural environments were limited to only those of a relatively small group of experts and researchers focusing primarily on isolated ecological restoration projects. Practically speaking, the focus of most environmental restoration efforts is limited to improvements of open spaces or public landscapes in urban areas (Van der Ryn & Calthorpe, 1986; Baldwin et al., 1994; Higgs, 1997; Gobster & Hull, 2000; Falk et al., 2006; Aronson et al., 2006; Clewell & Aronson, 2007).

Ecological restoration needs to be conceived as “a holistic endeavor," seeking to “address issues of ecological degradation, biodiversity loss, and sustainability science simultaneously [while drawing upon] cultural resources and local knowledge and skills in restoration work.” As such, it is important to adopt a holistic point of view in regards to restoration – as opposed to simply focusing on “the application of independent and incremental solutions to specific and more narrowly conceived problems” (Clewell & Aronson, 2007, p. 1).

This research expressly points to the necessity to not only promote a certain restorative awareness but also develop a methodology of urban design and planning toward accomplishing widespread rehabilitation of the natural environment. The existing processes, methodologies, and models developed thus far by a myriad of theoreticians and practitioners to deal with inherent complexities as well as the lessons learned in sustainability paradigm form a formidable foundation for the future efforts in the restoration paradigm.

Orr (2002) is one of a series of authors who points out the importance of ecological design toward the restoration of human place within a harmonious natural environment. He asserts that in the century ahead, we must chart a different course that leads to restoration, healing, and wholeness, and that ecological design is “a kind of navigation aid to help…the human presence in the world in a way that honors ecology, evolution, human dignity, spirit, and the human need for roots and connection” (Orr, 2002, p. 30).

5. Restorations in Urban Ecology

The simplest way to solve any environmental problem is to prevent it from happening in the first place. However, when the natural ecosystems are frequently damaged beyond the ability to rejuvenate, regenerate or recover, the restorative courses of actions will be increasingly necessary in order to reestablish the balanced conditions prior to these disturbances (Berger, 1985; Hall, 2005).

The same restorative formula is theoretically also applicable at scales of restoration within the urban ecology where the central focus has to be refinement of contemporary urban design principles and strategies for restorative purposes specifically. Implementing key strategies within and around urban ecosystems as well as urban ecology enables not only reduction and minimization of negative human impacts but also expansion and maximization of positive impacts on the natural environment (Laurie, 1979).

> The nature we wish to develop is, in principle, a dynamic self-sustaining system containing representatives of all those forms of life which would exist if man were not present, in the correct ecological relationships to each other and to an unmodified environment. Some degree of retreat from the purest interpretation of nature is necessary, and inevitable, in the urban context. (Laurie, 1979, p. 23)

C. Theory of Restorative Urban Design

The planning and design agenda of an environmentally responsible future starts with a vision of rehabilitation and restoration that is all-inclusive and equitable to all forms of life. In such an environment, all human purposes transcend the exclusive benefit of self or group, and aim to serve that of the whole. The highest values, principles guiding the efforts, are placed back on nature. All environmental planning and design efforts aim collectively higher–beyond sustainability–toward the rehabilitation and restoration of the natural environment.

One of the most seminal authors on the subjects related sustainable environmental and ecological design Coates (1981) eloquently summarizes the challenges of restoration within the human environment, institutions as well as consciousness as follows:

> If we are to survive as a species we must learn to restore the circular ecological structure of the world which our increasingly powerful technology has disrupted. This, in turn, requires the restoration of wholeness to our socio-politico-economic systems as well as to the structure of consciousness itself. Whether or not such profound changes in our thought and institutions can be accomplished in time to avoid the fate which usually accompanies the loss of evolutionary flexibility is the central question facing us today. (p. 537)

In the light of such an awareness, other necessary priorities fall readily in place as well. The projected human footprint is aligned with the carrying capacity of the planet, which requires nothing less than an enormous, conscious, and collective effort on a global scale. All human activities, currently degrading natural systems, are modified or transformed to conform within natural cycles and functions, or completely abandoned as expeditiously as possible. In other words, all elements, processes, and practices–shown to cause detriment and degradation to the natural environmental beyond regeneration–are phased out, and replaced by more naturally benign ones. Although this may seem impossible on the outset, having this as our stretch-goal is imperative if we are to ultimately achieve holistic restoration of our neighborhoods, cities, regions, and the planet.

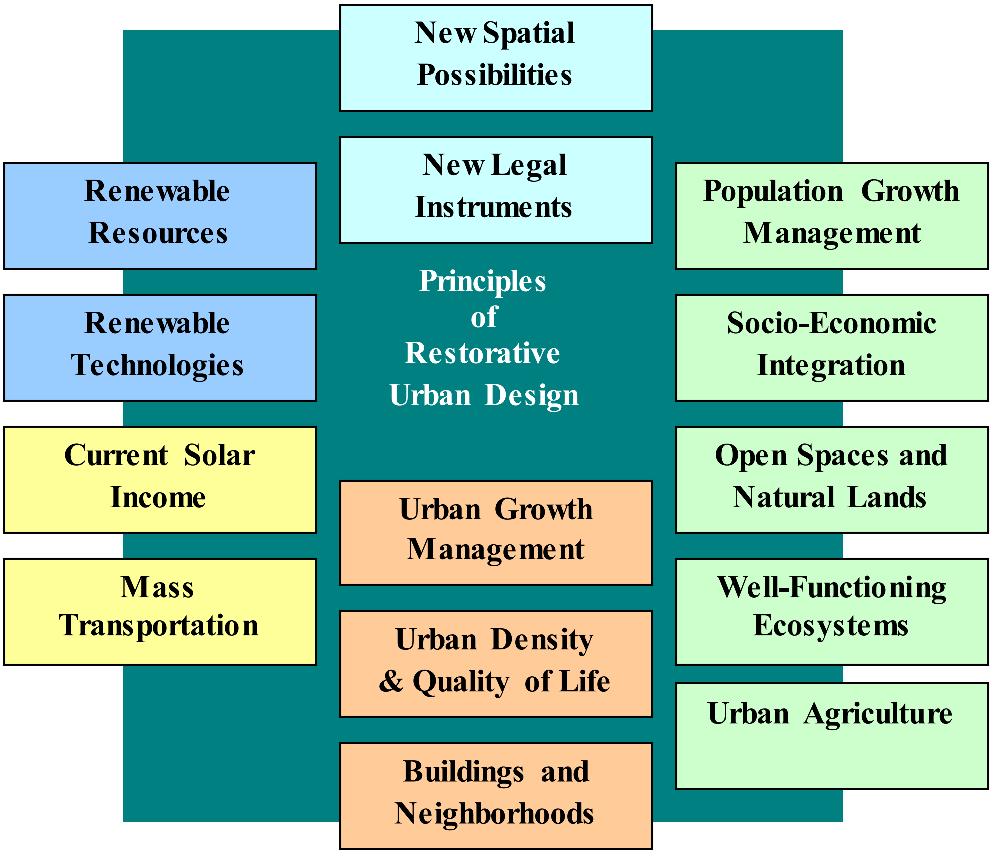
In order to create naturally integrated human ecologies that are intrinsically life-enriching and sustainable, the principles of planning and design need to be recalibrated at many design levels, ranging from that of a region down to a neighborhood, site or a building. At each level, restorative measures need to be implemented along parallel and complimenting goals.

1. Principles of Restorative Urban Design

The fundamental focus of restorative urban design and planning approach is concentrated on the development and operation of human-made environments and landscapes, as well as lifestyles since the roots of major environmental problems are found in and around urban areas and how we inhabit them. This means that human impacts have to be identified and neutralized at the source through a focus on urban planning, design, implementation, and operation.

This research places the focus of ecological and sustainable urban design and planning efforts on environmentally restorative principles. The major principles of Restorative Urban Design are initially summarized in the following categories (see Figure 2.4):

Figure 2.4 Principles of Restorative Urban Design address major urban impacts



a) Population Growth

Exponential growth of human population along with post-industrial technological advances is arguably the single most important contributor to the environmental degradation today (Brown, 1981; 1995; 2003; 2009; 2011). The population changes are being closely monitored today and the historical statistics and trends inform the future forecasts on urban growth in nearly all countries around the world. Growth of population often translates directly into intensification of environmental stresses on air, water, land, ecology, and resources that, in turn, necessitate appropriately simple to complex design solutions.

The continuing growth pattern in the global populations is perhaps largely attributable a wide range of circumstances created by the advances in sciences such as agriculture, biology, chemistry, medicine, and so on, as well as technologies such as mechanization, construction, infrastructure, electronics, and so forth. “The human population did not reach one billion until about 1820; in less than two centuries since then, it has increased nearly six-fold. This is a rate of growth unprecedented in human history” (Heinberg, 2003, p. 30). Reviewing the global population trend in recent history, Friedman (2008) observes the fact that throughout history the world population is believed to have “never exceeded 1 billion, which has presumably happened for the first time in 1800” (p. 68). After that point the UN World Population (2004) reports the world population to have grown exponentially, reaching 2 billion in 1930, 3 billion in 1960, 4 billion in 1975, 5 billion in 1988, and 6 billion in 2000 (p. 5). The report estimates the current world population to be approximately 6.8 billion in 2011, and extrapolates it to reach 8 billion in 2030, and 9 billion in 2050 (UN, 2004, p. 5).

This trend in global demographics correlates to a myriad of current and future environmental problems. Orr (2002) summarizes these problems as “a considerable challenge”, which includes “feeding, housing, clothing, and educating another 4 to 6 billion people [by the end of the century] and providing employment for an additional 2 to 4 billion without wrecking the planet in the process” (p. 16).

The population growth and urban expansion projections from China are as sobering and concerning as well. Among other facts, Friedman (2008) documents that, according to the official Chinese plans and estimates, that by 2040: 400 million people will have moved to urban centers (about 134% of the current size and population of the entire United States), erecting more than half of all the buildings built in the world during this period; more than 40 new, large airports will be brought online; 14,000 new cars to be built every day reaching a total of 130 million cars by 2020 (more than the current totals in the United States) (p. 59-60).

Such "runaway growth" is also reportedly well underway in India, where the rate of growth is expected to remain at a minimum of about 9% a year within the same time frame (Friedman, 2008, p. 61). Meanwhile, American-style metropolitan regions, downtowns, highways, and suburbia continue to mushroom in the North African, Egyptian, Arabian deserts and even in the dormant civilizations of ex-Soviet nations and South America in breath-taking rates of acceleration (Friedman, 2008, p. 62).

Forecasts of population expansion in many major metropolitan areas for the foreseeable future show no apparent indications of slowing down, promising to extend these trends well into the twenty-first century. Unless significant changes in lifestyles and economic emphases occur, this practically guarantees further worsening circumstances for the limited natural resources and environment. It is of paramount importance to plan toward a future where the human population grows in reasonable manner.

Heinberg (2003) pins rapidly expanding growth of human population on the use of technological innovations and states that "there are now somewhere between two to five billion humans alive who probably would not exist but for fossil fuels." He further argues that "if the availability of these fuels were to decline significantly without our having found effective replacements to maintain all their life-sustaining benefits, then the global human carrying capacity would plummet – perhaps even below its pre-industrial levels" (p. 33).

Chiras (1992) notes that the environmental problems the humanity faces today are among the unmistakable "signs that we have transgressed critical ecological thresholds," and he continues to add that, unfortunately, "few people in positions of power understand the meaning of carrying capacity and the limits it places on human endeavor. Even fewer people understand how far we have overstepped ecological boundaries, and the long-term consequences of continuing to do so" (p. 9) and that the demands of our civilization "have exceeded the Earth's carrying capacity" (p. 10).

Brown (1981) points out that the first manifestations of the ecological stress and resource scarcities that emerge as population increases are physical, such as overgrazing, overfishing, deforestation, and soil erosion, but then these translate into economic stresses such as lower output, inflation, and unemployment. Nevertheless, they "ultimately…translate into social stresses [such as] hunger, demoralization, forced immigration, higher infant mortality, and reduced life expectancy" (Brown, 1981, p. 132).

Brown (1981) asserts that population growth is not merely an obstacle to improving our lot, "it may eventually make improvement impossible" (p. 144). If the current trends in consumption of "biological capital" and mining of soils continue human civilization is likely to seal its fate as the Mayans did. That path is simply not tenable or consistent with the course an inherently resilient society. In order to strike a sustainable balance goals for slowing population growth have to be established. Brown (1981) advocated the first step in tackling the population problem was "reducing the average birth rate from 32 per thousand (the 1980 level) to 26 by 1990" (p. 148). Then, each decade thereafter, he prescribed a drop by 5 until reaching 11 in 2020, which would be about the rate in Austria, Sweden, or West Germany today.

Population management in the majority of world's countries remains as a great challenge still to be addressed. Ecologically responsive and environmentally responsible design practices may not directly address the population issues; however, they can facilitate the containment of human populations, and help reduce the sprawling development of built environments through revitalization, redevelopment, and restoration of the human settlements. In the end, human populations, activities and environments have to be in harmony with natural limits and processes. Otherwise, truly healthy and ecologically appropriate communities cannot be created (Beatley & Manning, 1997; Bernard & Young, 1997).

b) Urban Expansion

The conversion rate of open spaces, green spaces, open lands, and undeveloped natural areas is potentially one of the most significant indicators of increasing human impacts on the natural environment. While the need for further expansion and urbanization of surrounding areas may be real and present the manner in which the urban growth is accommodated needs to be looked at carefully. Conversion of undeveloped land and open spaces is often irreversible whereby making the recovery of precious naturally living ecosystems very difficult at the very least and even impossible on many occasions. Urban expansion onto previously undeveloped areas need to be more effectively managed through urban planning methodologies such as growth boundaries (Porter, 2008), rate programs (Kelly, 2004; Kemp, 2008), as well as various planning (Calthorpe, 2011), permit, incentive, and reward techniques (Williams, 2000).

c) Open Spaces & Natural Lands

Open spaces and natural lands have to be both preserved and expanded in and around urban environments (Laurie, 1979). Creating integrated networks of green infrastructure, parks and natural areas (Forman, 1995; McHarg & Steiner, 1998) is vital to maintain and restore biological diversity and effectively protect water supply systems for people and other organisms (Gill & Bonnett, 1973; SSI, 2009). This requires us to understand principles related to landscape and urban ecology (Calthorpe, 1993; Calthorpe & Fulton, 2001; Perlman & Milder, 2005; Calthorpe, 2011). Placing the preservation open spaces and natural lands must be a prerequisite for environmentally restorative efforts.

d) Well-Functioning Ecosystems

Natural rehabilitation and restoration of living ecosystems have to take place not only outside and around buildings, neighborhoods, and cities but also inside them. Urban re/developments have to be modeled after biological organisms and ecosystems, rather than mechanical processes and systems (Berger, 1985; MEA, 2003; MEA, 2005). The creation and restoration of well-functioning and adaptive ecosystems play essential roles in natural rehabilitation (Falk, Palmer & Zedler, 2006; Yeang, 2006; Clewell & Aronson, 2007; Skabelund, et. al., 2008). Placing rehabilitation of well-functioning ecosystems has to be an intrinsic priority for environmentally restorative interventions.

e) Current Solar Income

Current solar income has to be the primary source of energy for all fundamental technologies just as it is for the rest of terrestrial nature (Coates, 1981; McDonough & Braungart, 2002; Orr, 2002; ILBI, 2010). Heinberg (2003) notes that "the sun continues to give off an almost unimaginable amount of energy – the equivalent of roughly 100,000,000,000 hydrogen bombs going off every second – radiating in all dimensions into space. The Earth, 93,000,000 miles away, is a comparatively tiny target for that energy, receiving only an infinitesimal fraction of what our local star radiates [1,372 watts/square meter]" (p. 12). He projects that "the total influx of solar energy to the Earth is more than 10,000 times the total amount of energy humankind presently derives from fossil fuels, hydropower, and nuclear power combined" (Heinberg, 2003, p.13). It is clear that a civilization that relies solely on current solar technologies should never have a real energy problem.

f) Supporting Renewable Resources

Renewable resources such as wind, geothermal, hydro, and tidal energies have to be harvested in support to the primary role of the solar technologies (Meadows, Randers & Meadows, 2004; Farr, 2008; Desai, 2010). The wind is utilized by windmills, turbines, and sails. Although it is a low-cost, low-impact source or energy the availability of sustained wind speeds for commercial capitalization is only regional, which is typically limited to mountain passes, ridges, along coastal lines, and in the Great Plains. The use of wind technologies is prominent in countries such as Denmark, Netherlands, India, South Argentina, and China (Heinberg, 2003, p. 156). In the United States, the wind harvest is concentrated primarily in California, Colorado, Kansas, Nebraska, New Mexico, Oregon, Texas, Washington, and Wyoming.

Currently, the major drawback the hydrogen technologies face is inefficiency. Heinberg (2003) summarizes that the available "process of hydrogen production always uses more energy than the resulting hydrogen will yield" (p. 161).

At the national or regional scales dams serve as effective sources of irrigation as well as hydroelectric generation. However, there are also environmental concerns with the interruption of riparian ecosystems. As the 'Microhydro' scale in some rural areas rely on local electrification systems, which are benign, locally-controlled, and smaller investments. The use of geothermal technologies is site specific and essentially available for any project. Heinberg (2003) records that the United States utilizes "44% of the global capacity" (p. 164).

Biomass simply refers to burning of energy stored in natural fibers such as plant materials, which are only viable in few urban areas and largely supplementary in most rural areas. Biodiesel is produced from animal fats or vegetable oil, which is only available in limited capacities. And, ethanol is fuel grade alcohol that is made primarily from corn throughout the world, which competes as a food source for animal and human populations. Manufacturing and burning of these types of fuels further increases the excess carbon dioxide in the atmosphere.

g) Renewable Technologies

Energy generation through unnatural and unsustainable means such as fossil fuels, gasses, burning, combustion or nuclear methods need to be phased out as quickly as possible. Subsidies to coal, petroleum, and gasoline auto industries have to be reassigned to renewable resources. Caution has to be employed in developing anti-gravity and magnetic field technologies (Heinberg, 2003; Yeang, 2006).

h) Urban Densities & Quality of Life

The dynamics between increasing urban densities versus quality of life is continuously debated as many find them to be in direct contradiction (Beatley, 2000; UNEP, 2002; AIA/COTE, 2005; Owen, 2009). The presumed inverse relationship is not necessarily true when the latter can be maintained through quality of design and construction quite effectively (Calthorpe, 1993; Ritchie & Thomas, 2009; ILBI, 2010). From an environmental impact standpoint urban densities do need to be raised responsibly while the quality of life is maintained and increased in order to achieve more connected, integrated, inclusive, diversified, and resilient communities (Lyle, 1994; Newman et al., 2009).

i) Socio-Economic Integration & Diversification

Social and economic composition of neighborhoods and districts is another aspect of environmental longevity that contributes to creation of more healthy and resilient societies and communities (Mumford, 1938). Planning for higher degrees of integration and diversification is desired from an environmental restoration standpoint as it lessens the distances and obstacles between different layers of urban societies (Todd & Todd, 1994; Wilson et al., 1998; Porter, 2002; Brickman, 2009).

j) New Legal Instruments

New legal instruments refer to the development of new regulations and ownership structures that do not legally exist today. Many significant sources of environmental degradation are directly or indirectly attributable to the weakness or lack of regulations to not only protect but also to restore the quality of air, water, and land in natural ecology. Beyond conservation and preservation of resources, new legal means of land ownership, assembly, as well as equitable transfer of development rights (Juergensmeyer & Roberts, 1998) may need to be enacted so that significant transformative changes in urban planning, zoning, and re/developments may take place at large scales.

Particularly, some of the patterns of land ownership may need to be restructured to enable collaborative neighborhood and district scale re/developments that can benefit the sustainability and resilience of urban areas to the fullest extent possible. For instance, appropriate mixture of land uses, juxtaposition of renewable energy generation, as well as reintegration of food production inside and/or adjacent to urban areas may present significant environmental and economic advantages (Farr 2008; Desai, 2010).

In the United States, the differences between various state laws and federal regulations – or in the case of carbon dioxide emissions, the lack of sufficient controls, incentives, and disincentives – must be accounted for. Despite the political or legal unwillingness to address CO_2 emissions, for instance, many districts and cities are moving ahead and taking bold initiatives to plan for and achieve drastic reductions in this area (Architecture 2030 Challenge, 2014).

k) Mass Transportation

The integration of mass transit and transportation alternatives is an aspect of urban areas that significantly reduces environments impacts (Chiras, 1992; Rudlin & Falk, 1999; Gilbert & Ginn, 2001; Dunphy, Myerson & Pawlukiewicz, 2003; Buchanan, 2005). Varying modes of mass transportation should provide creative and benign new alternatives as well as economic opportunities (Calthorpe, 1993; Cervero, 1998; Kelly, 2004). An array of new transportation technologies should be powered by solar technologies (Beatley, 2000; Girardet, 2008; Coyle, 2011).

l) New Spatial Possibilities

As a species, humans are still crawling on a two-dimensional ground-plane. Many urban designers feel trapped within the inherent restrictions of gravity and development laws, which monumentalize the lack of imagination, entrepreneurship or excitement in urban environments. Could it be time to finally take advantage of the unexplored potentials of the third dimension? Neighborhoods and towns can be made much more connected in the third dimension, especially in the denser urban cores. Mobility and movement between the buildings can be freed from the ground floor and be greatly increased (Yeang, 2006; Birkeland, 2012).

m) Existing Buildings & Neighborhoods

The restorative design principles and strategies have to gradually transform the existing buildings, neighborhoods and cities to be more energy efficient and ecologically integrated with the earth's natural fabric (Beatley, 2000; Yeang, 2006b). Regulations, adaptions, and renovations can improve reliance on local means, materials, and resources of sustenance (Calthorpe, 1993;

Bernick & Cervero, 1997; Cervero, 1998; Lang, 2005; Williams, 2007; Porter, 2008). Enhanced industrial processes need to be incentivized to locate near urban settlements they serve.

n) Urban Agriculture

Food production as well as transportation and distribution of the food for the urban dwellers present enormous challenges and opportunities from an environmental restoration standpoint (Coates, 1981; Van der Ryn & Calthorpe, 1986; Lyle, 1994). Agriculture has to be diversified and localized to the furthest extent possible in order to minimize the distance and time between areas of production and consumption (Newman & Jennings, 2007). Federal, state and local regulations as well as incentives have to be put in place to support urban design and planning efforts (Yeang, 2006; ILBI, 2010). Urban agriculture needs to be envisioned as a way to create truly productive and self-reliant cities (Girardet, 2008; Gorgolewski, Komisar & Nasr, 2011).

2. Scales of Environmental Restoration

Achieving comprehensive restoration of natural functions in urban areas involves resolution of a myriad of inherently complex multidimensional and multidisciplinary issues that spread across a wide spectrum of different scales. From the scale of a single human to communities on up to global issues there are measures that need to be taken. Just as the actions at all of these levels have both direct and indirect impacts on degradation of the environment, comprehensive restoration can only be expected as a collective outcome of the interactions between all of them. Some restoration experts point out that the process is already under way:

> An epochal development has clearly begun: For the first time in human history, masses of people now realize not only that we must stop abusing the earth, but that we also must restore it to ecological health. We must all work cooperatively toward that goal, with the help of restoration science and technology. (Berger, 1990, p. xvii)

The comprehensive restoration of natural environment relies on improvements taking place across the spectrum of environmental scales. It is a given that the relevance and significance of each environmental scale is defined by the extent and magnitude of degradation or deterioration prevented or restored. Any environmental intervention in urban design and planning has to interact with a number of different scales simultaneously.

a) Human Scale

All human impacts on the environment originate at the level of single human being. At this level, the individual or collective philosophies, lifestyles, habits, and behaviors of each and every person, family or business function as the smallest unit in the environmental transformation, and therefore, the lowest level of possible restoration on the environmental scale.

The type and nature of environmentally restorative actions at this scale are much more directly dependent on the specific values, knowledge, and decision making mechanisms of each individual person, family or business. Education and awareness are perhaps among the most critical traits that effect outcomes to be expected from this level (Leopold, 1966; Berry, 1999; Palmer, 1999; Hawken, 2007; Desai, 2010; Hawken, 2010).

b) Building & Site Scale

Individual persons, families or businesses interact with one another as part of larger groups and clusters inside or outside of their own immediate homes, schools, businesses, and sites, giving way to larger environmental formations. It is at this level that the dynamic changes and transformation within the human-made environment start to take shape.

At this scale, the individual buildings and small parcel developments in urban environments start to form the potential for next levels of degrading or rehabilitating impacts. This level is a significant platform for restorative efforts which can lead to widespread restoration in the natural environment (AIA/COTE, 2005; LEED-NC&MR; BREEAM, 2011).

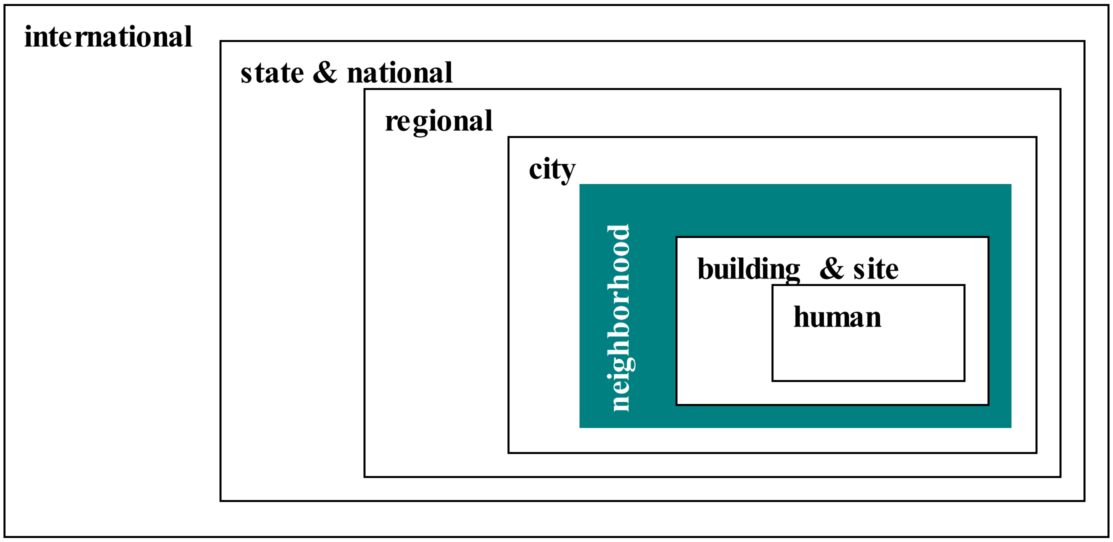
c) Neighborhood Scale

Groups of buildings and small parcels come together to form campuses, neighborhoods, and districts, which typically serve as the building blocks of cities and regions. Most principles and strategies of urban design and planning are implemented at this scale. Policies formulated, decisions and actions taken at neighborhood or district levels need to be well-suited to the unique local requirements of each geographic location. At the neighborhood scale the local economic, social, and environmental inertia of communities begin to exert considerable impacts on the surrounding natural environment and ecology (LEED-ND, 2009; CASBEE-UDe, 2007).

Also at neighborhood level, human settlements start to reach the critical mass to become independent, autonomous, self-sufficient, self-sustaining, and more resilient. Consequently, this is effectively the scale of choice for the restorative urban design model.

Even though different aspects of degradation, deterioration and depletion need to be mitigated at different scales of the environmental spectrum, the neighborhood scale is the appropriate – or chosen – level of scale for the restorative model proposed in this research (see Figure 2.5) (Rudlin & Falk, 1999; Barton, 2000; Beatley, 2004; Brickman, 2009).

Figure 2.5 Neighborhood is the appropriate level of scale for the RUD model



d) City Scale

The disciplines of city planning and urban design operate at a larger scale, at which major land use, transportation, infrastructure, public service and facilities can be made more favorable for restorative efforts. The social, economic, and political forces in communities really begin to shape the local physical environment and geographic landscape of an urbanized area at this level.

As the challenges of human impacts on natural environment become more pronounced at this scale, so do the opportunities for environmental rehabilitation and restoration. Van der Ryn and Calthorpe (1986) identify that self-reliance is not an individual affair and that in an urban area, "no one is a tight little island, and survival is a collective enterprise. Constructive action should be cooperative" (p. xii).

McHarg and Steiner (1998) point out to many aspects of intense environmental challenges generated by industrialized urban areas in rather blunt terms:

> The large modern metropolis may be thirty miles in diameter. Much, if not all, of the land which it covers is sterilized. The micro-organisms in the soil no longer exist; the original animal inhabitants have largely been banished. Only a few

> members of the plant kingdom represent the original members of the initial ecology. The rivers are foul; the atmosphere is polluted, the original configuration of the land is only rarely in evidence; climate and microclimate have retrogressed so that the external microclimate is more violent than was the case before the establishment of the city. Atmospheric pollution may be so severe as to account for 4,000 deaths in a single week of intense 'fog,' as was the case in London. Floods alternate with drought. Hydrocarbons, lead, carcinogenic agents, carbon dioxide, carbon monoxide concentrations, deteriorating conditions of atmospheric electricity – all of these represent retrogressive progress introduced and supported by man. The epidemiologist speaks of neuroses, lung cancer, heart and renal disease, ulcers, the stress diseases, as the badges of urban conditions. There has also arisen the specter of the effects of density and social pressure upon the incidence of disease and upon reproduction. The modern city contains other life-inhibiting aspects whose effects are present but which are difficult to measure: disorder, squalor, ugliness, noise. (p. 14)

At the scale of planning cities and towns, regenerative and restorative design opportunities become more prominent within the surrounding landscape. The measures introduced at this level of intervention have farther reaching effects on nature (Todd & Todd, 1994; Jackson & Svensson, 2002; Bang, 2005; Dawson, 2006; Owen, 2009).

e) Regional Scale

Especially in those areas where several megalopolitan governments or counties coalesce, different sets of synergies and opportunities emerge with regards to land use, transportation, infrastructure, civic services, and facilities, which may not be feasible otherwise. These opportunities toward environmental restoration at this scale have even broader reach than others (Frampton, 1983; Calthorpe, 1993; Calthorpe & Fulton, 2001; Calthorpe, 2011).

f) State & National Scale

At state and national levels of environmental design and planning, the nature and extent of restorative implementations are vastly potent and significant. From this perspective, policy decisions and planning regulations offer unparalleled potential to transform relationships among urban, suburban, exurban and nonurban areas. In a state-wide effort, and The Land Institute work to restore the health to agricultural systems by "consulting the genius of the place" (Jackson, 1994). Restoring the state or nationwide community health and wealth is among central goals of many other programs, which recognize and highlight the important roles state policies and national leadership play (Berry, 1995).

d) International Scale

While all the previous scales are important and instrumental in implementing significant restorative objectives, at an international or global scale strategic alliances and treaties are also needed to foster environmentally restorative design and planning. These dimensions generally include migration of people, goods, services and ideas through international communication, transportation and exchanges.

From an environmental restoration stand point, even though the scientific knowledge, public awareness, and political drive have been raising in the last few decades, restorative efforts do not appear to keep pace with the degradation. International platforms such as IPCC, Climate Change, Green Building, Sustainable Design and Development conferences and/or agreements create great opportunities to guide policies and actions in full support of restorations. The Society for Ecological Restoration International is certainly one of the leaders in this arena, supporting the integrated, holistic views of restoration from urban to natural open lands.

3. Scope of Environmental Restoration

Within the spectrum of environmental restoration, the scope of this research focuses primarily on initiating a restorative methodology for defining, modeling, and implementing multidisciplinary, multidimensional, and comprehensive environmental design that could accomplish restoration through urban development, redevelopment, and rehabilitation (Toros, 2011).

The ultimate goal of such a restorative methodology is very much in line with other prominent ecologically responsive and environmental responsible urban design and planning approaches. One of these approaches is the Biophilic City as introduced by Beatley (2011), which is simply envisioned to manifest a biodiverse city, a city full of nature, a place where in the normal course of work and play and life residents feel, see, and experience rich nature – plants, trees, animals:

> The nature is both large and small – from treetop lichens, invertebrates, and even microorganisms to larger natural features and ecosystems that define a city and give it its character and feel. Biophilic cities cherish what already exists (and there is much, as we have already seen) but also work hard to restore and repair what has been lost or degraded and to integrate new forms of nature into the design of every new structure or built project. (Beatley, 2011, p. 45)

Chapter 3 - Toward A Method of Restorative Urban Design

This chapter focuses primarily on the main objectives and design of research associated with the Restorative Urban Design (RUD) approach. The following discussions introduce and elaborate on the core elements and procedures of such a method including the indicators of environmental restoration, the analyses of restorative indicators, as well as building, comparing, evaluating and optimizing different urban re/development scenarios. Key questions and expected results related to this restorative research are presented in a concise manner while aspects such as context, focus, and extent of research are addressed. Also, in this chapter, the processes of data collection and analysis are outlined, setting the stage for the next chapter where an illustrative Case Study is presented.

A. Developing A Restorative Urban Design Method

In accordance with the principles of restorative design outlined in Chapter 2, this research seeks to develop a design method that can be a part of a restorative design methodology targeting exclusively on assessing and offsetting urban impacts on natural environment through urban re/developments. While such an urban design method necessarily needs to be at neighborhood or district-scale it is also possible to expand the scope or area of restorative applications beyond a neighborhood or district if adequate resources are in place. It is conceivable and more desirable to apply the restorative measures at larger scales as long as the level of complexity in relationships, detail, and data for the analyses can be managed effectively.

The definitions, principles, and theory of restorative research have been discussed in the previous chapters, however, it is appropriate to reiterate that the scenario-based principles of ecological restoration modeling are at the core of the restorative approach, which need to be tailored to environmental design and planning within the urban ecology. While discussing some of the most pressing ecological challenges Harris et al. (2006) points to the fact that the use of ecological restoration will continue to increase "as a primary component of humanity's toolbox," and cities, organizations, and individuals will be "required to respond" to many global and regional challenges where traditional approaches that rely on historical ecosystem references will be insufficient. Harris et al. advocate that among our ecological restoration goals should be "the continued protection of species and ecosystems at risk…as well as the reinstatement of natural capital with the explicit aim of enhancing ecosystem service provision at local, regional, national, and global scales" (p. 175). To do this well the role of urban ecological restoration must become more ambitious and holistic -- something possible if we create truly restorative urban design scenarios throughout the world. This will take time and testing, including experimentation with partial restoration, for example, by focusing on key components such as nitrogen and carbon cycles and restoring CO2 to more reasonable levels.

1. Theoretical Framework & Conceptual Model

The restorative urban design approach presented in this dissertation proposes a theoretical framework of establishing ideal and/or desired sets of conditions that need to be functionally similar to – or better than – those that existed prior to industrialized human settlements. To that end, the conceptual model for restorative urban design is specifically designed to analyze and evaluate a select list of environmental design dimensions and indicators from the exclusive perspective of restoration. It establishes a group of dimensions, in which a carefully assembled series of indicators are estimated, analyzed, evaluated and optimized for urban design purposes. The restorative approach envisions scenario-based modeling practices similar to those in the field of ecological restoration. It aims to formulate restorative projection scenarios based on reference states of the past and present conditions to guide the urban re/developments of future (Campagna, 2000; Urban, 2006).

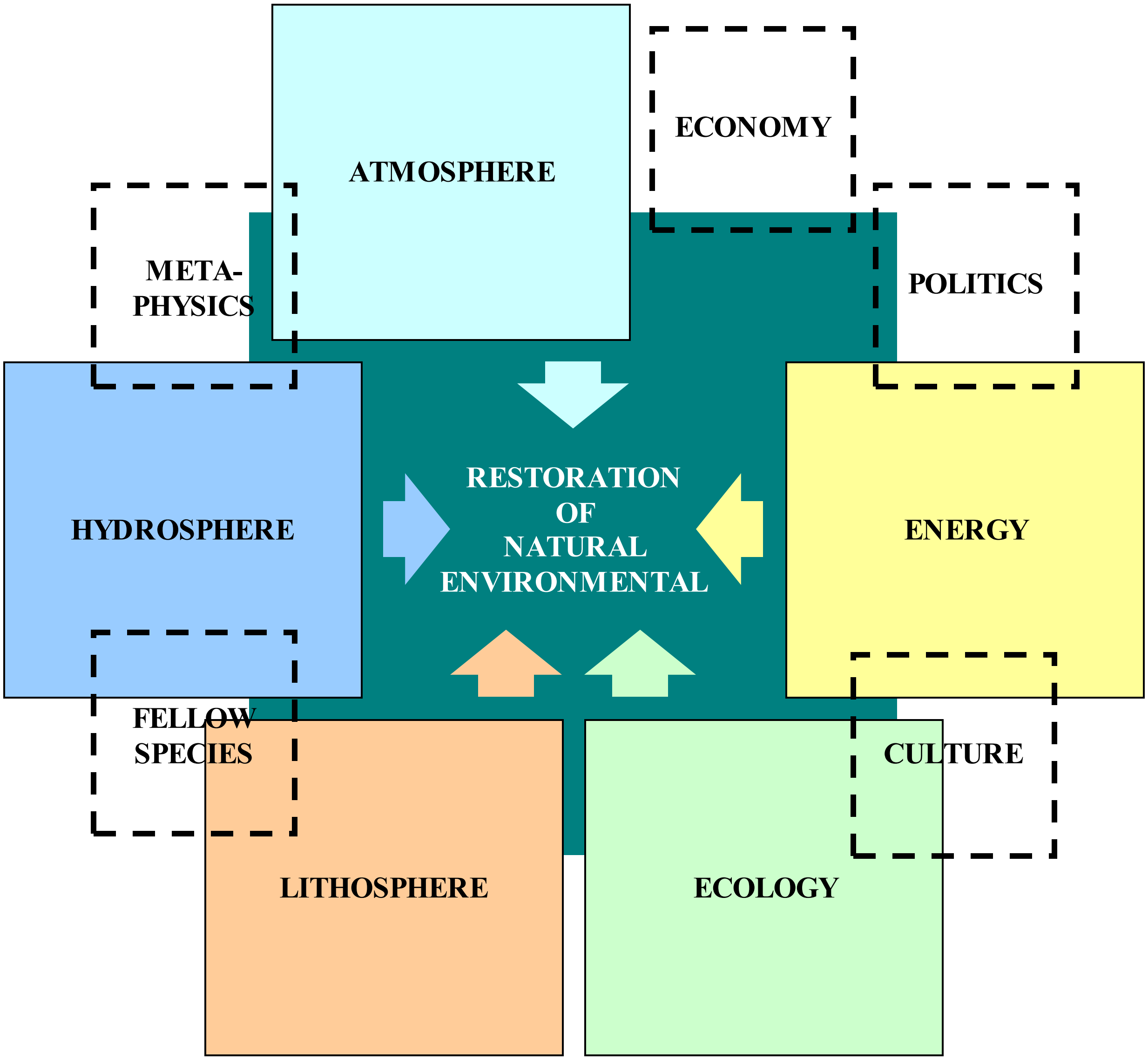
From an operational perspective, the restorative model is envisioned to be adopted by public authorities as well as private entrepreneurs of community re/developments, through which cumulative effect of restorative mitigations can facilitate comprehensive restoration. The RUD approach asserts that the scale of urban design and planning at neighborhood or district scale is perhaps the most effective level to operationalize the restorative principles and strategies discussed in the previous chapter.

2. Dimensions of Environmental Restoration

The restorative model considers a select set of significant indicators in five primary dimensions of the natural environment: Atmosphere (emissions, pollutants, ozone depletion); Hydrosphere (stormwater, domestic water, wastewater); Lithosphere (land use, land cover, food and wastes); Ecology (habitat resilience, biodiversity, population and resources); and Energy (renewability, reduction and efficiency, transportation) (see Figure 3.1).

The conceptual model proposed by the restorative research focuses exclusively on the physical aspects of urban design and planning issues as separate and independent from the related social, cultural, economical, or political factors that are likely to influence the real-world circumstances. Such an abstraction is simply an unavoidable necessity of modeling and evaluating environmentally restorative strategies.

Figure 3.1 Five primary dimensions are chosen to guide the environmental assessment

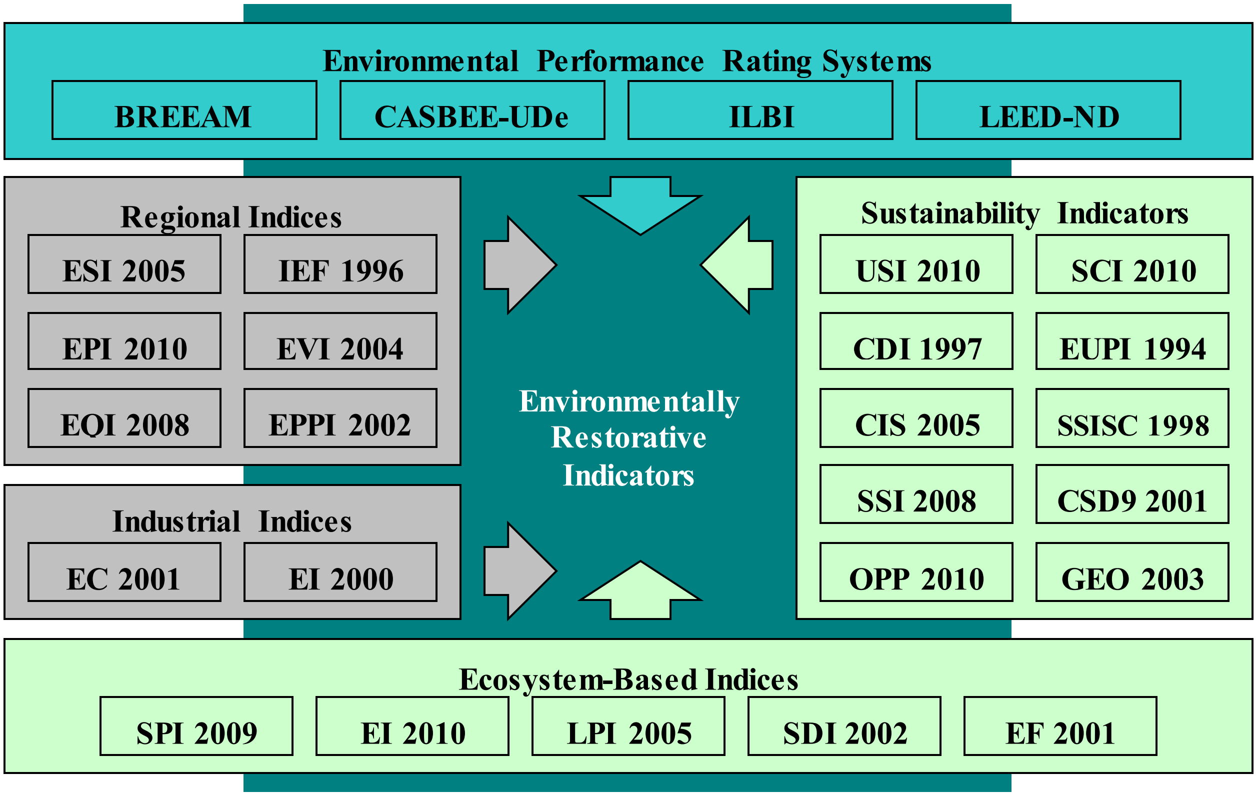


The conceptual model of restorative design for urbanized areas holds that the comprehensive restoration of natural environment is ultimately achievable if and when the negative impacts of urban developments are effectively estimated and appropriately mitigated. The restorative urban design and planning strategies are optimized in the process of applying the RUD model – thus restoring and maintaining the harmony between urban and natural environments. Estimated urban impacts are required to be mitigated fully through a combination of onsite and offsite improvements as necessary.

3. Indicators of Environmental Restoration

Since the most significant sources of degradation, deterioration and depletion in the natural environment are typically concentrated within urban areas, restoration efforts need to start at the very source of environmental problems. There is indeed a rich variety of environmental indicators which are currently used to monitor various aspects of degradation, deterioration and depletion. Figure 3.2 below summarizes the environmental performance rating systems and assessment indices where each indicators has been reviewed as part of the restorative research.

Figure 3.2 Restorative indicators from environmental rating systems and indices



The survey of restoratively relevant indicators in the existing environmental performance rating systems, assessment indices, and sustainability indicators was carried out in a methodological manner. Every single indicator has been carefully reviewed, evaluated, and assigned a relative score based on its role, effectiveness, and potential impact toward achieving comprehensive environmental restoration. At the end of this review, it was determined that a select portion of these indicators are more relevant to comprehensive restoration of the natural environment than others. Those indicators that directly monitor and/or affect the quality of air, water, soil, habitat, and energy aspects have been assigned higher score on a simple Likert scale (refer to Appendix B, C and D). The highest scoring indicators in the survey have been assembled and categorized within the RUD model a basis for developing the dimensions and categories, indicators of the model (refer to Appendix E). The following briefly discusses the reviews and synthesis process by which the indicators of Restorative Research were identified.

a) Review of Environmental Performance Rating Systems

In developing the RUD model, hundreds of indicators in relevant environmental performance rating systems have been closely examined for their restorative significance (refer to Appendix C) and integrated into the restorative research as appropriate (refer to Appendix D). These indicators have been merged into three subcategories under each of the five restorative dimensions (refer to Appendix E). Other environmental performance rating systems such as Green Globes (USA, CAN), Green Star (AUS, NZD, SAF), VERDE (SPA), AQUA (BRA), GRIHA (IND), HQE (FRA), Estidama Pearl Rating System (UAE), Passivhaus (DEU), and SBC-ITACA (ITA) have not been specifically included in the survey of environmental restoration indicators. However, these systems do monitor similar urban design and planning concepts, strategies and techniques used throughout the world. While restorative indicators are primarily inspired by the popular environmental performance rating systems of the Western hemisphere such as BREEAM (2011), CASBEE-UDe (2007), ILBI (2010), and LEED-ND (2009), gaps in existing strategies and techniques have been bridged by other studies such as Xing et al. (2008), Edwards (2010), and Haapio (2012).

b) Review of Environmental Assessment Indices

In developing the RUD model, literally hundreds of indicators in relevant environmental assessment indices were also carefully reviewed. These indicators have been individually examined for their potential restorative significance and integrated into the restorative research as indicators in the analyses. The indicators of high restorativeness (as defined by the restorative research) have been merged and consolidated into three subcategories under each of five primary dimensions (refer to Appendix E). The following review of environmental assessment indices specifically related to sustainable urban design and planning issues informs the final synthesis of restorative indicators that make up the RUD model.

i. Ecosystem-Based Indices

Initiated by Mathis Wackernagel and William Rees in 1996, the Ecological Footprint (EF) establishes a level of land and water requirements in order to sustain a certain living standard, which is assumed to continue in perpetuity assuming certain efficiency improvements (Palazzo & Steiner, 2011). Calculation of EF values is largely based on data from national consumption statistics, thus, relying primarily on the normalized conversion of consumption to land use. Weighting of consumption statistics is incorporated in all land and water related calculations. Böhringer and Jochemc (2007, p. 3) note several different approaches to the ecological footprint calculations such as the MIPS (Material-Input-Per-Service) concept (Schmidt-Bleek, 1994), the Sustainable Process Index (Narodoslawsky & Krotscheck, 2004; Gassner & Narodoslawsky, 2004), and the Ecoindex (Chambers & Lewis, 2001). The RUD model is conceived to employ similar but less sophisticated calculation methods on each urban impact to be monitored.

Published by World Wildlife Fund in 1998, the Living Planet Index (LPI, 1997) establishes a global biodiversity indicator measuring living trends in terrestric, freshwater, and seawater ecosystems (Loh et al., 2005, p. 291). The LPI monitors over 2000 populations of more than 1100 species. For every species the ratio between its populations in pairs of consecutive years is calculated. The geometric mean of different species multiplied by the index value of the former year yields the biodiversity index taking 1970 as the base-year (Böhringer & Jochemc, 2007, p. 3). Ecologically restorative indicators such as EBD-ETS, EBD-TSE, and EBD-IEA are established to monitor biodiversity and living species in a given study area (refer to Appendix E).

Developed by Best Foot Forward (Chambers et al., 2000), the Eco-Index methodology (EI, 2010) performs a bottom-up (component) ecological footprint analysis. The analysis remains compatible with top-down (compound or collective) approaches using international trade statistics. In this methodology, the ecological footprint is derived from full life-cycle impact data using conversion factors. The ecological footprint index value is normalized by the application of equivalence factors (Singh et al., 2009, p. 200). Indicators of key restorative significance from this index related to manufacturing of materials and transportation (refer to Appendix B) are integrated into the RUD model under the subcategories such as resources, efficiency, and transportation (refer to Appendix E).

Barrera-Roldán and Sald´ivar-Valdés (2002) conceive the Sustainable Development Index (SDI) as an instrument to maintain "a sustainable balance between ecology and human settlements," which provides policy makers with sound information to protect and restore the welfare both of the environment and of the human population (p. 255). While the SDI includes many economic and social indicators that are excluded from the RUD model, the majority of the natural indicators contained in the index are seen as highly significant from an environmental restoration point of view (refer to Appendix B). Indicators related to air, water, soil quality, hydrological balance, wildlife habitat preservation and restoration are integrated into the restorative research indicators such as AOD-AQD, HSW-PPT, HWW-WDS, EHR-PRO, and EHR-RSE, which are simply different indicators of monitoring, estimating, and mitigating major urban impacts (refer to Appendix E).

Singh et al. (2009, p. 200) discusses the Sustainability Performance Index (SPI) which at its core is the calculation of the area needed to embed a process completely into the biosphere including the production of raw materials, energy generation, and necessary supporting installations and by-products within an ecosystem area of study (Lundin, 2003; Narodoslawsky & Krotscheck, 2004). The results of analyses in the RUD model can easily be compounded and normalized to similarly represent a single index value for restorative performance. This is not done via this dissertation. However, developing the RUD model into an environmental performance rating system may offer great environmentally restorative benefits. Several restorative research indicators including LFW-RRC, EPR-RNR, and ERN-SHW are established to be in parallel with eco-system based indices like SPI (refer to Appendix E).

ii. Environmental Indices for Regions & Nations

The RUD model incorporates indicators from a number of regional and national environmental assessment indices, which have been closely examined for their restorative significance (refer to Appendix B) and integrated into the restorative research as appropriate (refer to Appendix E). This is only an initial review and synthesis, which does need to be refined by the future research on environmental restoration. Many indicator categories such as air pollutants, greenhouse gas emissions, rainwater management, wildlife habitat protection, resource consumption reduction, energy efficiency, renewability and transportation are common denominators among several regional and national indices of environmental sustainability.

Developed by Adriaanse in the Netherlands in 1993, the Environmental Policy Performance Indicator (EPPI, 1993) is a composite indicator aiming to monitor the trend in the total environmental pressure in the Netherlands and indicate whether the environmental policy is heading in the right direction or not. Six theme indicators are composed of several components dedicated to change of climate, acidification, eutrophication, dispersion of toxic substances, disposal of solid waste, and odor and noise disturbances (Singh et al., 2009, p. 205). The restorative indicator indicators address only a limited number of major concerns among those included in EPPI such as AOD-GCE, HWW-WWT, LFW-PUW, EPR-RNR, and ERE-TER (refer to Appendix F).

Puolamaa et al. (1996) describes the Index of Environmental Friendliness (IEF, 1996) as a general model for the aggregation of direct and indirect data regarding problem indicators, which are further merged into an overall index (p. 9). Singh et al. (2009) identifies the scope of the IEF model as being designed to cover the key areas of environmental problems such as greenhouse effect, ozone depletion, acidification, eutrophication, ecotoxicological effect, resource depletion, photo-oxidation, biodiversity, radiation and noise (p. 205). Several indicators such as AEM-CDE, AEM-MTE, AEM-NDE, AOD-GDE, EBD-ETS, EHR-HDB, and ERN-OSR in the restorative model parallel these key areas of concern (refer to Appendix F).

The Environmental Vulnerability Index (EVI, 2004) is made up of a total of fifty indicators in five categories (refer to Appendix C). Thirty-two of these indicators focus on environmental resources and services dealing primarily with health and productivity of ecosystems. The EVI (2004) includes six indicators related to interactions with human populations, ten indicators related to the geographic and geological occurrences, while remaining indicators are about weather and climate (Böhringer & Jochemc, 2007, p. 4). The EVI scale is normalized to range between a value of 1 – indicating high resilience/low vulnerability – and 7 – indicating low resilience/high vulnerability. All fifty indicators are given equal weight and then aggregated by an arithmetic mean. The restorative indicators of RUD model feature a number of indicators that are very closely associated with those of EVI (2004).

Esty et al. (2005) notes that the Environmental Sustainability Index (ESI, 2005) quantifies the likelihood of a country preserving valuable environmental resources effectively over the period of several decades (p. 23). Böhringer & Jochemc (2007) describes the ESI index to consist of five major component categories that contain a total of 21 indicators derived from 76 variables (p. 4). Environmental systems subcategory includes indicators on air quality, biodiversity, land and water quality. The subcategory of reducing environmental stresses concentrates on reducing air pollution, ecosystem stress, pollution pressure, waste and consumption pressures, water stress, and resource management. The human vulnerability reduction subcategory features indicators to monitor environmental health, basic human sustenance, and natural disaster vulnerability. In addition, the ESI index incorporates a number of social and institutional capacity indicators such as environmental governance, eco-efficiency, science and technology, and transboundary environmental pressures (refer to Appendix C). The restorative research closely examines each one of these indicators in the ESI index, rates each one for its restorative significance, and incorporates only those most relevant to the restoration of the natural environment with the exclusion of social, economical, and political issues (refer to Appendix E). A large portion of indicators in the RUD model serve purposes parallel with this index e.g. AEM-CDE, APL-CFC, AOD-GCE, HSW-SRW, HDW-NZW, LLC-FRT, HER-RSE, and ERE-TGR so on (refer to Appendix F).

The Environment Quality Index (EQI, 2008) features four main subcategories focusing on soil condition, surface water health, land habitat, and air quality. A weighted sum of all ten environmental factors gives a numerical representation of the overall environmental quality using the Analytic Hierarchy Process (AHP) methodology (French et al., 2008). Each environmental indicator is normalized to assume a value between 0 and 10, where the weights are given according to the relative importance of each factor (Singh et al., 2009, p. 205). The restorative research closely examines each indicator in the EQI index (refer to Appendix B), rates and incorporates the essence of restoratively most significant indicators. Many indicators of the RUD model such as APL-CFC, APL-NH3, HWW-HLT, EHR-HDB, and EBD-ETS are directly influenced by those in the EQI index (refer to Appendix E).

The Environmental Performance Index (EPI) serves as a gauge of policy performance in reducing environmental stresses on human health and promoting ecosystem vitality and sound natural resource management (Böhringer & Jochemc, 2007, p. 4). The EPI focuses on "current on-the-ground outcomes across a core set of environmental issues tracked through six policy categories for which all governments are being held accountable [air pollution, water, agriculture, forests, fisheries, climate change]" (Esty et al., 2006). All variables are normalized between 0 and 100, where the maximum value is targeted and the minimum characterizes the worst conditions in the field (Singh et al., 2009, p. 205). The RUD model examines each of the twenty-two indicators in the EPI index (refer to Appendix B), rates and incorporates the most significant ones from an environmental restoration perspective (refer to Appendix D). The indicators such as AEM-CDE, APL-CFC, AOD-GCE, HDW-DWU, EHR-PRO, and ERN-SWH serve parallel purposes with those in the EPI index (refer to Appendix E).

iii. Environment Indices for Industries

Eco-Indicator 99 is another industrial performance index for assessing environmental risks associated with various types of mining and manufacturing processes (EI-99, 2000). The index is made up of three subcategories i.e. resources, ecosystems, and human health, which feature a total of eleven indicators that monitor the risks of damages to natural surroundings, species, resources, ozone layer, and climate change (refer to Appendix B). The RUD model incorporates indicators such as AOD-GCE, EBD-ETS, EPR-RNR, and ERE-CGB that monitor parallel concerns as Eco-Indicator 99 index (refer to Appendix E).

Eco-Compass is an environmental performance assessment index that is specifically designed in order for industrial processes to closely monitor and better manage resources and wastes while increasing their system efficiencies (Yan et al., 2001) (refer to Appendix B). The index is comprised of six indicators that concentrate on resource conservation, potential risks to environmental health, as well as intensity of energy (refer to Appendix B). Many indicators in the RUD model like AEM-CDE, APL-CFC, AOD-GCE, HWW-WWT, EPR-RNR, and ERE-TGR address comparable concerns as Eco-Compass index (refer to Appendix E).

c) Review of Sustainability Indicators

The RUD model thoroughly examines hundreds of indicators in sustainability indices, for their individual contributions to the comprehensive restoration of the natural environment. The reviewed indicators are rated in accordance with their restorative significance (refer to Appendix B), and incorporated into the restorative indicators under each dimension of the restorative research (refer to Appendix E). The following review of sustainability indicators specifically related to urban design and planning issues informs the final synthesis of restorative indicators that make up the RUD model.

i. Sustainability Indices for Cities

The Ecosistema Urbano Performance Index (EUPI, 1994) is an environmental performance index that is designed to evaluate several indicator factors including air quality, green spaces, transportation modes, and management of water, natural resources, recycling and wastes. The index consists of eighteen indicators that concentrate on the urban areas (refer to Appendix B). A number of indicators within the RUD model specifically address parallel environmental concerns as EUPI index e.g. AOD-AQD, HDW-NZW, ERE-CGB, and ETP-PTA (refer to Appendix E).

Originally conceived by the United Nations Centre for Human Settlements (HABITAT), the City Development Index (CDI, 1997) consists of five subcategories monitoring infrastructure, waste production, health, education, and city product index. Infrastructure indicators monitor percentages of households that are connected to clean water supply, canalization, electricity and a phone network (refer to Appendix B). Waste indicators monitor the percentage of untreated sewage in total wastewater and the percentage of disposal of solid waste in total solid wastes. Health subcategory monitors rates of life expectancy and infant mortality (Böhringer & Jochemc, 2007, p. 4). While the city product is based on the city's GDP the education indicators (literacy and enrolment) are excluded from the scope of restorative research. Several indicators in the RUD model like HDW-FWA, HDW-DWU, HWW-WWT, and EPR-UPD target similar urban characteristics (refer to Appendix E).

Confronted with the health problems of the city, the Sustainable Seattle Initiative has been established by the community leaders from different areas of Seattle metropolitan area (Hak et al., 2007; Bell & Morse, 2008). The indicators of Sustainable Community (SSISC, 1998) are conceived to measure long-term community well-being. Based on a consultative process, a set of forty indicators covers issues related to environment, population/resources, economy, youth/education, and health/community (Singh et al., 2009, p. 204). For the purposes of restorative design, specific indicators such as AOD-AQD, HDW-NZW, LFW-PUW, EPR-RNR, and ERN-OSR in the RUD model focus on similar aspects related to ecological and environmental restoration (refer to Appendix E).

Singh et al. (2009) describes the Compass Index of Sustainability (CIS) as a simple averaging method for indicators clustered in four subcategories i.e. Nature (N), Economy (E), Society (S) and Well Being (W) (p. 204) (refer to Appendix B). The indicators in CIS (2005) are assigned normalized values on a performance scale from 0 to 100 where each indicator has an equal weight (Atkinson et al., 1997). As the social and economic factors are excluded from the scope of the RUD model only a few indicators are common to both addressing the natural resource and ecosystem concerns e.g. EHR-PRO, EHR-RSE, EBD-ETS, and EPR-UPD (refer to Appendix E).

While Mori and Christodoulou (2011, p. 105) call for a number of methodological improvements, the Sustainable Cities Index (SCI) effectively tracks sustainability in large cities in the United Kingdom, ranking them across three broad subcategories: environmental performance; quality of life; and future-proofing (SCI, 2010, p. 5) (refer to Appendix B). The index provides a snapshot of urban sustainability through environmental performance indicators such as air quality, biodiversity, household waste, and ecological footprint (p. 11). The quality of life indicators monitor and compare employment, transportation, education, human health, and green space (p. 15). Future-proofing indicators include climate change, economy, recycling, and local food measures (p. 19). The RUD model effectively covers majority of these environmental and ecological concerns through indicators like AEM-CDE, APL-CFC, AOD-GCE, HWW-WWT, EPR-RNR, and ERE-TGR (refer to Appendix E).

Developed by Zhang (2002), the Urban Sustainability Index (USI) is based on twenty-two indicators in the context of urban China, chosen from a database of 387 sustainability indicators (refer to Appendix B). The total urban sustainability score is based on three components, each of which is calculated from a number of individual indicators where the normalized score varies from 0 to 1 (Singh et al., 2009, p. 204). The USI (2010) consists of five subcategories: basic needs, resource efficiency, environmental cleanliness, built environment, and future sustainability (refer to Appendix B). Except for the social and economic considerations, a number of the RUD model indicators cover the same environmental factors, including air pollution (APL-CFC), water supply (HDW-DWU), wastewater treatment (HWW-WWT), building efficiency (ERE-CGB), urban density (EPR-UPD), and mass transit usage (EPT-PTA) (refer to Appendix E).

ii. Social & Quality of Life-based Sustainability Indices

The Sustainable Society Index (SSI) aims to define the components of sustainability in measurable terms and clearly, fixing the responsibility to assess progress comprehensively (Van de Kerka & Manuel, 2008, p. 228). The SSI classifies sustainability under five subcategories: personal development, clean environment, air quality, sustainable use of resources, and sustainable world. The ecological and environmental indicators of the index address governance, preservation, population growth, biodiversity, forestation, consumption/wastes, quality of air, water, soil, emissions, food, sanitation, recycling, and renewable resources/energy (Van de Kerka & Manuel, 2008, p. 239). With the exception of social, economic and political considerations, a number of indicators in the RUD model facilitate environmental restoration on similar aspects e.g. AOD-GCE, EBD-ETS, EPR-RNR, and ERE-CGB (refer to Appendix E).

iii. Global Indices

Initiated by the United Nations Commission on Sustainable Development (UNCSD) the 2001 report (CSD-9, 2001) focuses on developing globally applicable indicators for sustainable urban re/developments. The framework of the report consists of a series of social, economic, environmental, and institutional priorities as a basis for monitoring. The environmental indicators are grouped under five major subcategories: atmosphere, land, oceans, seas/coasts, freshwater as percentage of total available water, and biodiversity (CSD-9, 2001, p. 15). The established indicators concentrate on climate change, ozone layer depletion, air quality, water quality, fisheries, agriculture, forests, ecosystems, species, desertification, and urbanization. Indicators of key significance from this report related to comprehensive restoration of the natural environment are incorporated within the RUD model (refer to Appendix D) under the subcategories such as pollutants, domestic water, land cover, food/wastes, biodiversity, population/resources, reduction/efficiency, and transportation (refer to Appendix E).

Hak et al. (2007) summarizes the GEO 2003 (2004) indicators established by the United Nations Environment Programme (UNEP), which are grouped under seven major subcategories for global environmental sustainability of human civilization: atmosphere, natural disasters, forests, biodiversity, coastal/marine areas, freshwater, and global environmental issues (p. 348). The GEO 2003 indicators are designed to monitor environmental issues such as climate change, ozone depletion, deforestation, species loss, habitat loss, sustainable water use/sanitation, and international governance. The subcategories as well as the indicators of the RUD model are strategically configured to provide appropriate coverage of these concerns as they relate to the restoration of natural environment through urban re/development e.g. pollutants, domestic water, land cover, biodiversity, population/resources, reduction/efficiency, and transportation (refer to Appendix E).

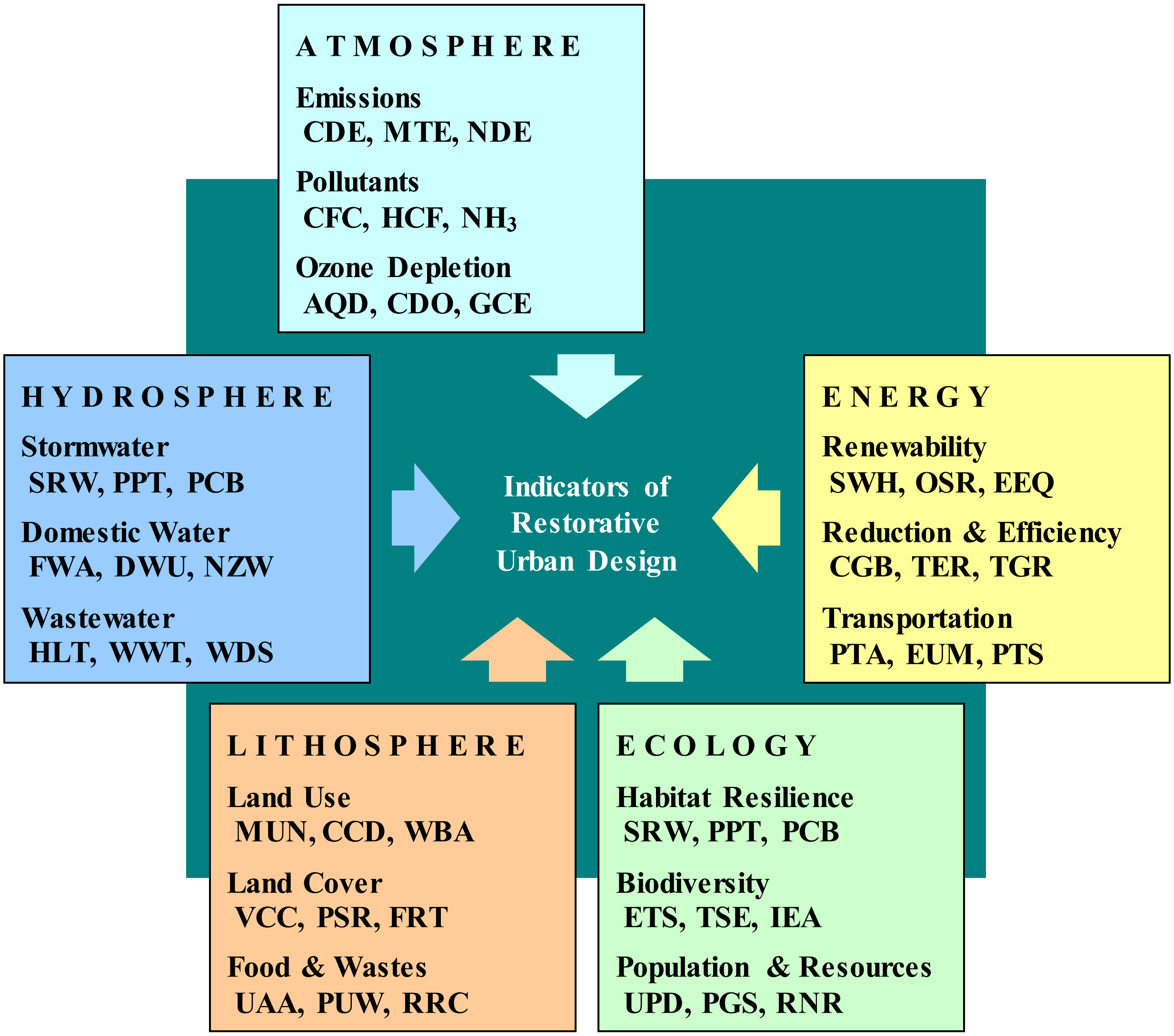
Desai (2010) compiles the goals and principles for globally sustainable urban design and planning, and calls for zero-sum carbon emissions, zero waste generation, sustainable transport, locally supplied sustainable materials, locally and sustainably grown food, sustainably cycled water, maintaining natural habitats and wildlife, nurturing culture and heritage, fostering equity and fair trade, and promoting health and happiness (Edwards, 2010, p. 87). The dimensions, subcategories, indicators, as well as the analyses of the Restorative Urban Design are all carefully aligned with a significant majority of these goals in order to accomplish the optimum level of mitigations toward the comprehensive restoration of the natural environment through urban re/development. The RUD model places primary emphasis on key environmental performance indicators perceived to be most urgent and critical to the global regeneration and rehabilitation (refer to Appendix E).

d) Synthesis of Environmental Restoration Indicators

During the review process, every single indicator has been carefully considered in terms of its relevance to the restoration of the natural environment as the over-arching priority. In so doing it is assumed that benefits will accrue to people and other species. Each indicator has been assigned a specific score – ranging from the lowest score of 1 to the highest score of 5 – depending on its restorative significance relative to the rest of the indicators. While the repetition and recurrence of certain environmental factors have been signs of how central these factors are within the sustainability literature, the synthesis of environmental restoration indicators has been concentrated on defining attributes of the functional or natural conditions to be restored. After the preceding reviews on the existing environmental performance rating systems and assessment indices, the indicators most closely related to the restoration of the natural environment were compiled into an inclusive list (refer to Appendix D).

The inclusive list of indicators presented in Appendix D has been further refined, regrouped and consolidated into a shorter and more concise list for restorative research purposes. The final selection of restorative indicators in the RUD model has been made by the author based on the relative importance of each issue. At the end, the RUD model is comprised of five primary dimensions as Atmosphere, Hydrosphere, Lithosphere, Ecology and Energy. Each dimension contains three subcategories, which are made up of several indicators specific to that subcategory (see Figure 3.3).

Figure 3.3 The RUD model is a synthesis of forty-five indicators in five primary dimensions



i. Atmosphere

EMISSIONS: In the atmospheric dimension, the subcategory of emissions represents one of the most critical areas of human impacts on the natural environment as related to comprehensive restoration, and needs to be mitigated appropriately. The RUD model primarily considers a specific set of indicators in order to determine the generation of greenhouse gases within a study area. The indicators in this subcategory include: 1) CO_2, 2) CH_4, and 3) NO_2 emissions.

POLLUTANTS: Another important set of atmospheric indicators are grouped under this category, which is an estimate of anthropogenic pollutants including: 1) CFC, 2) HCFC, and 3) NH_3 emissions.

OZONE DEPLETION is a critical global problem that can effectively be targeted by local design measures, indicators, which include: 1) number of days attention levels defined by law are exceeded, 2) CO_2 emissions per capita, and 3) Global Climate Equivalent (GCeq) = total greenhouse gases (CO_2, CH_4, N_2O and CFCs).

ii. Hydrosphere

STORMWATER is one of the most significant aspects of the natural water cycle. The restorative indicators of stormwater assessment include: 1) rainwater harvesting, 2) mitigation of surface runoff using permeable paving and percolation trenches, and 3) mitigation of rainwater outflow using retaining ponds and flood control basins.

DOMESTIC WATER is another fundamental component in the water cycle, which is monitored as: 1) freshwater availability; 2) domestic water distributed for use and services, and 3) net-zero water.

WASTEWATER is another major subcategory of water cycle in urban areas, which is primarily monitored for: 1) load reduction using high-level treatment, 2) wastewater treatment rate, and 3) waste discharge into water resources.

iii. Lithosphere

LAND USE subcategory indicators identify and monitor: 1) mixed-use neighborhood, 2) compact contiguous development, and 3) walkability to daily uses, facilities, amenities.

LAND COVER monitors: 1) vegetation cover change, 2) pervious/impervious surface ratio, as well as 3) forestation rate.

FOOD & WASTES are monitored by the following indicators: 1) urban agricultural area, 2) production of urban waste, and 3) all reused, recycled and composted materials.

iv. Ecology

HABITAT RESILIENCE monitors: 1) protection of open space, ecosystem, habitat, wetland, and water bodies, 2) restoration of site ecology (i.e. flora and fauna, perennial and woody host plants), and 3) habitat defragmentation and buffers (maintaining functional habitats for pollinators, songbirds, raptors, and other wildlife).

BIODIVERSITY subcategory focuses on: 1) protection of endangered and threatened species, 2) tracking species extinctions, and 3) participation in international environmental agreements.

POPULATION & RESOURCES indicators measure: 1) urban population density, 2) area of public green space per capita, and 3) regeneration of natural resources (open space).

v. Energy

RENEWABILITY indicators analyze: 1) solar, wind, hydro and geothermal energy production, 2) on-site renewable energy, and 3) energy equivalent (Eeq) per inhabitant per year.

REDUCTION & EFFICIENCY subcategory contains indicators that monitor: 1) percentage of certified green buildings, 2) total electricity consumption reduction, and 3) total gas consumption reduction.

TRANSPORTATION indicators provide a measure of: 1) public transport adjacency, 2) urban mobility indicator – Enforced UMeq, and 3) number of public transport stops.

B. Restorative Dimensions & Indicators

The indicators of environmental restoration identified in the preceding sections can be further developed into quantifiable indicator to be used in the scenario-comparison process of the RUD model. The measurement and analysis of each indicator is closely aligned with the intended evaluation and optimization of urban impacts on natural environment so that the proposed mitigations work to facilitate restoration. The following is an outline of indicators to be analyzed in each dimension of the RUD model.

1. Atmosphere

1) EMISSIONS (AEM): AEM-CDE (Annual anthropogenic CO_2 emissions per hectare) (tons/ha/yr); AEM-MTE (Annual anthropogenic CH_4 emissions per hectare) (tons/ha/yr); AEM-NDE (Annual anthropogenic NO2 emissions per hectare) (tons/ha/yr)

2) POLLUTANTS (APL): APL-CFC (Annual anthropogenic CFC emissions per hectare) (tons/ha/yr); APL-HCF (Annual anthropogenic HCFC emissions per hectare) (tons/ha/yr); APL-NH_3 (Annual anthropogenic NH_3 emissions per hectare) (tons/ha/yr)

3) OZONE DEPLETION (AOD): AOD-AQD (Number of days attention levels defined by law are exceeded) (NAAQS days/yr); AOD-CDO (CO_2 per capita) (tons/capita/yr); AOD-GCE (Global Climate Equivalent) (tons/ha/yr)

2. Hydrosphere

1) STORMWATER (HSW): HSW-SRW (Rainwater harvesting) (tons/ha/yr); HSW-PPT (Mitigation of surface water runoff) （tons/ha/yr）; HSW-PCB (Mitigation of rainwater outflow) (tons/ha/yr）

2) DOMESTIC WATER (HDW): HDW-FWA (Freshwater availability) （tons/ha/yr); HDW-DWU (Domestic water distribution) (tons/ha/yr）; HDW-NZW (Net-zero water) （tons/ha/yr）

3) WASTEWATER (HWW): HWW-HLT (Load reduction using high-level treatment) (tons/ha/yr）; HWW-WWT (Wastewater treatment rate) （tons/ha/yr）; HWW-WDS (Waste discharge into water sources) (tons/ha/yr)

3. Lithosphere

1) LAND USE (LLU): LLU-MUN (Mixed-use neighborhood) (#uses/ha); LLU-CCD (Compact contiguous development) (m^2/ha); LLU-WBA (Walkability and bikeability to daily-uses, facilities, amenities) (< 400m)

2) LAND COVER (LLC): LLC-VCC (Vegetation cover change) (%); LLC-PSR (Pervious/impervious surface ratio) (%); LLC-FRT (Forestation Rate) (%)

3) FOOD & WASTES (LFW): LFW-UAA (Urban agriculture) (tons/ha/yr); LFW-PUW (Production of urban wastes) (tons/ha/yr); LFW-RRC (All reused, recycled and composted materials) (tons/ha/yr)

4. Ecology

1) HABITAT RESILIENCE (EHR): EHR-PRO (Protection of open space, ecosystem, habitat, wetland, water bodies) (ha); EHR-RSE (Restoration of site ecology, flora and fauna) (ha); EHR-HDB (Habitat defragmentation and buffers) (ha)

2) BIODIVERSITY (EBD): EBD-ETS (Protection of endangered and threatened species) (#/ha); EBD-TSE (Tracking species extinctions) (#/ha); EBD-IEA (Participation in international environmental agreements) (#)

3) POPULATION & RESOURCES (EPR): EPR-UPD (Urban population density) (#/ha); EPR-PGS (Area of public green space per capita) (m^2/capita); EPR-RNR (Regeneration of natural resources) (ha)

5. Energy

1) RENEWABILITY (ERN): ERN-SWH (Solar, wind, hydro and geothermal energy production) (%); ERN-OSR (Onsite renewable energy) (%); ERN-EEQ (Energy equivalent (Eeq) in TOE–tons of oil equivalent) (tons/capita/yr)

2) REDUCTION & EFFICIENCY (ERE): ERE-CGB (Percentage of certified green buildings) (%); ERE-TER (Total electricity consumption reduction) (%); ERE-TGR (Total gas consumption reduction) (%)

3) TRANSPORTATION (ETP): ETP-PTA (Public transport adjacency) (< 1000m); ETP-EUM (Urban mobility indicator – EUMeq) (pass-km/capita/yr); ETP-PTS (Number of public transport stops) (#/ha)

C. Measurements & Analyses

The restorative research evaluates the key environmental impacts of urban areas by using atmospheric, hydrospheric, lithospheric, ecology and energy indicators related to quality of air, water, soil, land use, land cover, as well as population, consumption, and wastes. Actual data for these indicators are used to quantitatively estimate four re/development scenarios. The first two establish the natural, historic, and present conditions for a given location, which are then used to help estimate the future scenarios i.e. a status quo trajectory and a restorative projection.

1. Measurements & Data

The RUD model primarily relies on simple numerical as well as more complex geospatial data offered by free access, non-classified, public sources online such as U.S. Census, Environmental Protection Agency, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, National Atlas, Geo-Data.gov, data.gov, esri.com, and so on. There may occasionally be a need for obtaining more specialized data from premier data sources and premium or subscription data providers, but for the most part the data accessible in public domains are reasonably satisfactory. Depending on the location of the study area, it is possible to run into breaks and gaps in the coverage of publicly available data, in which case statistical estimations may be utilized.

Similarly, the geospatial data for any application of RUD model within a specific urban study area does not normally require primary data collection such as field measurements or verification although such data would be quite valuable if collected. Typically, the secondary data available from publicly accessible sources is sufficient for the purposes of most analyses in the model (IEA, 1995; TLGDB, 2001; GEO4, 2007; TLGDB, 2009; UNEP, 2011; EPA, 2012).

The atmospheric data such as CO_2, CH_4, N_2O, CFC, HCFC, NH_3 emissions (tons/ha/yr) as well as historic data on number of days attention levels defined by law exceeded (NAAQS days/yr) are available at [http://www.epa.state.il.us/air/emissions-trends.html] and [http://www.airnow.gov/index.cfm?action=airnow.local_city&cityid=50].

The local hydrological data such as rainfall, precipitation, surface water runoff, and rainwater outflow (tons/ha/yr) are available from [http://waterdata.usgs.gov/il/nwis/sw]. Freshwater availability is virtually a non-issue in cities such as Chicago due to the presence of Lake Michigan [http://www.epa.state.il.us/water/surface-water/lake-michigan-mon.html]. The data on freshwater availability, domestic water distribution, and net-zero water (tons/yr) are available from [http://waterdata.usgs.gov/il/nwis/wu]. Load reduction strategies using high-level treatment are site specific and would have to be investigated separately.

Land use data is contained in the relevant base maps (RUD – Parcels, 2013), which can be used to calculate development compactness and contiguity. Walkability and bikeability to daily-uses, facilities, and amenities is calculated using proximity tool (buffer) in existing GIS data. Calculations on percent change in pervious/impervious surface ratio or vegetation cover are based on data from [http://www.isgs.uiuc.edu/nsdihome/webdocs/ landcover/index.html]. GOTO

2040 (2010) provides planning information on urban agriculture. Urban wastes are well-documented [http://www.epa.gov/epawaste/nonhaz/municipal /index.htm] and some of the locally reused, recycled and composted materials are recorded (RUD – Recycling, 2013).

The ecological data on protection of open spaces, ecosystems, habitats, wetlands, and water bodies comes from [http://data. cityofchicago.org]. Protection of endangered or threatened species is tracked by several federal and state agencies including [http://www.fws.gov/midwest /endangered/lists/illinois-cty.html]. Demographic statistics for the study area are available from the U.S. Census [http://www.census.gov] and American Community Survey [http://www.census. gov/acs/www] and can be used to calculate population density and historic trends.

GIS Data on energy indicators are assembled from a variety of sources. The data on percentage of certified green buildings is obtained from U.S. Green Building Council, LEED [http://www.usgbc-illinois.org]. Percentage of solar, wind, hydro and geothermal energy production requires site specific investigation, just as onsite renewable energy generation does. Energy equivalent in TOE (tons of oil equivalent) per capita per year is calculated by applying a specific formula using GIS data.

All data to be used in the restorative research, regardless of their type, source or origin, is converted into metric units system prior to any analyses. All results are to be expressed in the most appropriate form of metric units for the specific subcategory.

2. Scenario-Comparison Process

The RUD model relies essentially on a scenario-comparison process that has been inspired by a fusion of urban growth scenario modeling and simulations (Campagna, 2000), and ecological restoration modeling techniques (Urban, 2006). Following advances in enabling computational technologies, complex urban growth scenario models are now being developed for estimating and analyzing different future re/development possibilities for the urbanized areas. Various techniques of urban growth analysis, modeling, and forecasting focus on developing viable indicators to describe and optimize sustainable urban growth patterns. 3D Agent-Based Models (ABM), Cellular Automata (CA) (Leao et al., 2005), SLEUTH-CA (Oguz et al., 2007), Multi-Criteria Evaluation CA (MCE-CA), Logistic-CA, Artificial Neural Network CA (ANN-CA), and Decision-Tree CA are among the most common modeling applications and simulation technologies (Cheng, 2003; Yang & Lo, 2003; Song & Knaap, 2004; Mani et al., 2005; Al-Kheder, 2006; Lemp et al., 2008; Wang & Mountrakis, 2011).

Urban growth scenario models and simulations often include a range of quantitative dimensions in order to represent real world phenomena (Campagna, 2000). Mani et al. (2005) elaborates on the relevance and significance of modeling urban sustainability indicators using a series of framework concepts and an integrated model in order to "alleviate current problems, keeping in mind the requirements of future generations" (p. 156). Mani et al. (2005) identifies the pressing need for timely advancement of integrated model-simulation systems to enable decision- and policy-making support. They propose a model framework for human-settlement sustainability assessment and forecasting that can be adopted and applied for tackling a diverse set of real-world problems.

The Composite Sustainable Development Index (CSDI) presents another example which focuses on the sustainability of select social, economic, and environmental dimensions for a given urban area through consecutive time periods (Petrosyan, 2010, p. 9). The CSDI model quantifies the economic, social, and environmental performance data in associated indicators of sustainability (including water and energy consumption, wastes, and emissions), and composes them into an index rating of overall performance (Krajnc & Glavic, 2004). The CSDI quantitative modeling technique, then, is used in estimating, evaluating, and optimizing other potential scenarios for sustainable re/developments within the urban area of study (Petrosyan, 2010, p. 12).

One of the largest implementations of sustainable growth modeling and simulations is the EU research project, Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability (PROPOLIS). The main objective of this project is to assess the long-term effects of sustainable urban re/development strategies in seven major European urban regions: Bilbao (SPA), Brussels (BEL), Dortmund (DEU), Helsinki (FIN), Inverness (SCO), Naples (ITA) and Vicenza (ITA). A large number of policies are tested with the growth modeling and scenario evaluation systems in these urban regions, where the long term policies are investigated for their costs and benefits. The PROPOLIS project is reported to integrate a comprehensive framework of land use regulation, transport, infrastructure, as well as environmental indicators. "Thirty-five key indicators were defined to measure the three dimensions of sustainability, such as air pollution, consumption of natural resources, quality of open space, population exposure to air pollution and noise, equity and opportunities and economic benefits from transport and land use" (Spiekermann & Wegener, 2003, p. 47).

Ecological restoration models, on the other hand, focus on defining a baseline design state, to the current conditions in a given areas are managed and eventually transformed. Five distinct purposes behind ecological restoration models, as identified by Urban (2006), are to: serve as an integrating framework; explore the implications of various management decisions, or alternate scenarios; design sampling or monitoring schemes; extrapolate understanding across spatial and temporal scales; and provide forecasts or predictions (p. 238).

Urban (2006) also explains few primary kinds of model applications used in ecological restoration i.e. heuristic, statistical (phenomenological), and simulator models. Heuristic models are often schematic diagrams and conceptual models that illustrate the general working understanding of system behavior, typically not formalized or implemented as working models. Statistical (phenomenological) models can take various forms of regressions (e.g. island biogeography), multivariate models (e.g. ordinations), which summarize complicated, multidimensional ecological relationships. Simulator models are implemented as numerical algorithms, solved by simulation (e.g. forest gap models, water quality, hydrology models) (p. 239). The ecological restoration models are typically built upon indicator categories where measurable variables in each dimension are monitored. The restorative goal is to move a degraded ecology toward a set of desired "natural" or reference conditions through careful administration and management of interventions (Urban, 2006, p. 240). The scenario-comparison process advocated by the RUD model is conceived to adopt the most suitable modeling method depending on the kind of analyses needed to be conducted. The restorative modeling can also be a combination of heuristic, statistical (phenomenological), and/or simulation-based depending on the complexity of analyses.

The scenario-comparison process adopted by the RUD model combines the essence of urban growth modeling and ecological restoration modeling techniques around building and refining scenarios. This synthesis is a blending of many methods used in the analysis of the existing and/or proposed urban re/developments. Similar to the urban growth scenario modeling techniques noted by multiple authors (Cheng, 2003; Yang & Lo, 2003; Mani et al., 2005; Al-Kheder, 2006; Oguz et al., 2007; Lemp et al., 2008; Wang & Mountrakis, 2011), the RUD model establishes a set of indicators in order to represent the present conditions and forecast possible future conditions of urban re/developments. At the same time, similar to the ecological restoration modeling techniques discussed earlier (Urban, 2006; Clewell & Aronson, 2007), the singular set of indicators established by the RUD model is used to define a baseline scenario, which the urban re/development conditions of the future projection scenario alternatives are approximated through reiterative evaluation and optimization, as exemplified later in Chapter 4.

A focus of this dissertation is to illustrate that such a synthesis is not only urgently necessary but also – at least conceptually – feasible. The process of scenario-comparison is one of the common practices used in both fields i.e. urban growth modeling and ecological restoration. It relies on collecting necessary information on the existing conditions, generating new data through analyses, generating alternative scenarios toward optimum future conditions (Nassauer & Corry, 2004, p. 344).

> While all prospective scenarios depict futures that may not be predictable, the specific type, normative scenarios, has the goal of generating desirable futures that are plausibly but not necessarily assuredly achievable. This is different from projective scenarios, which extend quantified trends of past change, prospective scenarios that focus on understanding processes that could lead to surprising outcomes, or prospective scenarios that anticipate undesirable frightening future states and model the probability of their occurrence.…Normative scenarios make an additional, different niche for science in the scenario development process. (Nassauer & Corry, 2004, p. 345)

In regards to scenario building and comparing, Steinitz et al. (2005) observes that no single vision of the future can be certain and that it is preferable to consider several alternatives encompassing a range of possibilities for the future. Each alternative scenario takes into account several variations in design assumptions, and hence, arrives at different results that could be representing the possible future of the study area more reliably than the others (p. 94).

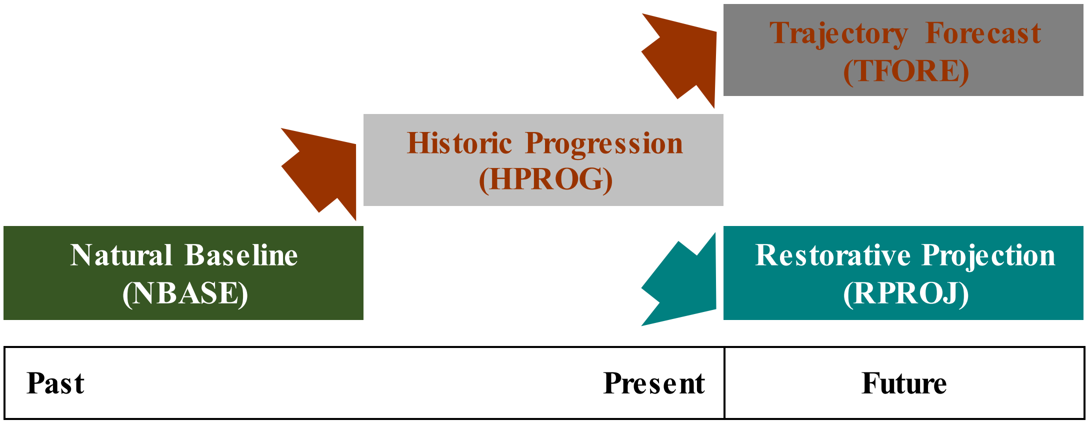
In a similar manner, Urban (2006) emphasizes the evaluation of alternative scenarios within the framework of ecological restoration models as follows:

> Evaluating alternative scenarios (effects forecasting) is a straightforward extension of this framework, requiring only that the simulator (or other model) provide output in terms of the appropriate indicator variables (e.g. in terms of compositional similarity to the reference or initial conditions). Scenarios would be evaluated in much the same way as long-term monitoring data – tempered, of course, by a consideration of uncertainty inherent in model of casts. (p. 250)

The Restorative Research fully acknowledges the fact that the current human-made environment is the direct cumulative result of the choices and decisions made in the past, and that the future is being written by the choices and decisions being made today. Hence, the way the urban re/development choices and decisions are made is critical to the process of transforming their impacts on the natural environment.

Restoring the future conditions to a set of baseline design conditions is not only highly desirable but also practically feasible. At its core, the RUD model is founded upon building and evaluating four primary scenarios, namely: Natural Baseline (NBASE), Historic Progression (HPROG), Trajectory Forecast (TFORE), and Restorative Projection (RPROJ) (see Figure 3.4). The figure schematically illustrates how these four scenarios build on one another in a progressive manner, and how the determining and achieving restorative conditions need to greatly influence the course of that progression. The mitigations to be addressed onsite and/or offsite by the RUD model are basically the difference between the TFORE and RPROJ scenario conditions. The model proposes to evaluate several alternative restorative scenarios – similar to the development of ecological restoration scenarios – during the optimization process, where different alternatives can be analyzed, adopted, further refined, or abandoned depending on their approximation to the baseline conditions as discussed in Section 3.D.

Figure 3.4 Four primary scenarios are built to achieve restorative results in the RUD model



These four primary scenarios quantitatively represent the four interdependent sets of conditions that the RUD model uses in order to achieve the most environmentally restorative scenario for the urban re/developments. First, a natural or functional set of baseline design conditions are established (Natural Baseline – NBASE), which propose a set of ideal or preferred ecosystems, soils, and vegetation criteria – appropriate to the geographic location and climate characteristics of a given study area – to be targeted by restorative urban redevelopments.

Second, the present conditions of the site in focus are identified together with a few key reference points in the recent past (Historic Progression – HPROG), which are used for the future projections. Third, assuming that there would be no significant changes in the historical progression of the past trends and current conditions, a projection of future conditions for urban re/developments are estimated (Trajectory Forecast – TFORE), which often becomes the worst case scenario for restorative purposes. And finally, a single restorative scenario is optimized through a reiterative refinement process (Restorative Projection – RPROJ).

The overall goal of restorative scenario-comparison is to arrive at an urban re/development scheme where the human impacts on the natural environment are mitigated for – not just some random amount like 10, 20, or 30 percent as is the case in many of today's sustainable urban design and planning methods – but for the entire amount of impacts estimated in relation to every indicator category. Especially through the application of offsite measures the full-scope of mitigations to address urban impacts becomes achievable within the timespan of the restorative study, which may be anywhere from two to four decades.

a) Natural Baseline (NBASE)

This scenario is the basis of design defined to represent the natural, ideal or desired conditions that are specific to the particular locality, geography, climate, and ecologic context often prior to industrial settlements and/or human disturbances. The baseline design conditions are established through either historical research or hypothetical assumptions to serve as a reference state for the purposes of the RUD model.

At the heart of this kind of scenario building lies the inherent question: what is the appropriate or "natural baseline"? How should "ideal conditions" be defined? The ecological restoration literature provides precedents for creating "natural" baselines or "pristine" reference states (Berger, 1985; Sauer & Andropogon Associates, 1998; Brown, 2003; SERI, 2004; Hall, 2005; Clewell & Aronson, 2007; Skabelund et al., 2008). Redman (1999) points out a common approach to determining a natural state for environmental decision-making as follows:

> First, there is no absolute when one refers to the natural state of the environment. Nature, herself, works continual change on every local environment through rhythmic cycles, long-term processes, and evolutionary change. Moreover, if that was not enough, humans have had a role in transforming virtually every environment and locale on this earth.…The second essential point for environmental decision-making [is] that.…a definition of an ideal, or best, environment is conditioned by human values and objectives. For many

> environmentalists the best environment is one that is ‘untouched by human hands,’ or in pristine condition. (p. 203)

The exact setting of natural or ideal conditions remains at the hands of the collaborative design or decision-making team that is initiating the restorative study. Well-reasoned, objective and realistic assumptions need to represent the state of natural environment (functional aspects and processes undisturbed by human interventions) that the mitigative efforts aim to reestablish. In the case of naturally degraded i.e. geographically and/or historically desert-like locations, a set of ideal or functional conditions may be targeted for reestablishing healthy, living, life-supporting, and sustainable conditions.

b) Historic Progression (HPROG)

This scenario represents the current conditions specific to the particular locality and context of the study area. The Historic Progression (HPROG) scenario aims to investigate the significant events and document the chronological progression of that specific urban settlement through time. Information on the initial date of establishment, the size of initial human population, the demographic makeup and mixture, as well as the significant environmental sources of livelihood are among the most basic and important facts to be explored.

The HPROG scenario requires a satisfactory level of intimate understanding of ecological interventions and environmental disturbances that happen through time as human settlement is established, grows, and expands – leading up to the present conditions. By its very nature, the discovery of past events and facts is a complex and difficult process, which gets even more complicated and cumbersome if the documentation is hard to reach or simply non-existent. Understanding the social, economic, cultural and political background is often helpful in pulling together the missing pieces of the puzzle. Under certain circumstances, the missing environmental information may be interpolated within the community, or referenced from adjacent communities of similar size and makeup where proper historic documentation is available to make these connections (Egan & Howell, 2005).

The HPROG scenario requires a fairly sophisticated level of documentation on the present ecological and environmental conditions. With the increased levels of record keeping in modern urban areas, it is increasingly easier to find factual data on all indicators of the restorative research. In cases where particular local information is unavailable the raw information from identical nearby locations may be applicable. In other instances, the regional, national, or international averages may be appropriately used.

While there are certainly many qualitative aspects to urban re/developments, the RUD model relies mostly on quantifiable information and data in order to carry out the types of optimization and projection analyses. The primary purpose behind investing the historic and existing conditions of a study area is not only to discover the extent and amount of historical change but also to prepare the foundation for forecasting the likely extent and amount of changes to be expected in the future.

c) Trajectory Forecast (TFORE)

The Trajectory Forecast (TFORE) scenario produces a representation of the future conditions for the study area, assuming that the historical urban growth rates, development and expansion patterns continue into the foreseeable future without significant changes. The process of forecasting a trajectory path builds on the establishment of historic and present conditions. The trajectory forecast may be determined using different methods, each of which may result in a slightly different projection depending on the underlying assumptions. At a minimum, key historic references in the past should be established and used to quantitatively extrapolate a linear, polynomial, or exponential regression in order to determine a reasonably possible future trajectory.

Today in the developed world where restorative research is becoming increasingly imperative, most urbanized areas closely monitor the growth and autonomously project the trajectory of their own human populations for various reasons. Scientifically researched and officially adopted population projections can be used as proxies to determine the TFORE scenario for restorative design purposes.

Once established, the TFORE scenario in the RUD model is used as a constant reference in the evaluation and optimization of restorative projection alternatives. The trajectory forecast scenario by itself is typically not a desirable end-product but a starting point for environmentally restorative mitigations. While the amount of mitigative measures may change with the amount of environmental impacts estimated by the trajectory forecast the purpose of evaluating and optimizing a singular restorative projection is to compare the future conditions to the Natural Baseline (NBASE) scenario as closely as possible through the next and final stage of the RUD model (refer to Figure 3.4).

d) Restorative Projection (RPROJ)

The evaluation and optimization of a single Restorative Projection (RPROJ) scenario, which guides the planning and design of environmentally restorative urban re/developments, is the ultimate goal of the RUD model. As discussed in the preceding sections, specific sets of natural, historic, existing and forecasted environmental design conditions are used to estimate the extent and amount of corrective projections proposed by the restorative research. The RUD model requires the analysis, evaluation, and optimization of future conditions in all indicator categories.

Once the natural baseline and trajectory forecast conditions are determined, the RPROJ scenario is reiteratively optimized primarily using onsite design assumptions and offsite mitigation measures where the estimated impacts are neutralized and/or reversed. The reiterative optimization process starts with determining the current amounts of onsite mitigations against environmental impacts on each indicator, as made possible by existing improvements on the re/development of the study area.

The current values are not the final values as the types and amounts of onsite installations are subject to change. Through incremental adjustment of various design assumptions for impact mitigations a number of different scenario alternatives are established, evaluated, tested, adopted, or abandoned for restorative urban re/development. The analysis, comparison and refinement procedure is repeated for each indicator until the best possible final scenario alternative for environmental restoration purposes is attained.

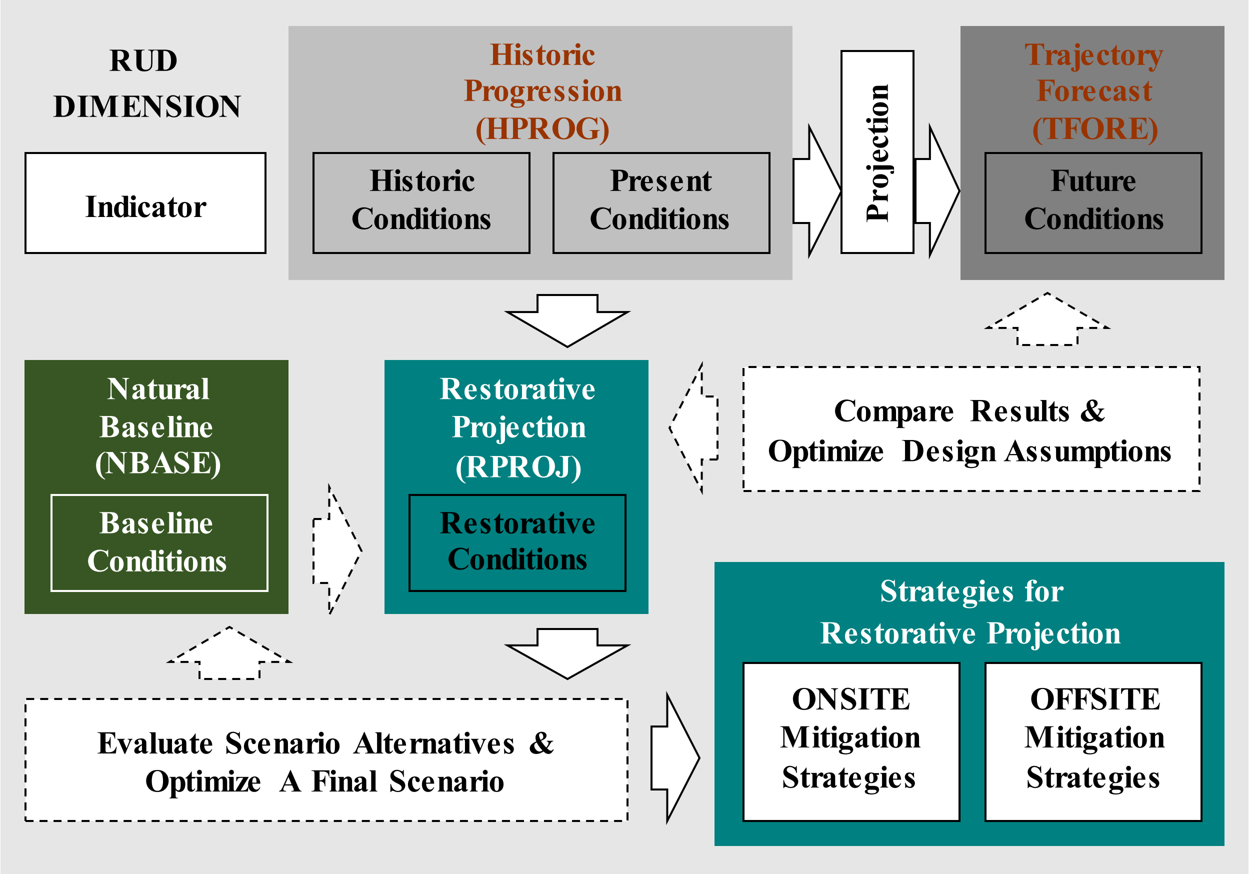
3. Sequence of Comparisons & Other Analyses

For all five dimensions of the RUD model, scenario-based comparisons and analyses start with the determination of data on Natural Baseline (NBASE) scenario, which is used to represent the baseline conditions that are based either on pristine (or natural) – preceding human settlements or industrial interventions – or ideal functional conditions for the study area. If any of the RUD indicators are simply not applicable to a particular study area, they should be either left out of estimations or simply assumed to be within normal range of conditions as appropriate for restorative research purposes.

The next step is the collection of historic and present data representing the human impacts for the same set of indicators (see Figure 3.5). For the historic conditions in Historic

Progression (HPROG) scenario a minimum of two or three reference states in the past are required so that a future projection can be constructed. Theoretically, the greater the number of historic reference states are, the more accurate future projections would be. The proximity or location of these reference states can be flexible, however, they are expected to represent the recent historic conditions in the most reliable manner possible. And, as for the present conditions, the collected data closest to the analysis date is considered present data, which ideally should not be older than a year. Historic reference states to be established for progression are typically either third type (same place, different time – where reference is available) or fourth type (different place, different time – where no information may be available) (Clewell & Aronson, 2007, p. 75).

Figure 3.5 Scenario-comparison is used to reiteratively refine the design assumptions



The Trajectory Forecast (TFORE) scenario may be estimated by a linear, logarithmic, exponential, polynomial or other types of regression analyses based on the data from historic and present conditions (see Figure 3.5). The calculated values from these analyses provide an estimation of future conditions that are used for the purposes of evaluating results and optimizing design assumptions.

The Restorative Projection (RPROJ) scenario may also be estimated by similar regression analyses using the data from baseline and present conditions. The differences between the baseline and the present conditions are targeted for minimization and offsets. The restorative conditions are determined by the level of minimization and offsets applied in this step.

Once the initial restorative conditions are estimated they are compared to both natural and future conditions through evaluation and optimization, which require introduction of various urban design strategies. The process of evaluating results and optimizing design assumptions can be repeated until the most effective combination of design strategies are achieved. At the end of this analysis, the ultimate goal is to approximate restorative conditions for baseline conditions. In many urban settings this may be best accomplished by minimizing human impacts on the environment through the use of both onsite and offsite mitigations.

a) Regression Analyses

The first two scenarios i.e. Natural Baseline (NBASE) and Historic Progression (HPROG) are used to estimate the third scenario i.e. Trajectory Forecast (TFORE) applying a reasonable method of future projection on the data (see Figure 3.5). The calculation of values for each indicator subcategory may involve quantitative forecasting methods such as regression analyses based on baseline, historic, and present conditions in order to establish the future conditions. From the projected conditions, the RUD model is used to evaluate and optimize the fourth scenario, Restorative Projection (RPROJ), which establishes the restorative goals of urban design and planning for re/development. As discussed in Chapter 4, linear and polynomial regression analyses were performed in the RUD Case Study as part of analyzing and determining the future conditions.

b) Descriptive Statistics & Bivariate Analyses

When there are gaps in the available data appropriate statistical methods can be applied to interpolate the lacking data. Descriptive statistics is employed in describing the central tendency and variance of each variable during regression analyses. Where there are gaps in the baseline, historic or present data a statistical method i.e. Maximum Likelihood Estimator (MLE) may be employed, which assumes normal (Gaussian) distribution with some unknown mean and variance. The mean and variance is estimated with MLE while only having some sample of overall population. MLE would accomplish this by taking the mean and variance as parameters and finding particular parametric values that make the observed results the most probable given the model. Bivariate analysis may be used in selecting the key variables of a regression.

Even though these computational techniques may be used more extensively in various portions of information modeling as part of the RUD model the case study contained in this dissertation employed descriptive statistics to summarize, analyze and evaluate the scenarios discussed in Chapter 4.

D. Evaluation & Optimization of Design Assumptions

One of the most critical segments of the restorative research is the evaluation of values for each indicator in the TFORE and RPROJ scenarios. Since the end goal of the RUD model is to produce a set of strategies for urban re/development the estimated values from these two scenarios are foundational in comparing, evaluating, and determining which aspects of the RPROJ scenario can be optimized further so that expected results approximate the NBASE scenario most closely.

The results from most indicator subcategories are expected to remain within the spectrum of viable restorative measures, however, they are almost certain to require a varying level of improvement in order to counterbalance the urban impacts. At this juncture, the restorative design measures – such as increased vegetation cover, green infrastructure, mass transportation, mixed-uses, or renewable resources – are assumed to mitigate the impacts onsite or offsite.

The important final step in the process is the optimization of design assumptions and reiterative revision of the RPROJ scenario. The initial evaluation results from the previous step of evaluation are expected to be continually refined until the most optimum restorative conditions – closest to the baseline conditions – are achieved.

1. Restoration of Nature within Urban Ecology

The strategies to be used in optimization of design assumptions can be found in a wide range of concepts that are in practice today, which focus on rejuvenation and refurbishment of natural ecologies within urban settings. Strategies most relevant to restoration can be found in Green Urbanism, Resilient Cities: EcoVillages, Eco-Cities, Living Buildings and Cities, and Regenerative Design principles.

The ultimate goal of restoring the natural cycles and balances within urban ecology would be to integrate all necessary and appropriate plants and animals, which can functionally coexist within a well-balanced urban community. Cycles of growth from birth to decay in such an urban ecology needs to be carefully considered to approximate the natural cycles.

Laurie (1979, p. 30) provides a good starting point for urban context and offers some of the general principles for design purposes: 1) exploit the full natural potential of the site, 2) conserve or develop diversity of habitat, 3) encourage a full range of organic life, 4) encourage the full cycle of growth from birth to decay, 5) develop, balanced self-sustaining communities, 6) control the system by management, 7) create maximum variety of opportunity for man and nature, 8) create a coherent landscape structure (site potential, habitat diversity, non-conflicting interests), and 9) design in four dimensions (extend into future).

2. Onsite Design Assumptions

One of the most critical strategies to strengthen natural cycles and balances on a given site is to increase vegetation cover, which provides restorative benefits at multiple levels including air, water, soil quality, biodiversity, biophilia, and potentially for fiber and/or food production. Trees, for instance, are naturally beneficial in conditioning the atmosphere (moisture, pollutants, production of oxygen, sequestration of excess carbon, etc.), improving soil properties (erosion control, moisture, nutrients, microorganisms, and drainage qualities, etc.), converting solar energy to biomass, producing fiber, biomass or food, improving habitat (providing shelter and shadow), regulating microclimate, and increasing aesthetic charm and serenity in their vicinity. Diverse, interacting plant and soil communities today are recognized as being very important in increasing ecosystem services in plenty of sources in ecology-based literature (Beck, 2013; Calkins, 2012; SSI, 2014).

Another crucial optimization strategy is responsible management of growth patterns for urban population and expansion, land use, transportation, infrastructure, food and energy generation measures, which can all be introduced and implemented at micro scales.

As discussed in length in Sections 2.a through 2.s in Chapter 2, other impact mitigation strategies include: capture and sequestration of undesirable emissions and pollutants; annual water budgeting and harvesting; purification, filtration, and ionization of local air, water, and soils; urban forestation, urban gardening, and urban agriculture; reduction of consumption; reuse and recycling of local resources; green infrastructure; climatically appropriate passive technologies; optimization of land uses and redevelopment (interconnectedness and compactness); reliance on regional knowledge, tradition, and materials; protection and rehabilitation of open space, farmland, grassland, and ecosystems; expanding biodiversity, vegetation cover, wildlife species and habitats; ecosystem restoration and integration in open lands, grasslands, watersheds, bioswales, wetlands; minimization of non-renewable consumption; reliance on local generation of renewable energies; management of resources and wastes; diversified modes of transportation (walkability, bicycle, streetcar, bus transit, light-rail, commuter, and heavy rail).

3. Offsite Mitigation Measures

There may be several reasons why certain human impacts may not be adequately addressed on a project site. In the likely – and often unavoidable – event of development impacts not being adequately addressed through measures implemented onsite, these impacts need to be mitigated offsite. Since the RUD model is designed to produce quantifiable results for each performance indicators the amount of restorative interventions beyond onsite strategies can be estimated. Arguably, the range and extent of planning and design measures to mitigate the major urban impacts on the natural environment cover a wide range of areas. Some of these measures are noted in Table 3.1 below.

Table 3.1 Following examples of mitigation measures can be used onsite as well as offsite

URBAN IMPACT	**MITIGATION MEASURES**
ATMOSPHERE	
Carbon Dioxide (CO_2)	Sequestration by vegetation cover Sequestration by industry
Methane (CH_4)	Methane to plastics Renewable power from methane
Nitrous Oxide (NO_2)	Mulching Drip irrigation practices
Chlorofluorocarbons (CFCs)	Prohibit use CFC recovery, recycle, and offsets

URBAN IMPACT (continued)	MITIGATION MEASURES (continued)
Hydrochlorofluorocarbons (HCFCs)	Prohibit use HCFC recovery and recycle HCFC offsets
Ammonia (NH3)	Transformation to nitrates by nitrite bacteria
HYDROSPHERE	
Harvesting	Onsite collection tanks Storage cisterns
Treatment	District wastewater treatment Bioswales Rain gardens Green roofs
Recycling	Net-zero water Retaining ponds Control basins
Percolation	Permeable paving Percolation trenches
Discharge	Release into water sources
LITHOSPHERE	
Neighborhood uses	Mixed uses, compactness, & contiguousness Infill re/developments Walkability & Bikeability
Production of food	Urban agriculture & gardening Community supported agriculture
Generation of waste	Reduce, reuse, recycle materials
ECOLOGY	
Open spaces, buffers, habitats	Protection of site ecology Flora and fauna
Ecosystems, wetlands, water bodies	Restoration of site ecology Flora and fauna

URBAN IMPACT (continued)	MITIGATION MEASURES (continued)
Endangered and threatened species	Protection International environmental agreements
Urban population	Reduction of density
Green spaces and natural resources	Regeneration of public land reserves Preservation of open spaces
ENERGY	
Renewable energy generation	Solar, wind, hydro, and geothermal
Energy efficiency	Certified green buildings
Consumption reduction	Electricity and gas
Urban mobility	Public transit adjacency Enforced UMeq (passenger kilometers) Number of stations

E. Application of Restorative Urban Design Model

The restorative model aims to evaluate the key environmental impacts of existing or planned urban areas under five primary dimensions i.e. atmosphere, hydrosphere, lithosphere, ecology and energy. Each dimension includes a series of indicators related to quality of air, water, soil, land use, land cover, as well as current and desired characteristics of population, mobility, resources, consumption and wastes in order to be used in the scenario-comparison process for restorative design of urban re/developments. Specific indicators are used to represent and estimate four re/development scenarios i.e. Natural Baseline (NBASE), Historic Progression (HPROG), Trajectory Forecast (TFORE), and Restorative Projection (RPROJ). The first two scenarios establish the natural (or ideal), historic, and present conditions for a given location, which are then used to help evaluate and optimize a restorative projection scenario for the future. During the evaluation and optimization process various restorative scenario alternatives are compared to Trajectory Forecast (TFORE) and, approximated to Natural Baseline (NBASE) scenario. The results are graphically visualized for the final design.

The restorative research at large is not specific to a location, but rather, it offers a body of indicators, measurements and analyses that could be applied at any specific location at any chosen scale of environmental restoration. As long as the principles of restorative design are adopted, the specific indicators of the restorative analyses may be customized to fit the requirements of any context, study area, population, or geophysical location. Then, the past and present conditions can be estimated, and projection scenarios can be optimized for restorative mitigations.

Ideally, the application of RUD model should be within urban areas that are large, populated, and diversified enough to be considered neighborhoods or districts. The study area is recommended to be more than a small cluster or campus of buildings and less than a section of a city or a region for managing complexity in calculations. It is preferable that there is a rich mixture of land use types, open spaces, and buildings in the area. The determination of the exact size and extent of RUD study area is flexible, and may depend on geographic features i.e. water bodies, land reserves, wildlife habitat boundaries, and on possible urban features – infrastructure or utility extents, or on jurisdictional features – city, county, state, or national boundaries. The following chapter illustrates the application of the restorative urban design model through a case study.

Chapter 4 - Case Study on A Restorative Indicator

As briefly discussed in the previous chapter, the location and size of the application area for the Restorative Urban Design (RUD) model can vary as long as the guiding principles of environmental restoration are followed. From a purely theoretical perspective, the larger the restoration area the better outcomes for the natural environment. The breadth and depth of applications in real-world situations are likely to be clouded by various political, social, cultural, and economic circumstance unique to each locality, however, those concerns are excluded from the restoration research for clarity.

The RUD model can theoretically be applied to any urban area of any population, size, density or demographic composition. While the actual size and locations of study areas are expected to be different, typically there are several research advantages to selecting a large neighborhood or a small township within a relatively well-developed metropolitan area. Studying these areas not only ensures the availability, reliability, and generalizability of relevant data and findings as inputs and outputs, but also contributes to the spread of knowledge, experience, and expertise for restorative efforts within the urbanized areas where most major impacts are concentrated.

The RUD Case Study focuses on a typical neighborhood (River North District) in a typical metropolitan city (Chicago, IL) in North America (the United States). It analyzes a single urban impact (anthropogenic CO_2 emissions) and applies the RUD model, producing alternative urban re/development scenarios toward achieving environmentally restorative results by 2040.

A. Focus on Anthropogenic CO_2 Emissions

The RUD Case Study focuses on illustrating the analyses, evaluation, optimization, and recommendation of a single indicator within the RUD model: AEM-CDE (Annual anthropogenic CO_2 emissions) (tons/yr) to be mitigated primarily through carbon storage and sequestration onsite as well as offsite. Among other measures, increasing tree and plant cover aims to accomplish multiple mitigation objectives simultaneously.

1. Significance of Mitigating Anthropogenic CO2 Emissions

The recent research and developments have certainly increased the depth and level of current understanding and awareness on many different kinds of human impacts on the natural environment. Many of these impacts, as summarized in Chapter 2, form the impetus behind the RUD model. The anthropogenic CO_2 emissions are particularly important for the restorative efforts, presenting perhaps one of the most urgent areas of attention.

Carbon dioxide is a naturally occurring gas that is fundamental in the cycles and balances of the natural environment. The earth's atmosphere, which enables the presence of life on the planet, relies on the regulating and warming effects of greenhouse gases, like carbon dioxide (CO_2), methane (CH_4), and nitrous dioxide (N_2O), in order to maintain conditions conducive to the health and longevity of living systems and organisms. McHarg (1969) explains:

> It is this carbon – central to life, emerging from methane, fixed in beds of ancient limestone, released by volcanism and by solution as CO_2 – which is used by plants again and again but is increasingly fixed in the oceanic foraminifera and lost to the system unless returned by volcanism. There is, however, a new element in the system – the enormous production of CO_2 as a byproduct of combustion – which has vastly increased the level of CO_2 with the result that ocean and atmosphere are not now in equilibrium. (p. 48)

Cited and referenced widely throughout the literature on CO_2 emissions, WCED (1987) records that the pre-industrial concentration was about 280 ppm (parts per million) in air by volume (Friedman, 2008). This concentration is reported to have reached about 340 ppm in 1980, recorded to have exceeded 400 ppm in November 2011, and is projected to reach 560 ppm between the middle and the end of the next century (Orr, 2006; Friedman, 2008; Van Ypersele, 2010, p. 87). The doubling of pre-industrial concentration level is considered to be a threshold for irreversible environmental changes. Beyond 560 ppm, the greenhouse effect is expected to have trapped enough excessive solar radiation near the ground to rapidly warm the globe, and permanently change the climate to be much less hospitable to life (WCED, 1987, p. 175; Homer-Dixon & Garrison, 2009, p. 16). Increased levels of atmospheric carbon dioxide are also expected to make the seas and oceans increasingly more acidic, effecting the rate of calcification, and reducing their ability to absorb more carbon dioxide (Schiermeier, 2007, p. 580).

Even though atmospheric greenhouse gases are natural and integral to the health and longevity of the earth's biosphere the unnatural or unbalanced increase of atmospheric greenhouse gases is posing an increasing threat to the cycles and balances of the natural environment. EPA (2009) explains:

> Although the direct greenhouse gases CO_2, CH_4, and N_2O occur naturally in the atmosphere, human activities have changed their atmospheric concentrations. From the pre-industrial era (i.e., ending about 1750) to 2005, concentrations of these greenhouse gases have increased globally by 36, 148, and 18 percent, respectively (IPCC 2007). (p. 8)

Analyzing the anthropogenic emissions EPA (2009) records that five major fuel consuming sectors contribute to CO_2 emissions: electricity generation (42%), transportation (33%), industrial (14%), residential (6%), and commercial (4%). The report further notes significant share of greenhouse gas emissions in major sectors as follows:

> When emissions from electricity are distributed among these sectors, industry accounts for the largest share of U.S. greenhouse gas emissions [30%] in 2007. Emissions from the residential and commercial sectors also increase substantially when emissions from electricity are included, due to their relatively large share of electricity consumption (e.g., lighting, appliances, etc.). Transportation activities remain the second largest contributor to total U.S. emissions [28%]. In all sectors except agriculture, CO_2 accounts for more than 80 percent of greenhouse gas emissions, primarily from the combustion of fossil fuels. (p. 20)

UNEP (2002) points out that recent human impacts on the atmosphere "have been enormous, with the anthropogenic emissions a prime cause of environmental problems. Emissions of almost all greenhouse gases continue to rise" (p. 298). The related literature outlining the greenhouse emissions (McKibben, 1989; Orr, 1994; Brown, 2003; OECD, 2003; Orr, 2006; IPCC, 2007; Hansen, 2007 May; Makhijani, 2007; Friedman, 2008; Girardet, 2008; EPA, 2009; Hansen, 2009; Desai, 2010; Van Ypersele, 2010; Brown, 2011; Architecture 2030 Challenge, 2014) suggests much has to be done in the way of reducing and/or mitigating emissions from primary sources such as agriculture, transportation, and manufacturing industries. However, the sustainable urban design and planning efforts focused on this study are related exclusively to the configuration and operation of urban environments (Girardet, 2008; Galatowitsch, 2009).

2. Importance of Restorative Design & Re/development

The neutralization of anthropogenic CO_2 emissions at a global scale involves a multitude of corrections and mitigations across a range of industries and operations where carbon-based fossil fuels are utilized. The greatest sources include contributors such as agriculture, electricity generation, commercial freight and transportation, private transportation, heating and cooling of buildings, and so on (EPA, 2009; Desai, 2010). Perhaps one of the most significant factors predicating the practices in the marketplace are the laws and regulations, codes and requirements, rules and standards associated with environmental performance of these industries and human-made systems. It can be observed that many industrial standards, zoning regulations, and building code requirements are dating back to earlier centuries when environmental ignorance was relatively more affordable, but arguably not geared up to perform at par with the current urgencies.

Since the sources of major environmental impacts on nature can be traced back to the human-made activities and environments, the majority of solutions also lie in the design and re/development patterns of the urbanized areas. Prominent sustainable urban design principles and strategies discussed in Chapter 2, including New Urbanism, Resilient Cities, Sustainable Communities, Living Cities, BREEAM, LEED-ND, and CASBEE-UDe, place special emphasis on the reduction and/or mitigation of significant greenhouse emissions among other impacts they mitigate. For instance, Calthorpe (2011) lays out "The 12% Challenge" for urbanism in the age of climate change as follows:

> If we are to arrest climate change at about 2ºC, developed countries must reduce carbon [emissions by] 80% from 1990 levels by 2050. To achieve this each person in 2050 must on average emit only 12% of their current rate. (p. 21)

Urban design and planning cannot deliver all the necessary mitigations, however, it can contribute significantly. Calthorpe (2011) estimates that in order to reach reduction of current emissions down to 12% of where they are today (so that the global temperature increase does not exceed 2ºC), 10 gigatons of carbon needs to be taken out of the U.S. economy by 2050:

> …Cutting the total to just 2.5 gigatons total greenhouse gas emissions. Of that amount, urbanism plus efficiency in cars and buildings can deliver over 4 gigatons of savings. The other part involves integrating green technology and renewable sources of energy within an urban future. (p. 37)

In the race to reduce the anthropogenic CO_2 emissions so drastically in such a short period of time, significant changes need to take place in how the urban areas are laid out, configured, and connected to function through the natural landscape. The sustainable design and planning principles and strategies behind current transformation efforts concentrate on the mobility of people, goods, and services since fossil fuels from transportation make up an important part of the emissions. They aim to provide increased connectivity while encouraging multimodal transportation networks such as walking, biking, and public transit options (Rudlin & Falk, 1999; Beatley, 2000; Calthorpe & Fulton, 2001; Farr, 2008; ILBI, 2010; LEED-ND, 2009; Newman et al., 2009; Beatley, 2011; Calthorpe, 2011; Louv, 2012). Economic transformations based on carbon accounting of offsets, taxation, and incentives are also possible (Galatowitsch, 2009).

The vision and intent behind current sustainable urban re/development efforts are to achieve more compact, denser, walkable, bikeable, mixed-use neighborhoods that are less dependent on automobiles and better connected with mass transportation modes, which are designed not only to reduce generation of CO_2 emissions but also to conserve energy and resources. Reliance on the local generation of renewable resources for materials, food, and energy is similarly conceived not only to reduce transportation impacts but also to increase the efficiency of tapping into renewable resources closer to where the demands are. The efficient design of human-made systems at the scale of buildings, neighborhoods, as well as cities have the unparalleled potential to make significant changes in the amount of carbon dioxide generated annually (Rudlin & Falk, 1999; Glaeser et al., 2008). Furthermore, the integration of new forests, green areas and systems into the fabric of urban areas result in further mitigation, sequestration and storage of the atmospheric carbon dioxide excesses (Rowntree & Nowak, 1991; McPherson, Nowak & Rowntree, 1994; Nowak & Crane, 2002).

a) What Is Being Done To Reduce & Mitigate CO_2 Emissions

In order to mitigate anthropogenic CO_2 emissions, the IPCC (2007) strongly encourages governmental incentives for immediate mitigation action and reduction of global greenhouse gas emissions via international cooperation (p. 18). In most of the developed countries, there is a wide range of national, regional, and local urban re/development efforts to reduce emissions by passing new laws, streamlining industry standards, and establishing planning and design initiatives to improve the performance of urban environments. Yet, the current legislation and regulation efforts are clearly not at par with the depth and breadth of the problems (Cairns, 2006).

Over the last few decades, a range of environmental performance assessment frameworks and green design guidelines have been developed around the world. Most notable ones are

AQUA (BRA), BREEAM (UK), CASBEE (JPN), Estidama Pearl Rating System (UAE), Green Globes (USA & CAN), Green Star (AUS & NZL), GRIHA (IND), HQE (FRA), ITACA (ITA), LEED and Sustainable Sites Initiative (USA), Living Building Challenge (CAN), Passiv Haus (DEU) and VERDE (SPA). Some of these rating systems are discussed in greater detail in Chapter 2. Almost all of these systems are geared toward improving energy conservation, increasing efficiency in consumption, hence minimizing anthropogenic CO_2 emissions among other goals. From the perspective of carbon dioxide emissions, zero generation, full mitigation and global remediation are rarely an explicitly linked goal for these systems. Even though the urgency of mitigation and remediation of CO_2 emission is widely understood and acknowledged, the regulations and supporting structures are presently not in place to manifest necessary results to move societies toward remediation. That is not to say that the environmental performance rating systems such as LEED (2009 & 2013) and SSI (2009 & 2014) – and numerous others – cannot assist in the process. They are helping and should continue to do so while continuing to spawn parallel – and even more visionary – efforts.

The literature focusing on the ecological urban design and mitigation of human impacts on nature features a number of notable communities throughout the world that are initiating self-imposed urban re/developments in addition to making voluntary and significant lifestyle changes in order to reduce their footprints. Among these exemplary cities and districts are: Christie Walk, AUS; Halifax Eco-City, AUS; Dongtan Eco-City, CHN; Jiangsu City, CHN; Eco-Viikki, FIN; Kronsberg, DEU; Vauban Eco-District – Freiburg, DEU; Hammarby Sjöstad – Stockholm, SWE; Malmö, SWE; Masdar City – Abu Dhabi, UAE; Sherwood Energy Village – Boughton, UK (Barton, 2000; Barton et al., 2003; Beatley, 2004; Register, 2006; Coates, 2009; Newman et al., 2009; Owen, 2009; Douglas et al., 2011; Coates, 2013). Besides aiming for considerably reducing their anthropogenic CO_2 emissions, these urban re/developments typically take extra measures to reduce the urban expansion, sprawl, consumption of water, energy, and non-renewable resources while increasing natural food production, renewable energy generation, and recycling materials.

Vauban Eco-District in Freiburg, DEU, a community of 5,000 households, is considered an ecological model and studied closely "with increasing interest as the economic, health, and environmental costs of car dependence come into focus. Residents are offered numerous incentives (such as free tram passes and options for carpooling) and disincentives (extremely pricey parking only available on the edge of town) to live car-free" (Newman et al., 2009, p. 55). The Vauban district employs a series of applied technologies on neighborhood scale such as a cogeneration power plant using wood chips generated from the local forestry, providing the residents and local businesses with heat and power, in addition to solar heating panels and photovoltaic collectors (Newman et al., 2009, p. 75).

Kronsberg near Hannover, DEU is prominent example of an ecological urban district where a number of low energy or renewable energy strategies are integrated into a compact, walkable community. The CO_2 emission reducing technologies include large wind turbines, centralized solar water heating systems, district heating, and combined heat/power plants (Newman et al., 2009, p. 72).

Western Harbor in Malmö, SWE is another illustrious urban re/development where the goal of achieving 100% renewable energy produced from local resources is largely realized by integrating a mix of renewable energy generation technologies such as a wind turbine and façade-mounted solar hot water collectors (Newman et al., 2009, p. 72).

Beddington Zero Energy Development (BedZED) in London, UK is perhaps one of the most published and well-known examples for low energy, low emission urban re/developments (Beatley, 2004; Farr, 2008; Desai, 2010; Edwards, 2010). Designed in 2003 for net zero energy performance, this project features 82 houses, 17 apartments, and 1,500 m^2 of office that rely mostly on solar panels and biomass fuel. It achieves about 88% heating reduction and 25% electricity reduction (Rudlin & Falk, 1999, p. 96).

In the United States, many state- and regional-scale climate action programs such as Western Climate Initiative (AZ, CA, NM, OR, WA), Vision California, and Sustainable Communities Initiative (SB 375), and Sustainable Community Strategies (SCS) aim to implement large-scale reductions through environmental performance incentives and regulations. More progressive states like California introduce legislation such as AB 32 (California Global Warming Solution Act 20064) to mandate the reduction of CO_2 emissions down to 1990 level by 2020, and down to 80% of 1990 by 2050. For urban areas, the electric generation, buildings, and transportation are among the most significant venues to achieve these aggressive goals. The AB 32 legislation keeps California Air Resources Board (CARB) in charge of establishing the carbon reduction standards and policies in the state. In other countries, there are numerous public or private initiatives – sometimes supported by local governments, organizations, and institutions

– that take action towards reducing and mitigating anthropogenic CO_2 emissions. The Canadian Zero Net Energy Program, for instance, targets 33% renewable electricity generation nation-wide by the year 2020.

Many building-, neighborhood-, district- and/or city-scale efforts in the United States aim to improve on the energy consumption, conservation, and renewable energy generation in order to minimize CO_2 emissions as well as reduce the ecological footprints. A number of communities are primarily conceived and designed to rely on non-CO_2 emitting renewable energy sources such as solar and wind. Van der Ryn and Calthorpe (1986) describe a number of these communities: Marin Solar Village (p. 59); Golden, CO (p. 83); and Chino Hills (p. 96). Many eco-districts or eco-neighborhoods in the United States are emerging to be successful examples such as: Civano – Tucson, AZ (Farr, 2008); Davis City, CA (Barton, 2000); Glenwood Park – Atlanta, GA (Farr, 2008); Holiday Neighborhood – Boulder, CO (Farr, 2008); and Lloyd Crossing Sustainable District – Portland, OR (Brickman, 2009).

The Architecture 2030 Challenge (2014) issued by Architecture 2030 in 2006 focuses on the reduction of energy consumption and greenhouse gas emissions from the building sector. This global initiative calls for “all new buildings and major renovations to reduce their fossil fuel, greenhouse gas emitting energy consumption” 60% by 2010, 70% by 2015, 80% by 2020, 90% by 2025, and become carbon neutral by 2030 (p. 14). The first five 2030 Districts are located in Seattle, Cleveland, Pittsburg, Los Angeles, and Denver. Seattle leads the charge with innovative, energy efficient systems that provide district-wide heating, cooling, and power (Farr, 2008; Architecture 2030 Challenge, 2014).

Linking environmental restoration to anthropogenic CO_2 emissions, there are communities that demonstrate dramatic ecologically responsive and environmentally responsible initiatives that integrate a range of measures including CO_2 emissions. Perhaps among the most notable communities around the world are ecovillages such as Kibbutz, ISR; Camphill Village, NOR; Findhorn, SCO; Lebensgarten – Steyerberg, DEU; Crystal Waters, AUS; EcoVille – St. Petersburg, RUS; Gyurufu, HUN; Ladakh Project – Kashmir, IND; and Ecotop, DEU (Bang, 2005). In the United States, there are also a number of ecovillages: Arcosanti – Mayer, AZ; Village Homes – Davis, CA; The Manitou Institute, CO; EcoVillage at Ithaca, NY; Albert Bates, TN; and The Farm / EcoVillage Training Center, TN (Jackson & Svensson, 2002). Nearly all of these communities are – not only firmly embedded within but also – nurturing and fostering the natural surroundings on which they depend. By choice and design, they have little or no reliance on automobiles, non-renewable sources of materials, foods, or energies. The carbon dioxide footprints of most of these settlements are better than net-zero carbon developments, in that they help sequester and store more carbon dioxide than they tend to generate or emit while supporting the human activities.

Dawson (2006) considers ecological community design to be the frontline of building future communities and notes that the types of applied research, demonstration, and training that these projects are engaged in are "precisely those that will be needed to navigate the rough waters ahead" (p. 77). "Seen in this context," Dawson argues, "the initiatives [of]…reforestation, seed-saving, place-specific technologies for energy-efficient housing, food-growing, [local renewable] energy-generation, the development of inclusive decision-making structures, voluntary simplicity, and so on – appear not so much idiosyncratic tinkering as the very stuff that the building of future societies will be made of" (2006, p. 77).

b) What More Should Be Done To Reduce & Mitigate CO_2 Emissions

The restorative research argues that the principles and strategies of sustainability are not sufficient to bring about the comprehensive restoration of the natural environment. Perhaps this is best illustrated in the example of anthropogenic CO_2 emissions, in that, despite the increasing scope and intensity of sustainable and green re/developments the level of excess emissions do not show any indication of stabilizing or retracting now or anytime in the near future. The recent record of anthropogenic CO_2 emissions makes it clear that more should be done, at least, different principles and strategies should be implemented.

> Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004….Global atmospheric concentrations of CO2 methane (CH4), and nitrous oxide (N20) have increased markedly as a result of human activities….Most of the observed increase in global average temperature since mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. (IPCC, 2007, p. 5)

The restorative research is a concentrated effort to develop an instrument of change and transformation, a new, different, and more effective way of catering solutions to the current environmental problems, which appear to be cascading despite the sustainable, green urbanist, new urbanist, resilient, regenerative or living design efforts. Adoption and regulation of urban design requirements similar to those proposed by the Restorative Urban Design model by governing bodies at local, regional, state, or national levels would, at least, provide some hope for reigning in the escalating environmental deterioration. Since the current re/development standards and regulations are not geared to deliver restoration, a moderate level of transformation and change is necessary. The new regulations should complement some of the existing requirements and introduce new mitigation procedures that narrowly focus on the comprehensive restoration.

Specifically, with regard to the anthropogenic CO_2 emissions, it is clear that emitting less – while helpful – is not sufficient. Ecologically responsive and environmentally responsible design principles and strategies are needed to estimate and mitigate not only the current emissions but also the emissions of the recent past. The RUD model proposes a scenario-based process of evaluating, estimating, and mitigating the anthropogenic CO_2 emissions to be implemented through onsite as well as offsite measures. Urban re/developments of today and foreseeable future need to be rehabilitating, remediating, and restoring their environments.

c) Contribution of The RUD model

The RUD model attempts to contribute to the restoration of the natural environment beyond the mere sustainability of urban lifestyles. It identifies the lack of systematic approach to achieve the comprehensive restoration of the natural environment and seeks to develop a methodological approach that can transform the way urban areas are re/developed so that they can be both more in tune with, and restoring and rehabilitating the natural cycles and balances.

The multidimensional environmental performance assessment and impact mitigation method proposed by the restorative research is possibly the only viable way to address the multitude of interconnected environmental concerns simultaneously in a widespread, large-scale, systematic and effective manner.

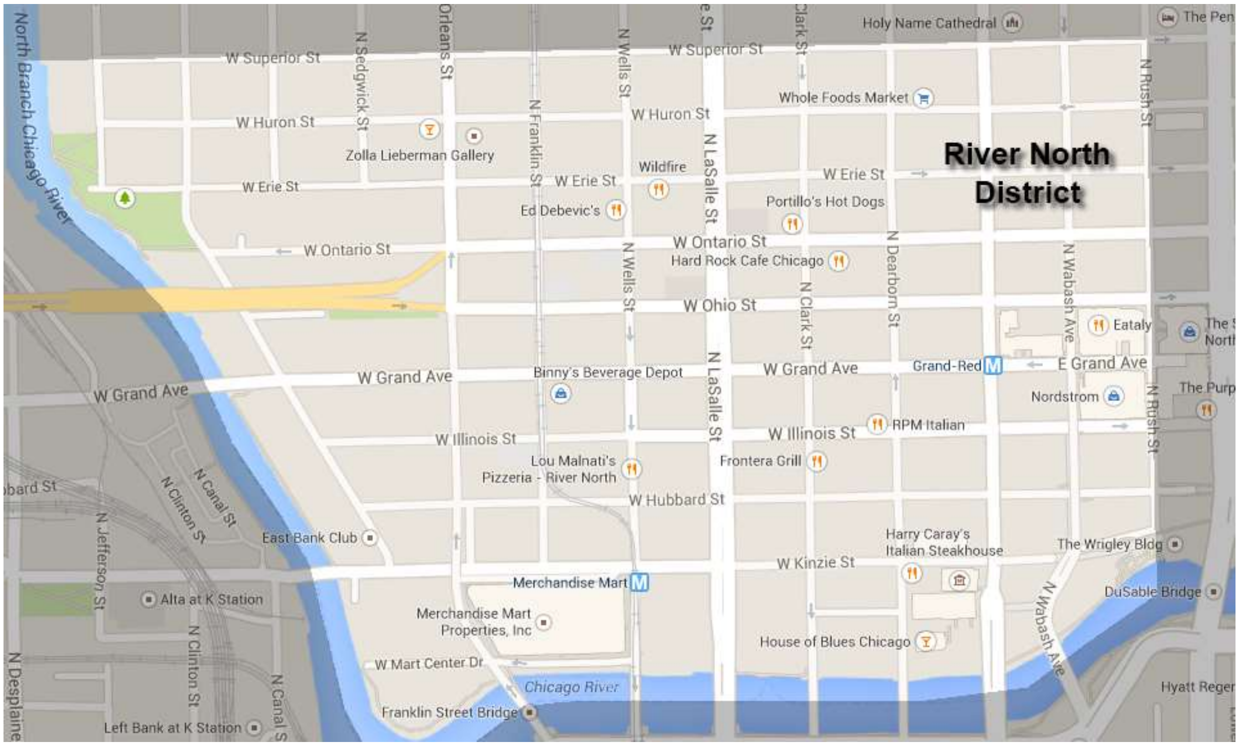
Specifically on the anthropogenic CO_2 emissions, the RUD Case Study illustrates how the restorative approach differs from the rest of the environmental performance assessment, rating systems, and sustainable design methodologies that are in practice today. Just as in other indicators of analyses, the RUD model starts by establishing a natural baseline for environmental restoration and optimizes urban re/development strategies in order to accomplish full mitigation of impacts. Perhaps the most significant contribution of the method is the requirement to estimate and mitigate all impacts either onsite or offsite.

B. The Case Study Area

Theoretically, the RUD Case Study could have been applied to any urbanized area in the world. In fact, the RUD model is conceived to be applied to any and all urbanized areas. At the end, it does not and should not make a big difference where exactly the case study is located as long as it is located within an urbanized area with a significant level of human impacts on the natural environment.

In order to illustrate the application of the RUD model a typical mixed-use district representative of a typical urban neighborhood from the Chicago Metropolitan Area has been selected: River North District (see Figure 4.1). At a closer look, there are several different definitions for the River North District in various records, which show quite a bit of variation. For the purposes of this study the definition provided by the City of Chicago GIS data has been adopted. Accordingly, the RUD Case Study area is bordered by Superior Street on the north side, Chicago River on south and west sides, and Rush Street on the east side.

Figure 4.1 River North District – Chicago, IL (©2014 Google Maps)



The selection of this particular area is, however, not totally random. There are a number of rather practical and illustrative reasons behind choosing Chicago Metropolitan Area and River

North District in particular. First, Chicago Metropolitan Area is one of the largest metropolitan areas in the western hemisphere. Locating the RUD Case Study here puts the emphasis at the heart of where the restorative mitigations need to take place. Second, downtown Chicago is a typical high impact urban area developed over time and has a significant amount of impervious hard surfaces with only a small amount of green and open spaces. Third, the City of Chicago and the metropolitan area counties and townships feature a variety of authorities, agencies, and organizations actively involved in documenting the planning and development of the area. Fourth, the planning efforts in the Chicago area appear to have a special sensitivity to sustainable urban design and re/development practices. And finally, the River North District specifically offers a choice location outside but immediately adjacent to the downtown area where extremely high urban densities start to transition to mid to low density developments within the confines of the study area. This unique mixture of building types, structures, land uses, street network, and transportation modes makes the River North District highly desirable location to investigate the amount and extent of mitigations necessary to fully neutralize the anthropogenic CO_2 emissions.

C. Research Questions & Expected Results

The overall restorative research is driven by a systematic review and a critical questioning of existing principles and strategies of sustainable urban design and planning practices as discussed previously in Chapter 1. The RUD Case Study specifically sets out not only to demonstrate the application of the RUD model as applied to a single indicator but also to find the answers to the following four research questions on the study area. Each research question is provided with a hypothetical range of possible answers where the results are likely to be as follows:

1. Question 1: Current Conditions – Anthropogenic CO_2 Emissions

What is the total estimated annual amount of current anthropogenic CO_2 emissions in the study area (tons/yr) as of year 2014?

The amount of anthropogenic CO_2 emissions of any given urban area for restorative research purposes is estimated by using four main sources of CO_2 generation: private transportation, public transportation, heating (natural gas and fuel oil), and electricity consumption (Glaeser, 2008). There are other kinds and sources of anthropogenic carbon dioxide emissions such as from production and transportation of goods, services, materials, and foods, which happen outside but support the daily life within the study area. If included in estimations, these excluded emissions would result in even larger mitigations. The estimation of current anthropogenic CO_2 emissions in the study area (tons/yr) as of year 2014 is likely to range:

a) High: 498,500 tons/yr, assuming 25% lower efficiency and/or more reliance on fossil fuels usage than regional averages.

b) Median: 398,800 tons/yr, assuming about 20 tons/yr per person on average (Rowntree and Nowak, 1991, p. 273; TLGDB, 2001, p. 219).

c) Low: 299,100 tons/yr, 25% higher efficiency and less reliance on fossil fuels.

2. Question 2: Trajectory Forecast – Anthropogenic CO_2 Emissions

What is the total annual amount of anthropogenic CO_2 emissions (tons/yr) to be restoratively mitigated by year 2040 in the study area?

It is expected that the total annual amount of anthropogenic CO_2 emissions in the study area (tons/yr) as of year 2040 depends largely on population and consumption patterns but is likely to be within a range of:

a) High: 579,300 tons/yr, 25% above historical patterns.

b) Median: 463,500 tons/yr, based on historical population growth patterns.

c) Low: 347,600 tons/yr, 25% below historical patterns.

3. Question 3: Restorative Projection – Onsite Mitigations

In an optimized restorative projection scenario, what percentage of the estimated annual amount of anthropogenic CO_2 emissions is likely to be mitigated through strategies implemented onsite by 2040?

The percentage range of projected restorative mitigations within the study area as of year 2040 is influenced by a series of factors such as population, growth, and design assumptions. However, possible scenarios could be grouped into the following categories:

a) High: 55%. This restoration projection scenario assumes a relatively lower level of future growth and development in the study area than the Central Chicago Area Action Plan (CCAAP, 2009) projection, with relatively high level of mitigation measures for anthropogenic CO_2 emissions by the year 2040.

b) Median: 30%. This projection scenario assumes an average level of growth and development in the study area as compared to CCAAP (2009) by the year 2040, as well as moderate mitigation measures.

c) Low: 5%. This projection scenario assumes a much higher level of growth and development in the study area by the year 2040, with the least amount of onsite mitigations.

4. Question 4: Restorative Projection – Offsite Mitigations

In an optimized restorative projection scenario, what percentage of the estimated annual amount of anthropogenic CO_2 emissions is likely to be offset by mitigation strategies implemented offsite by 2040?

In most parcels of the RUD Case Study area, it is expected that the estimated range of anthropogenic CO_2 emissions cannot be sufficiently mitigated onsite, and therefore, significant offsite mitigations are likely to be implemented offsite. The percentage of offsite mitigated emissions could potentially be in the range of:

a) High: 95%. This projection assumes a relatively high level of growth and development in the area with relatively low level of onsite mitigation measures for emissions.

b) Median: 70%. This projection scenario assumes an average level of growth and development in the study area as compared to CCAAP (2009) by the year 2040, as well as a moderate level of onsite mitigation measures.

c) Low: 45%. This projection scenario assumes a lower level of growth and development in the study area by the year 2040, with the most amount of onsite mitigations.

D. Methods in The Case Study

The application of the RUD model in most urban areas can be accomplished by using publicly available secondary data such as population, demographic, geographical, physical as well as statistical information. Most types of analyses do not require collection of primary data in the field such as measurements, surveys, and/or interviews. In certain instances, field observations and verification of collected information may be helpful and necessary.

1. Measurements, Data, & Observations

In addition to the norms and standards already published in literature, there is ample amount of public information and data available electronically and digitally to be used for restorative analyses as long as the study locations fall within well-documented metropolitan areas. A majority of local jurisdictions (i.e. city, county, or regional governments and planning organizations) offer the kinds of environmental data that are needed for the RUD model purposes. Techniques such as remote-sensing and satellite imagery practically provide a range of valuable information.

a) Collection & Sources of Data

The analyses in the RUD Case Study did not require collection of any field observed data i.e. through onsite or field measurements, surveys, or questionnaires. Open source data such as online photographs, satellite imagery, and other geospatial visualization specific to the River North District, Chicago Metropolitan Area and other geographical areas are adequate for most evaluations of the study area. A moderate level of difficulty in collecting, combining, and synthesizing appropriate parcel data for the entire study area was available. Most importantly, the existing condition survey of the RUD Case Study relies heavily on collection and documentation of a vast amount of geographically referenced data, which has been summarized in Table 4.1 (refer to Appendix G). Translated by using ArcGIS, the information is tabulated into a database spreadsheet, grouped, categorized, and summed up in Microsoft Excel.

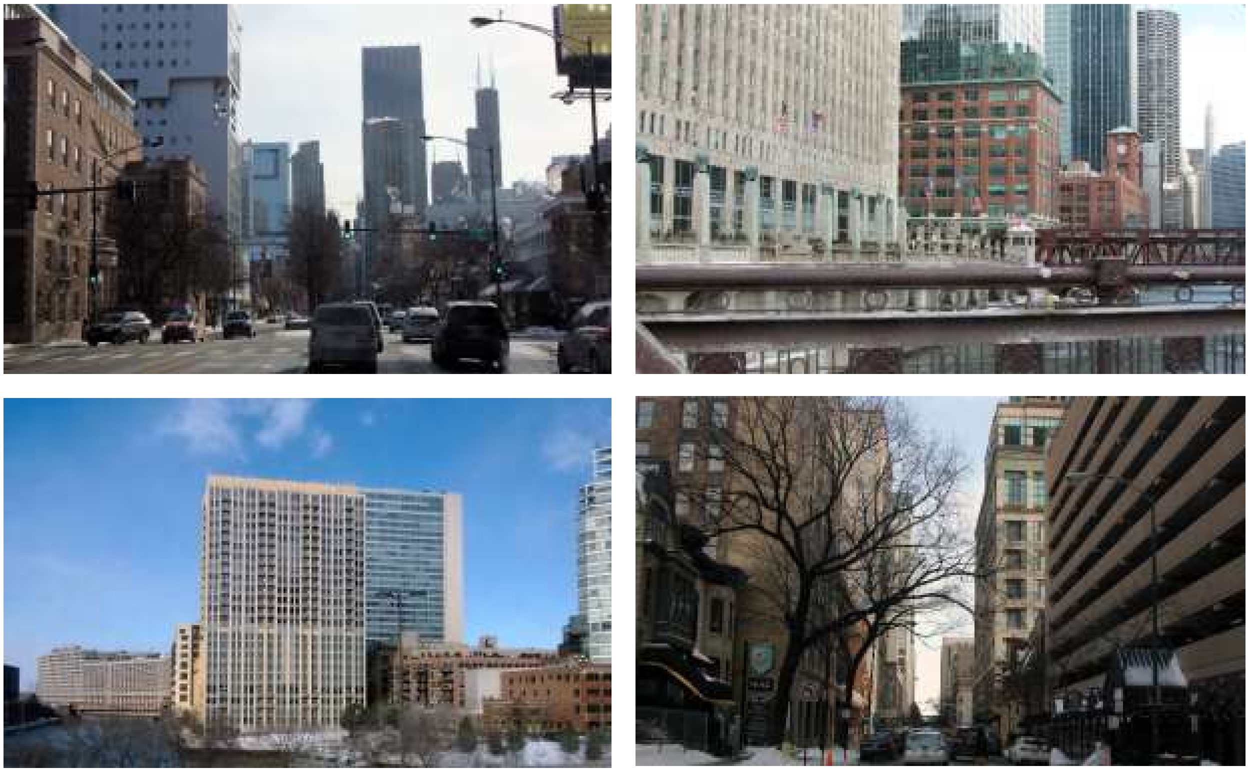
All data to be used in the RUD model, regardless of their type, source or origin, is converted into metric units system prior to any analyses. All results were to be expressed in the most appropriate form of metric units for the specific subcategory.

Most of the georeferenced data on the RUD Case Study area was available from governmental agencies or open source in the United States such as U.S. Census Bureau (census.gov), Bureau of Economic Analysis (bea.gov), Environmental Protection Agency (epa.gov), Metropolitan Planning Council (metroplanning.org), Chicago Metropolitan Agency for Planning (cmap.illinois.gov), and City of Chicago (cityofchicago.gov). Some of the sources of publicly available data on the RUD Case Study have been collected from sources such as U.S. Census Bureau (census.gov), Bureau of Economic Analysis (bea.gov), and Environmental Protection Agency (epa.gov).

b) Site Observations

The case study site was visited on several occasions during the course of this research including December 2012, October 2013, and January 2014 (see Figure 4.2).

Figure 4.2 Site observations and photographs assist in the process of verifying data



The visits involved getting more familiar with as well as verifying some of the features and activities of the study area where valuable observations were made. During the course of rest of the restorative research additional site visits were not necessary in order to verify and/or confirm certain information. For other site photographs, refer to Figure H.1 through H.12 in Appendix H.

2. Procedure of Estimating Generation & Mitigations

Since the RUD Case Study is designed to illustrate the application of the RUD model to the anthropogenic CO_2 emissions in the study area the procedure of estimating generation and mitigations is vitally important, which is summarized in the following.

a) Equation of Impact Generation & Impact Mitigation

The estimation of urban impacts under the RUD model aims to balance two counter-acting sides of an equation: impact generation versus impact mitigation, which should equal the generation at a minimum (see Figure 4.3). For the purposes of RUD Case Study computations, the amount of required impact mitigations (i.e. reductions, sequestration and storage) should be equal to – or greater than – the generation amount of anthropogenic CO_2 emissions. Hence, the restorative scenarios based on the estimated total amount of emission generation – at present and in the future – need to be mitigated through a combination of onsite and offsite measures.

Figure 4.3 Impact mitigations should equal total estimated generation at a minimum

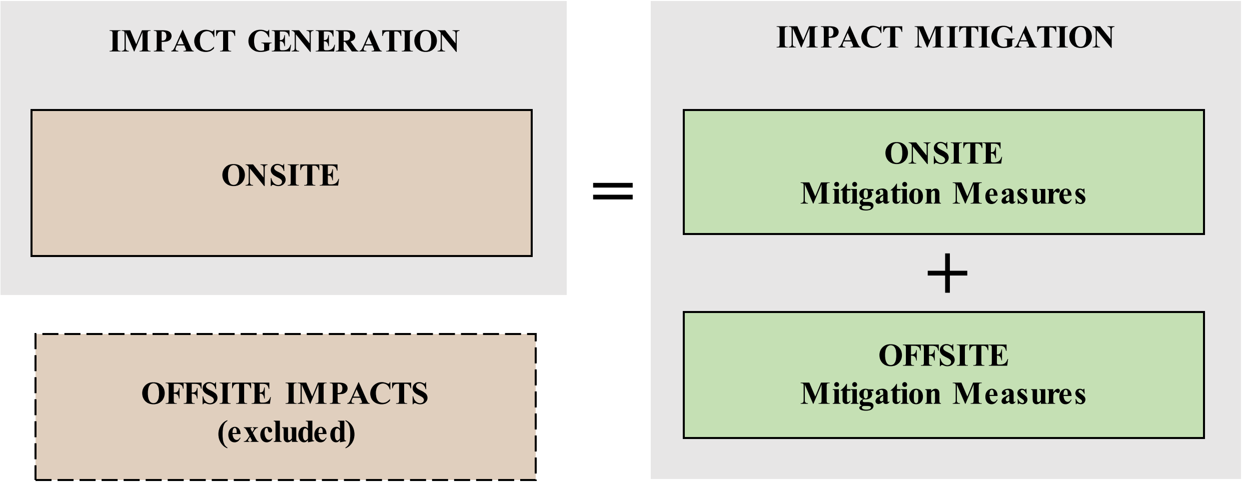


Figure 4.3 above outlines both sides of the equation, balancing the estimated amount of anthropogenic CO_2 emission generation and necessary mitigations in the RUD Case Study. Even though in reality there are other major sources (e.g. agriculture, manufacturing, commercial and freight transportation, and other industries) as well as mitigating sinks (e.g. wetlands, lakes, oceans, etc.) these offsite elements have been excluded from the estimations. As discussed previously, emissions only from buildings, private and public transportation are included in the estimation (refer to Research Questions & Expected Results section). If the share of offsite impacts were to be averaged or estimated and included in the calculations it would be reasonable to expect that the resultant onsite and offsite measures would be significantly higher.

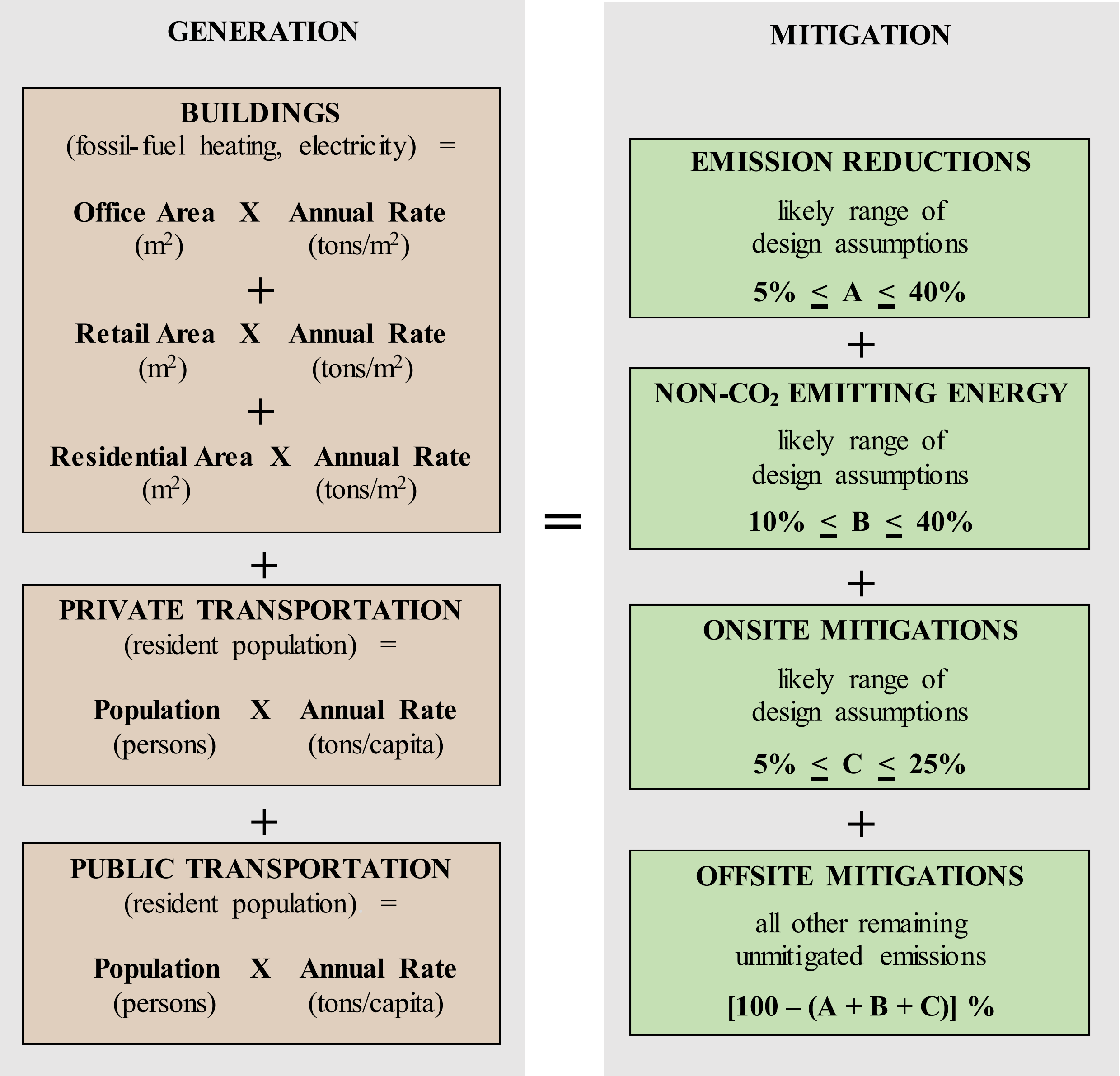
It is useful to examine the feasibility or difficulty of accomplishing all mitigations onsite, without any offsite measures. The Zero Offsite Mitigation (RPROJ3) scenario alternative offers an estimate of possible design assumptions under which all generated emissions might be mitigated through measures implemented onsite.

That said, it is also possible – and perhaps even more desirable – to optimize the design assumptions for a restorative scenario that mitigates more emissions than the total amount generated from a particular site. The fourth scenario alternative presented in the RUD Case Study i.e. the Global Remediation (RPROJ4) aims to accomplish just that.

b) Estimation of Study Area Emission Generation & Mitigations

As discussed in detail in the research question section of Chapter 4, the current total generation is estimated as a sum of emissions from buildings, private and public transportation for the RUD Case Study purposes. The corresponding total mitigation is a combination of emission reductions, non-CO_2 emitting energy, onsite and offsite mitigations, where the design assumptions are likely to range as shown in Figure 4.4 below.

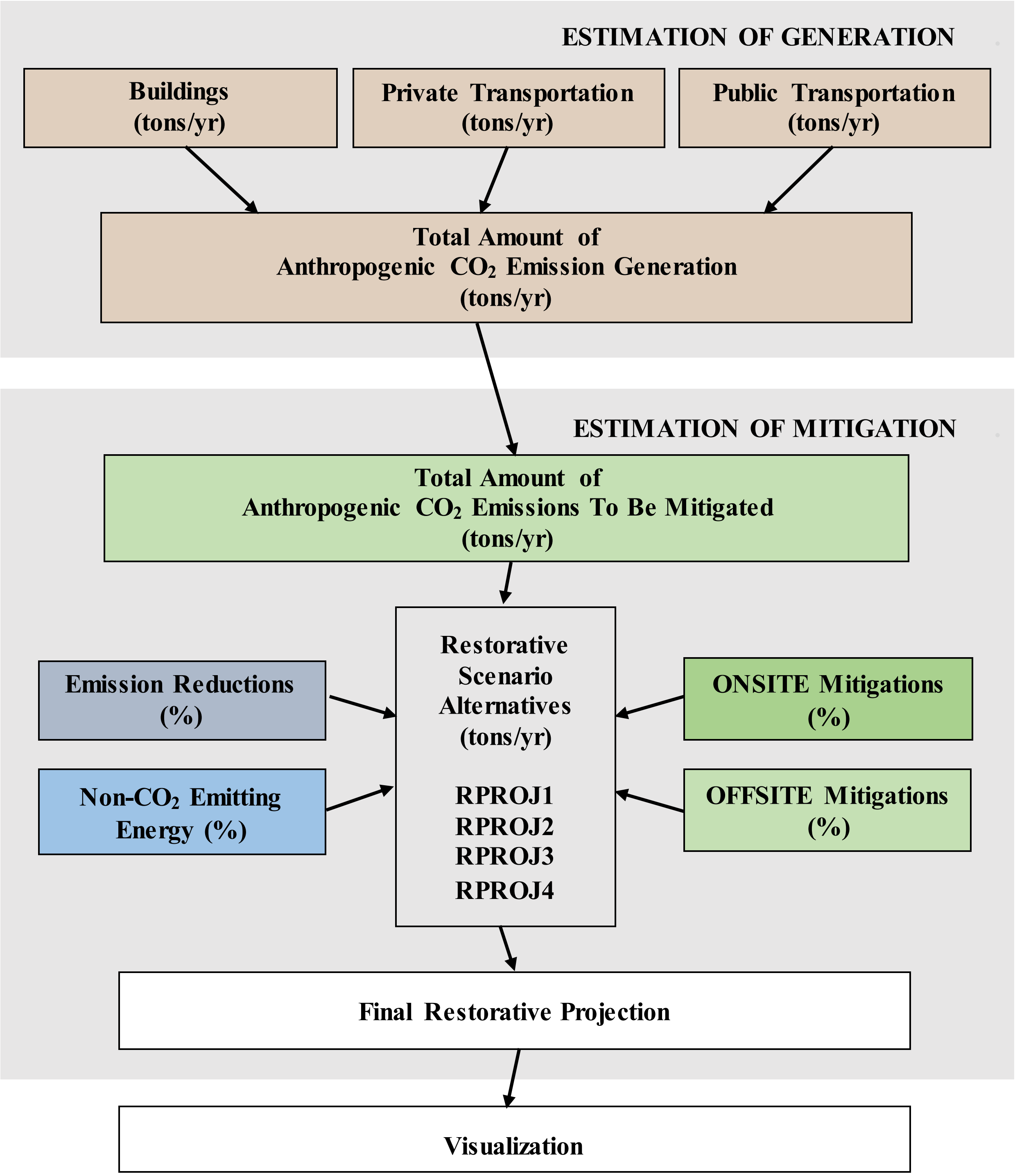
Figure 4.4 Total emission generation and mitigation are estimated to be equal



c) Workflow of Data in Calculations

Figure 4.5 below illustrates the workflow of data and calculations within the information model of the RUD Case Study, which are discussed in further detail in the following sections.

Figure 4.5 Diagram of data workflow in the estimations of the RUD Case Study



3. Scenario-Comparison in Case Study

All the important calculations and estimations in the RUD Case Study take place as a part of the application of scenario-comparison process. The steps 1 and 2 are used to arrive at the total annual amount of historic and current emissions, which is a critical figure used in determining the future projections i.e. Trajectory Forecast (TFORE). The forecasted total generation is, then, used to evaluate and optimize a number of different Restorative Projection (RPROJ) scenario alternatives through the following steps:

1) Defining Baseline Conditions: Natural Baseline (NBASE)
2) Establishing Historic & Present Conditions: Historic Progression (HPROG)
    a) Determining Extents of Study Area
    b) Establishing Base Map & Database: Neighborhood & Parcels
    c) Establishing Other Layers on Base Map & Database: Parks, Streets, Buildings
    d) Obtaining Representative Data: Historic Conditions
    e) Determining Present Conditions
    f) Researching Generation Rates: Per Capita Averages
    g) Researching Generation Rates: Per Unit Area Per Building Type
    h) Researching Generation Rates: Private Transportation
    i) Researching Generation Rates: Public Transportation
    j) Establishing Average Generation Rates on Emissions
    k) Calculating Total Amount of Current Anthropogenic CO2 Emissions
3) Determining Future Conditions: Trajectory Forecast (TFORE)
    a) Linear Regression Analysis
    b) Polynomial Regression Analysis
    c) CCAAP (2009) Population Forecast
4) Exploring Restorative Conditions: Restorative Projection (RPROJ)
    a) Restorative Projection Scenario Alternative 1 – Least Ambitious (RPROJ1)
    b) Restorative Projection Scenario Alternative 2 – Intense Greenification (RPROJ2)
    c) Restorative Projection Scenario Alternative 3 – Zero Offsite (RPROJ 3)
    d) Restorative Projection Scenario Alternative 4 – Global Remediation (RPROJ4)

4. Evaluating Alternatives & Optimizing Design Assumptions

Within the final step of scenario-comparison process the conditions of the restorative projection are explored by reiteratively comparing the design assumptions for the RPROJ scenario to those of TFORE and NBASE scenarios (refer to Figure 4.6). The process of evaluation and optimization for the final restorative scenario inherently creates a number of different possible scenario alternatives depending on the variation and number of reiterations. In determining a final restorative projection scenario, the key design assumptions to be considered are:

1) Emission Reductions: Achieving Up To 40% Reduction In CO_2 Emission
2) Non-CO_2 Emitting Energy: Achieving Up To 40% Reliance on Renewables
3) Estimating Magnitude of Onsite Mitigations
    a) Researching Sequestration Rates: Tree Cover
    b) Researching Sequestration Rates: Green Roofs & Green Walls
    c) Establishing Average Sequestration Rates on Mitigations
4) Offsite Mitigation Forest
5) Optimizing A Final Restorative Projection

5. Visualizing Restorative Conditions

The visualization piece of the RUD Case Study findings is an important outcome of the restorative research. The RUD model as well as the Case Study are not only primary elements of an academically conducted research but are also conceived to be instruments of professional urban design practices as well. As the final product of the dissertation, the visualization graphics and images help illustrate the following elements:

1) Green Roofs & Green Walls
2) Network of New Green Spaces
3) A Summary of Onsite Mitigations at City Block Scale
4) The Size of Offsite Mitigation Forest

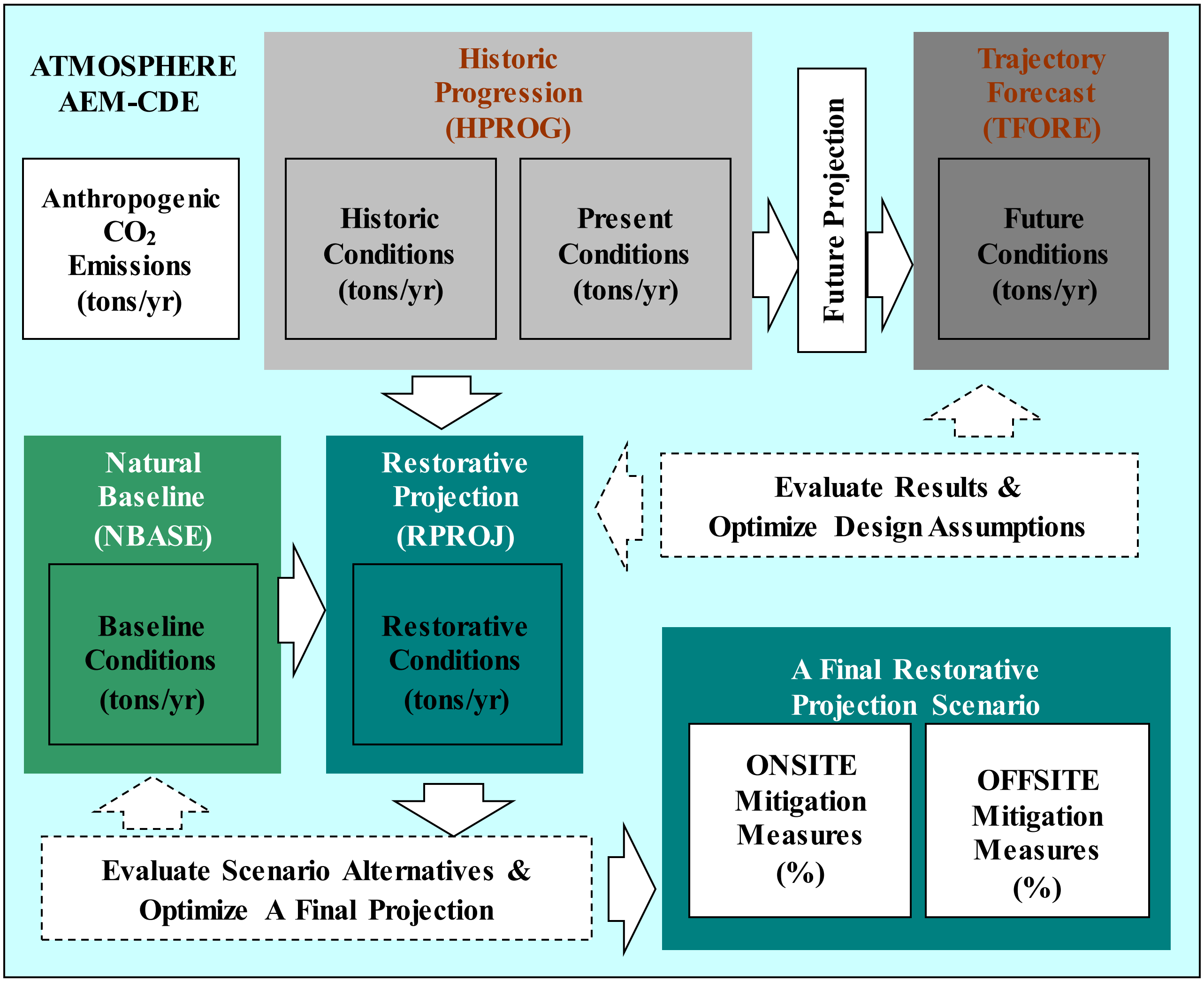
6. Summary of Case Study Findings

The final section at the end of the RUD Case Study provides an overall summary of the case study and its findings.

E. Scenario-Comparison in The RUD Case Study

The scenario-comparison process proposed in this research is a customized procedure for scenario-based environmental restoration studies. It is similar to some techniques used in urban growth modeling and ecological restoration as discussed in Chapter 3. Integrated modeling and simulation techniques are steadily gaining prominence in urban design and planning processes as the computational and visualization capabilities of growth modeling technologies continue to advance further (Crooks et al., 2010; Li et al., 2010).

Figure 4.6 Alternatives are reiteratively evaluated and optimized into a final projection



As shown in Figure 4.6 above, the RUD Case Study application of the scenario-comparison procedure is, for the most part, the same that proposed for the RUD model (refer to Figure 3.5). Therefore, the case study focuses on balancing the design assumptions through restorative scenario alternatives where they are reiteratively tested and compared against those of natural baseline conditions until optimum conditions – those most closely matching the natural baseline design conditions – are reached.

1. Defining Baseline Conditions: Natural Baseline (NBASE)

One of the initial steps in applying the RUD model to a study area is the establishment of a design baseline conditions, which are later used to compare the future re/development to other scenarios. The criteria for various definitions and assumptions behind baseline (natural or ideal) conditions of the RUD model are discussed in Section 3.D.1. At this juncture, the Mannahatta Project (Sanderson, 2009), in the case of Manhattan Island, arises as one of the most informative ecological context and precedence studies illustrating the complexities involved in determining the pristine natural conditions of an extremely dense urban area.

> The Mannahatta Project shows us what the world was like when the human footprint was dramatically less intense, and the rest of the natural world was freer to express itself. It shows what nature, given a chance, can deliver. It's not that Mannahatta was unpeopled, but rather that its form of human civilization did not overwhelm the ecological systems on which the island depended. The Lenape did not have the capacity, nor, as far as we can tell, the desire to remove the green woods and glittering marshes, their idea of home. In contrast to Mannahatta, Manhattan has been transformed by a civilization with a global reach, unprecedented technology, and enormous appetite; to satisfy our idea of home, we have created the quintessential modern city. (Sanderson, 2009, p. 32)

Like Manhattan Island, there is of course hardly any place left in the core of Chicago Metropolitan Area that has not been transformed directly or indirectly by human activities in one form or another over the centuries. For the purposes of the case study, natural baseline conditions are set to be similar to a natural open space and reserve area with vegetation and wildlife mostly native to this geographic region: Catherine Chevalier Woods in O'Hare, IL (see Figure 4.7).

Approximately 20 km northwest of the RUD Case Study area, this reserve of open and natural land features a fairly dense tree cover, perhaps averaging 60 to 80 percent, with a healthy ground cover of shrubs, native grasses, wildlife habitats, and supporting natural ecosystems, which are representative of an environment that is least influenced by human activities.

Specifically in terms of the anthropogenic CO_2 emissions, this study assumes an ideal set of conditions where there is very little – almost negligible – amount of anthropogenic emissions in the Natural Baseline (NBASE) scenario, which equates to a few thousand tons per year or less than half a percent, and hence, numerically represented by zero in the Trajectory Forecast (TFORE) and Restorative Projection (RPROJ) calculations.

Figure 4.7 Catherine Chevalier Woods in O'Hare, IL (©2014 Google Earth)

2. Establishing Historic & Present Conditions: Historic Progression (HPROG)

The foundation of applying the RUD model and scenario-comparison in any given study area is to establish the historic progression of current conditions, which need to be thoroughly investigated and documented. The subsequent analyses, evaluation, and optimization in the following steps all rely on the data gathered in this critical step, which is also reiteratively revised and edited as the research deepens.

a) Determining Extents of Study Area

The documentation starts by determining the extents of study area. Since the optimum size of study area is theoretically between that of a neighborhood and a district the RUD Case Study area was chosen to be the River North District, a 141.72 ha (1.417 km^2 or 0.547 mi^2) mixed-use urban neighborhood located immediately to the northwest of downtown Chicago (RUD – Neighborhoods, 2013) (see Figure 4.8). The RUD Case Study area boundaries are: Superior Street (on north), Chicago River (on south and west), and Rush Street (on east).

Figure 4.8 Extent of case study area follows River North District boundaries

b) Establishing Base Map & Database: Neighborhood & Parcels

One of the key steps in the restorative research sequence is to establish the current parcel map for the entire study area, which would form a base map for subsequent analyses. In the River North District, specifically, there are 352 urban parcels located contiguously (RUD – Neighborhoods, 2013; RUD – Parcels, 2013). Eighteen of these parcels belong to waterways, bodies, or highways as distinct from the other parcels with urban parks and buildings. There are no reserve lands, open spaces, or wildlife habitats under protection or conservation. While the smallest parcel is only 0.01 km^2 the largest is about 0.24 km^2 where the mean of parcel sizes in the study area is 0.11 km^2. The GIS database includes facility names, street names, ownership in addition to size and land use information for each parcel map (refer to Appendix G).

c) Establishing Other Layers on Base Map & Database: Parks, Streets, Buildings

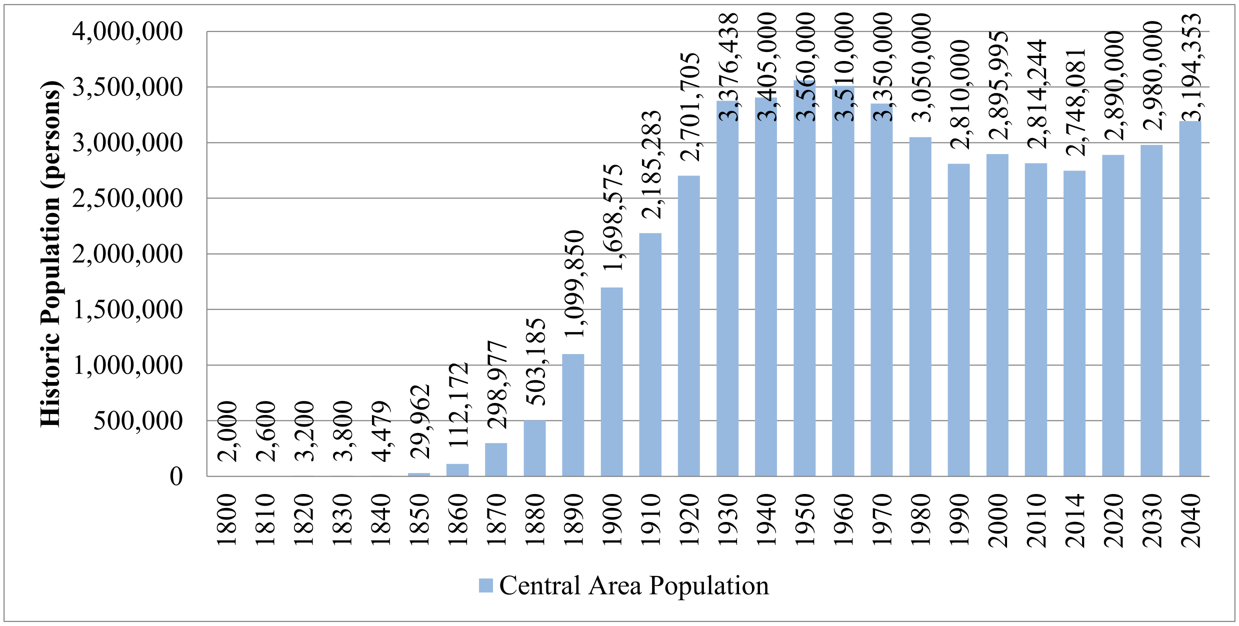
Using the actual city parcels as base, the present physical features of the study area were documented as an ArcGIS Base Map showing parcels, streets, parks, buildings etc. (RUD – Parks, 2013; RUD – Streets, 2013; RUD – Buildings, 2013). In the River North District study area, there are currently 479 buildings with a wide range of variation in the age of construction (from 1864 to 2012). The existing buildings contain approximately 5.55 km^2 in size, range up to 92 stories in height, and contain up to a maximum of 825 dwelling units (Trump Tower) on a single parcel. According to CMAP GIS data there are 18 different types of land uses in the study area (RUD – Buildings, 2013) (refer to Appendix G).

The Base Map was edited to achieve two important layers of information i.e. parcels and buildings. Detailed database tables were extracted from these layers, where each parcel and building within the study area was represented by a unique identification number (FID). In addition to coordinates, area, and height for each building, the database also includes identifier building names, street names, number of uses, stories, year of construction, as well as other categories (refer to Appendix G).

d) Obtaining Representative Data: Historic Conditions

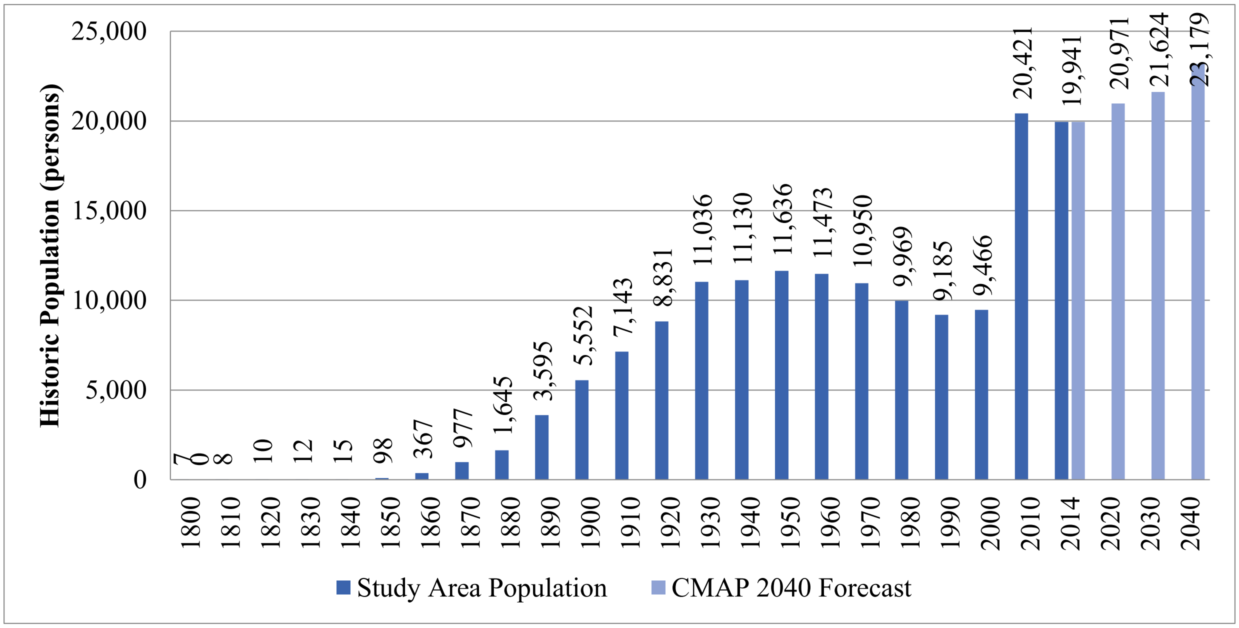
As part of estimating historic conditions for the HPROG scenario, the trend profile of historical population growth for the Chicago area was examined (Guyer, 1862; Cutler, 2006; Keating, 2008). In particular, the Chicago Central Area Action Plan (CCAAP, 2009) as part of CMAP 2040 was used to determination the historic progression of population in the central Chicago area as shown on Figure 4.9 below. The CCAAP data included population projection through 2040 as used by CMAP 2040 forecast.

Figure 4.9 Historic progression of population in the Chicago Central Area (CCAAP, 2009)



The historic progression of population from CMAP 2040 (CCAAP, 2009) was then used as a proxy to interpolate the historic progression of population of River North District (see Figure 4.10).

Figure 4.10 Historic progression of population (CCAAP, 2009) is adopted to the study area



The big jump in population was mainly caused by the completion of a single massive project within the district boundaries, which significantly increased the resident population as reported on CCAAP (2009, p. 16): The Trump Tower. Using a database worksheet and charting tools, the population forecast for the central area was translated to a population forecast for the study area as shown on Figure 4.10 above.

The yearly population trajectory forecast was worked out separately as part of determining future conditions i.e. Trajectory Forecast (TFORE) in Section 4.E.3, which forms the basis to estimate the future CO_2 emission conditions as a continuation of the historic and present generation rates.

e) Determining Present Conditions

To begin with, the existing or present conditions are identified in a Base Map for the entire study area, in this case generated from the 2008 City of Chicago GIS data including land uses, city blocks, parcels, buildings and population (refer to Appendices F and G). In the RUD

Case Study, each city block was individually identified with a unique number and summarized quantitatively using ArcGIS as shown in Figure 4.11 and Appendices F and G.

Using the base map and database initiated in the earlier steps, the data on present conditions are collected and summarized as necessitated for the anthropogenic CO_2 emission estimations. The City of Chicago Data Portal offers recent usage data only on total electricity and gas consumption, so finding historical data on specific parcels and/or private buildings was a formidable challenge. The number of present public transport stops in the study area per hectare was contained within available GIS data from RTA [http://www.cityofchicago.org/ city/en/depts/doit/dataset/ railroads.html] (CTA – BusStops, 2013).

The RUD Case Study includes other non-local information and/or average data adopted from other studies (e.g. average rates of emission generation and sequestration), which are considered to be fundamentally similar. The representative information and data used in the estimation and optimization of the restorative scenarios serve to represent the conditions in the study area as being similar to other cases where more in depth research has already been conducted.

Figure 4.11 Base Map of city blocks, parcels and buildings

Then, the historic population, land use, building size data on each city block and parcel were reviewed and documented in order to arrive at a composite representation of conditions in the study area for the years 1800, 1900, 2000 and 2014 (U.S. Census, 2000; U.S. Census, 2010). In reconstruction of this data, additional online resources such as federalregister.gov; lib. uchicago.edu/e/collections/maps/chigis; inhs.illinois. edu/resources/gis/glo; library.illinois.edu/ prairie/inhs; landplats.ilsos.net/FTP_Illinois; nhgis.org; inhs.illinois.edu/inhsreports/fall-02/fgis, and censusrecords.net were also used to verify findings.

In documenting and analyzing the present conditions for the case study, a thorough review of existing land uses, parcels, and buildings in the entire study area was conducted for each individual city block as identified A1 through K9 on Figure 4.11. The various bits of data – e.g. building types, uses, area, height, exterior openings, and roof conditions – was also verified using Google Earth as well as site photographs taken during field observations (see Figure 4.12).

Figure 4.12 Each existing land use, parcel, and building was verified (©2014 Google Earth)

The Table 4.1 below tabulates the distribution and totals of estimated areas for each building use category i.e. office, retail, and residential. Further details of the distribution is located in Appendices F and G for reference.

Table 4.1 Distribution of total estimated building areas by major use categories

Study Area City Blocks	Office (m^2)	Retail (m^2)	Residential (m^2)	Totals Per Block (m^2)
A1 through A9	1,718	57,023	510,466	579,207
B1 through B9	297,439	20,416	380,867	698,722
C1 through C9	137,154	16,820	1,041,943	1,195,917
D1 through D9	246,742	5,803	252,284	504,829
E1 through E9	49,293	7,786	260,732	317,811
F1 through F9	16,057	9,982	443,929	469,968
G1 through G9	439,547	7,310	100,897	547,754
H1 through H9	169,364	3,409	366,022	538,795
J1 through J9	25,394	4,205	384,956	414,555
K1 through K9	14,209	2,527	367,327	384,063
Overall Totals (m^2)	**1,406,918**	**135,281**	**4,109,422**	**5,651,621**

f) Researching Generation Rates: Per Capita Averages

There is an abundance of research and data on anthropogenic CO_2 emissions available on annual per capita basis on national or global scales. A myriad of literary sources, research, and studies report on the subject with results and figures that do not completely correlate or coincide in all the cases due to variations in methodology or chronology. The overall carbon emission per capita rate for the United States, for instance, is reported to be 2.3 tons/yr in 1988, topping the world's per capita ranking due to intense urbanization, industrialization, and reliance on transportation (Rowntree & Nowak, 1991, p. 273). The Little Green Data Book (TLGDB, 2001) estimate for the per capita CO_2 emissions for the U.S. in 2001 stands at 20.1 tons/yr (p. 219). TLGDB (2009) estimates the same rate at 19.5 tons/yr (p. 216). These resources and figures are helpful in understanding the variation and range in overall per capita magnitude of emissions, which include all sources of emissions such as agriculture, manufacturing, commercial and freight transportation, and other industries at national scale.

g) Researching Generation Rates: Per Unit Area Per Building Type

The restorative research reviews a selection of narrowly focused resources estimating emission generation as well as storage only from certain sources, and adopts a small number of median figures for the purposes of estimating the CO_2 emissions in the study area. Finding pertinent carbon emission, storage, and sequestration information on smaller scales (city or neighborhood levels) proves to be an inherently complicated and challenging process.

A key source of annual CO_2 emissions data for commercial buildings is the following tabulation from Building Research Establishment in UK, adopted by BREEAM (2007), which suggests that the emissions vary from 77 to 140 kg/m^2/yr (see Table 4.2).

Table 4.2 OECD (2003) Table 15 (p. 79) notes the estimated emissions for building types

Types of Buildings	Estimated CO_2 emissions (kg/m^2/yr)
BREEAM assessed buildings	56
Good practice buildings	77
Typical buildings	140

Note: Typical building: building that has median level of energy efficiency of UK building stock; Good practice building: building that is in the top quartile of UK building stock with regard to energy efficiency (Source: Building Research Establishment)

Freidman (2006) reports that the average annual CO_2 emissions for the commercial type of governmental buildings is 0.014 lbs CO_2/ft^2 (p. 16), which is a gross average of hundreds of governmental buildings studied in the State of Massachusetts specifically in terms of their annual CO_2 emission generations. The average given by this study equates to about 0.059 tons/m^2/yr, which is considerably less than the results offered by other studies in absence of estimated CO_2 emission due to electricity generation.

Research by Mumovic and Santamouris (2009, p. 84) focusing exclusively on the annual CO_2 emissions generated by heating, cooling and air conditioning systems in different types of buildings suggests that rates range from 0.007 to 0.027 tons/m^2/yr (see Table 4.3).

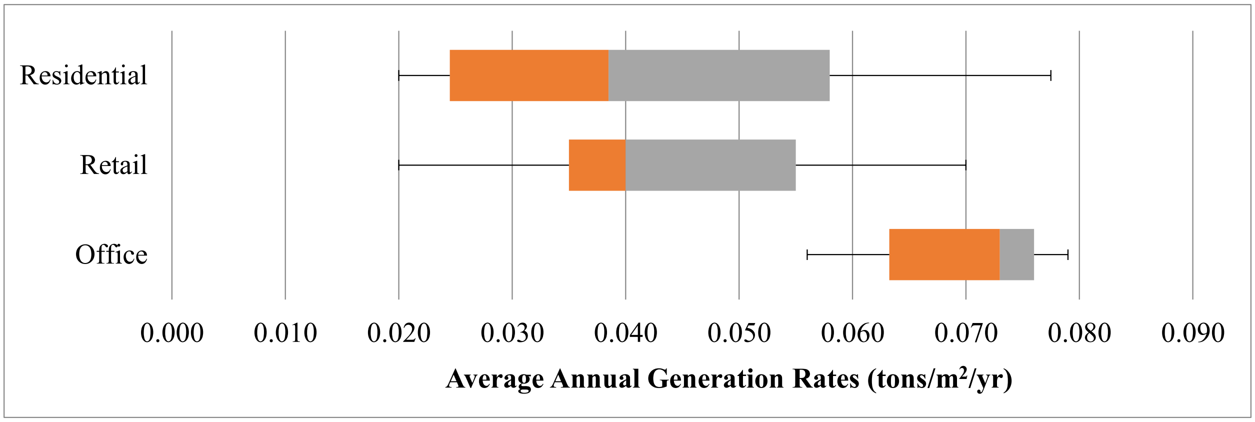
Table 4.3 Typical emission averages for buildings (Mumovic et al., 2009, Table 5.2, p. 84)

Types of Buildings &	Typical (kgCO_2/m^2/yr)			Good Practice (kgCO_2/m^2/yr)		
Mechanical Systems	Heating	Cooling	Fan/Pumps	Heating	Cooling	Fan/Pumps
Prestige air-conditioned	11.8	5.8	9.5	5.9	3	5.1
Standard air-conditioned	9.8	4.4	8.5	5.3	2	4.3
Naturally vented, open	8.3	0.3	1.1	4.3	0.1	0.6
Naturally vented, cellular	8.3	0	0.8	4.3	0	0.3

The EPA Calculation and References publication (EPA-REFS, 2014) indicates that the average total CO_2 emissions for energy use for a home is 10.97 tons CO_2 per home per year [7.270 tons CO_2 for electricity plus 2.85 tons CO_2 for natural gas plus 0.37 tons CO_2 for liquid petroleum gas plus 0.48 metric tons CO_2 for fuel oil]. Considering an average home size of 1,500 ft^2 (168 m^2), this translates to an average rate of 0.079 tons/m^2/yr.

Figure 4.13 below summarizes the range of averages encountered in the literature of available research on the annual CO_2 emissions from buildings as related to various types of construction, mechanical and operational systems. For the RUD Case Study purposes, the generation rates for the main building types i.e. Office, Retail, and Residential are taken as the median for the range of values in each category.

Figure 4.13 Median values are used to establish the average building generation rates



Generation (tons/m^2/yr)	Min.	Max.	Median	Standard Deviation	Sources
Office	0.056	0.140	0.073	0.0594	OECD (2003); Friedman (2006); Mumovic et al. (2009)
Retail	0.020	0.055	0.040	0.0247	OECD (2003); Friedman (2006); Mumovic et al. (2009)
Residential	0.020	0.079	0.039	0.0417	EPA (2014)

Based on these estimations, the median average generation rates are determined as 0.073 tons/m^2/yr for office buildings, 0.040 tons/m^2/yr for retail buildings, and 0.039 tons/m^2/yr for residential buildings.

h) Researching Generation Rates: Private Transportation

A key source of annual CO_2 emissions data for passenger vehicles including cars and average trucks is the EPA Calculations and References publication (EPA-REFS, 2014), which reports that the average annual CO_2 emission rate for passenger vehicles is approximately 4.75 tons per vehicle per year. In another detailed lifecycle analysis study done in Japan, Matsumoto et al. (2012) estimates that a typical household passenger vehicle driven at an average of 10,000 km generates an average of 8.350 tons of CO_2 emissions per year (p. 792) (see Table 4.4).

Table 4.4 Annual emissions from vehicles (Matsumoto et al., 2012, Table 1, p. 792)

Automobile	Calculation Conditions (Household Basis)	CO_2 Emissions (Production)	Duration	Data Reference
Gasoline (10 km/L)	10,000 km/yr	8,350 kg	2,040 kg/yr	[3]

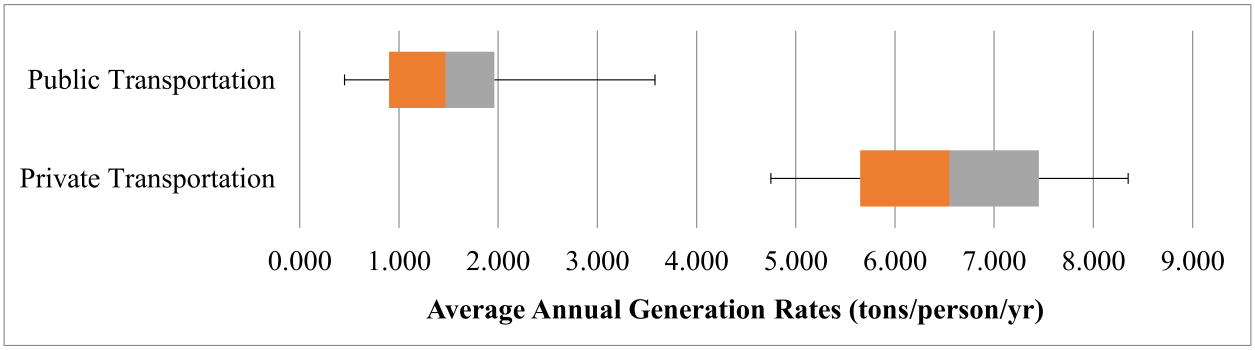
i) Researching Generation Rates: Public Transportation

There are some studies in the literature about the generation of annual CO_2 emissions from public transportation systems (UITP, 1998). The majority of these studies are about the functional and financial efficiency of major transportation networks in the larger metropolitan areas such as New York, Los Angeles, Denver, Houston, or Atlanta. For the purposes of the RUD Case Study, it was neither possible nor necessary to find a specific study that was conducted on the various modes of public transportation servicing the River North District. It is possible and appropriate to use estimated per capita emission rates from literature.

Specifically for the Chicago Metropolitan Area, APTA (2012) reports that the public transit system is estimated to register some 2,003,807,500 passenger-miles annually (APTA, 2012, p. 8). American Bus Association (2014) reports that CO_2 emissions per passenger-mile varies from 0.045 kgCO2/passenger-mile for motorcoach, 0.098 kgCO_2 for van service, to 0.179 kgCO_2/passenger-mile for commuter rail (ABA, 2014, p. 7). Using total population of the metropolitan area as well as the rates of average CO_2 emission per passenger-mile, it is possible to estimate average per capital emissions (tons/yr) and apply this average to the calculations.

Based on these estimations, the median average generation rates are determined as 6.550 tons/person for private transportation and 1.470 tons/person for public transportation (see Figure 4.14).

Figure 4.14 Median values are used to establish the average transportation generation rates



Generation (tons/person/yr)	Min.	Max.	Median	Standard Deviation	Sources
Private Transportation	4.750	8.350	6.550	2.5456	EPA (2014); Matsumoto et al. (2012)
Public Transportation	0.450	1.790	1.470	0.9475	APTA (2012); ABA (2014)

j) Establishing Average Generation Rates on Emissions

To summarize again, as the preceding research results indicate, the specific figures on the annual average CO_2 emissions per unit area (for buildings) and per person (private and public transportation) tend to show a significant variation depending on the scope, goals, assumptions and specific methodology of each type of research and/or study, which makes it difficult to decide on one single figure. As indicated on Figure 4.11, the median values of the variation in the data obtained from literature were used to establish average rates for the RUD Case Study. Based on the review of different resources cited in the preceding sections, the case study assumes the following set of average generation rates for purposes of estimating and calculating annual CO_2 emissions in the study area:

Office Buildings: 0.073 tons/m^2/yr
Retail Buildings: 0.040 tons/m^2/yr
Residential Buildings: 0.039 tons/m^2/yr
Private Transportation: 6.550 tons/yr per capita
Public Transportation: 1.470 tons/yr per capita

k) Calculating Total Amount of Current Anthropogenic CO_2 Emissions

By applying the above rates, the RUD Case Study estimates the overall total anthropogenic CO_2 emissions in the RUD Case Study area to be 422,952 tons annually. Of these emissions, those from buildings make up 62.19% (263,026 tons/yr) and private transportation 30.88% (130,613 tons/yr = 6.5499 tons/yr per capita x 19,941 persons) while the public transportation modes account for only 6.93% (29,313 tons/yr = 1.4699 tons/yr per capita x 19,941 persons) (see Figure 4.15 and refer to Table 4.5).

Figure 4.15 The total amount of current emissions is estimated as 422,952 tons/yr

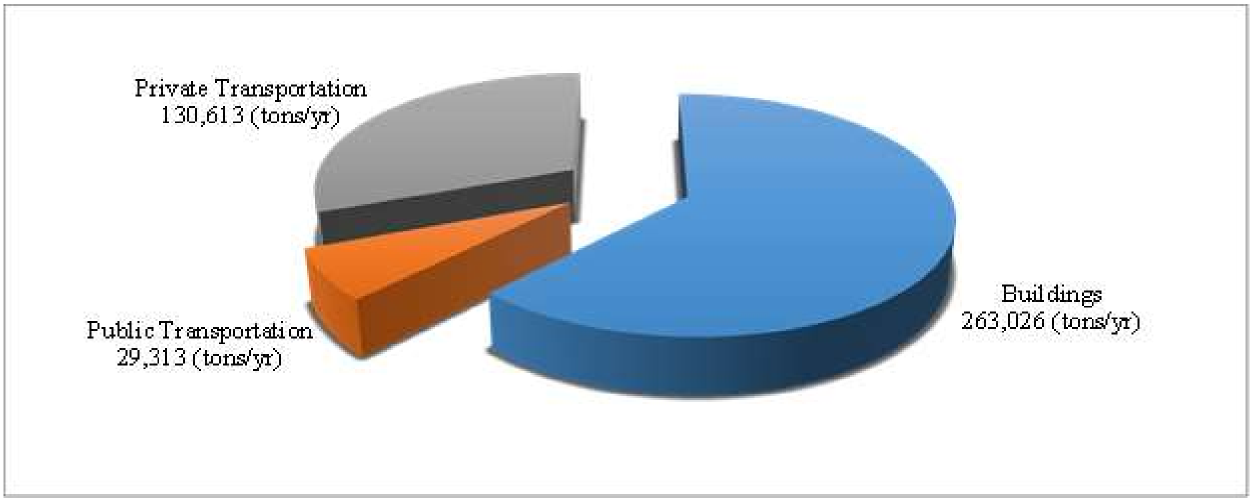


Table 4.5 Distribution of the estimated total of current emissions to major building types

Study Area City Blocks	Office (tons/yr)	Retail (tons/yr)	Residential (tons/yr)	Totals Per Block (tons/yr)
A1 through A9	852	2,253	19,653	22,757
B1 through B9	21,617	806	14,663	37,087
C1 through C9	5,720	664	40,305	46,690
D1 through D9	17,932	229	9,713	27,875
E1 through E9	3,582	308	10,038	13,928
F1 through F9	2,104	394	17,621	20,119
G1 through G9	31,945	289	3,885	36,118
H1 through H9	12,309	135	14,092	26,535
J1 through J9	1,846	166	14,821	16,832
K1 through K9	871	100	13,198	14,169
Overall Totals (tons/yr)	**98,940**	**5,344**	**158,742**	**263,026**

Considering that the total estimated anthropogenic CO_2 emissions are 422,952 tons/yr and the existing population of the study area is 19,941 persons, the current anthropogenic CO_2 emissions per capita can be estimated as 21.2103 tons/yr per person, which is a fairly high.

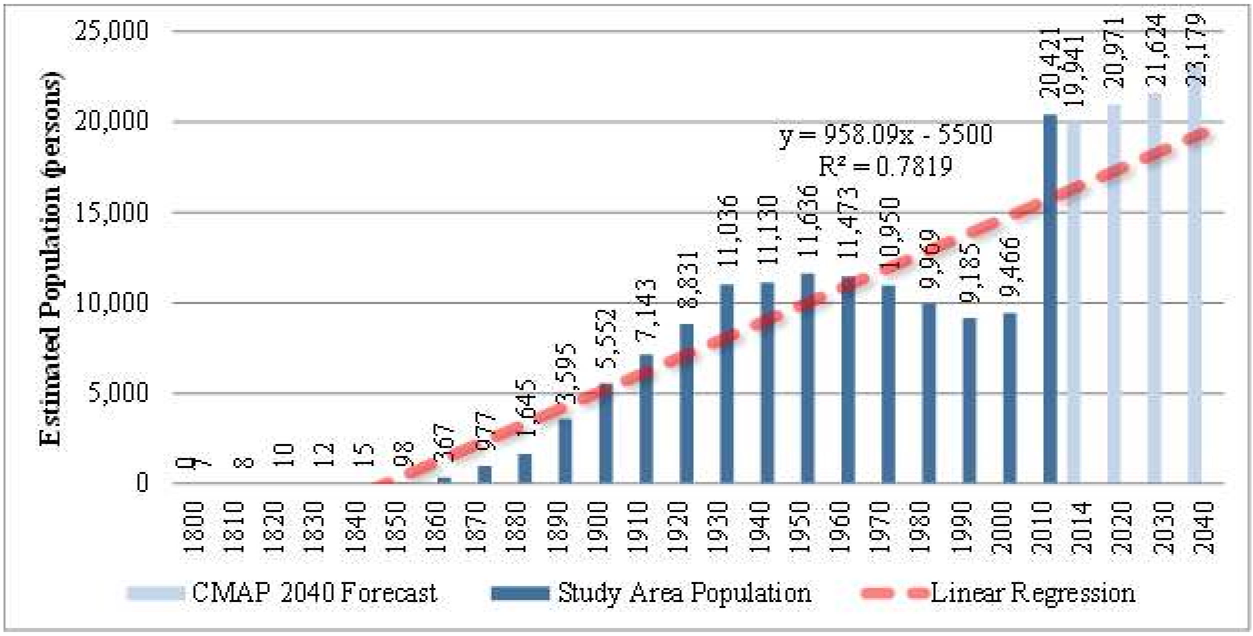
3. Determining Future Conditions: Trajectory Forecast (TFORE)

In the RUD model the historic and present conditions of a study area are used to forecast the future trajectory of that study area. The model calls for regression analyses in order to establish the trajectory forecast (TFORE) scenario based on the historic progression (HPROG) scenario (refer to Figure 3.5). Even though there are officially adopted urban population growth forecasts available for the Chicago Metropolitan Area by the Chicago Metropolitan Agency for Planning (CMAP, 2012), the TFORE estimations of the case study included two regression analyses to describe and evaluate other viable projections in determining trajectory forecast.

a) Linear Regression Analysis

The first example is a linear regression analysis based on the available data set for the study area population through 2014 (see Figure 4.14). The analysis yields an R^2 value of 0.7819, which is a reasonably modest fit considering the fluctuations in the historical data. The population data records a significant downturn in growth starting 1940s (refer to Table 4.6). The population in the study area continues to recede considerably between 1950 and 2000 as shown.

Figure 4.16 Linear regression analysis produces an R^2 value of 0.7819



Perhaps one of the most significant issues in this particular projection is that the estimated population forecasted by linear regression in 2014 (17,194 per Table 4.6) is well below the available estimated population for 2014 for the study area (19,941). Although the linear regression trendline runs fairly parallel to the CCAAP (2009) forecast it does not even reach the level of current population (19,941) until much later than 2040. This can be adjusted by translating the trendline by the difference between the available population (19,941) value and the regression value (17,194) for 2014, i.e. 2,747. However, that would change the R^2 value significantly. Therefore, it is reasonable to explore other methods of forecasting in search of a better fitting curve for the projection.

b) Polynomial Regression Analysis

The second example is a polynomial regression analysis based on the same data set for the study area population through 2014 (refer to Table 4.6). The analysis achieves an R^2 value of 0.7963, which is a slightly better fit than the linear regression analysis. Concerns similar to the previous analysis are also present in these results as shown on Figure 4.17 as summarized in Table 4.6. The estimated 2014 population projected by the polynomial regression (17,462) is below the available estimated population value for the study area (i.e. 19,941 in 2014). Since this regression trendline has a greater slope than the CCAAP (2009) forecast it surpasses the level of current estimated population of 19,941 by 2030, reaching 20,013 (refer to Table 4.6).

Figure 4.17 Polynomial regression analysis produces an R^2 value of 0.7963

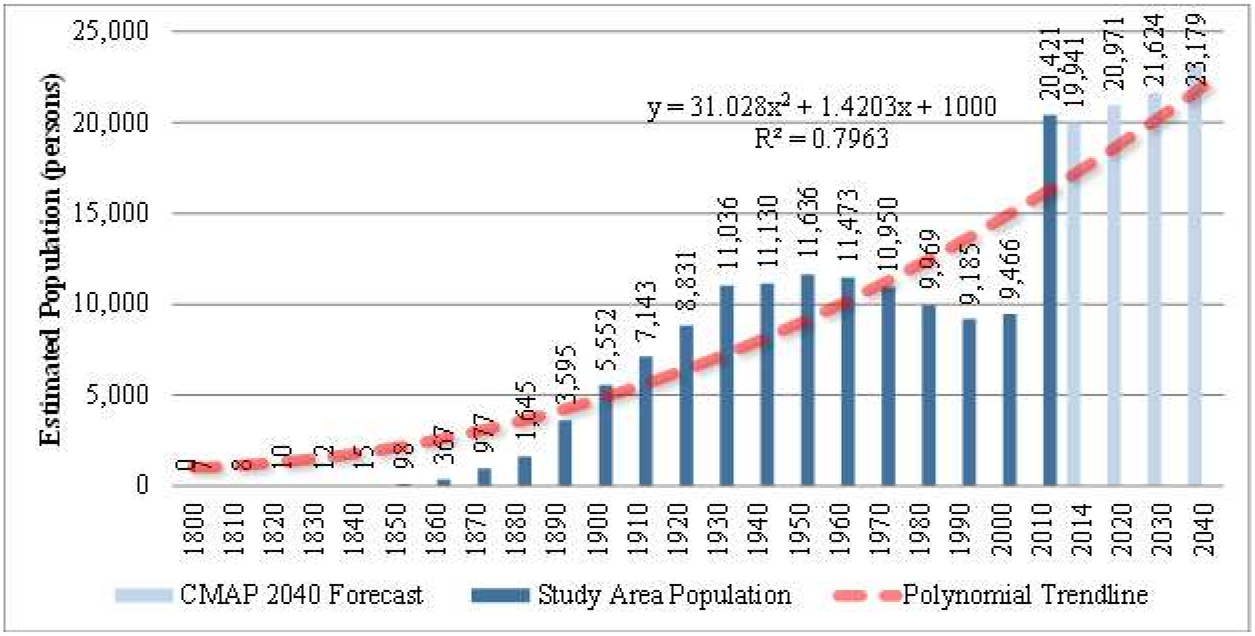


Table 4.6 Historic, present and projected population

Year	Study Area Pop.	CCAAP Forecast	Linear Regression	Residual	Stand. Dev.	Polynomial Regression	Residual	Stand. Dev.
1800	3			3,557	1.2841	1,000	-993	-0.3921
1810	7			2,589	0.9348	1,037	-1,029	-0.4061
1820	10			1,622	0.5856	1,147	-1,136	-0.4484
1830	13			654	0.2363	1,327	-1,315	-0.519
1840	15		327	-313	-0.1129	1,580	-1,565	-0.6179
1850	98		1,297	-1,199	-0.4328	1,905	-1,807	-0.713
1860	367		2,266	-1,899	-0.6857	2,301	-1,934	-0.7633
1870	977		3,235	-2,258	-0.8152	2,769	-1,791	-0.707
1880	1,645		4,205	-2,560	-0.9242	3,308	-1,663	-0.6565
1890	3,595		5,174	-1,579	-0.5701	3,920	-325	-0.1281
1900	5,552		6,143	-591	-0.2135	4,603	949	0.3747
1910	7,143		7,113	30	0.011	5,358	1,785	0.7046
1920	8,831		8,082	749	0.2704	6,184	2,647	1.0446
1930	11,036		9,051	1,985	0.7167	7,083	3,954	1.5605
1940	11,130		10,021	1,109	0.4005	8,053	3,077	1.2144
1950	11,636		10,990	646	0.2334	9,095	2,542	1.0032
1960	11,473		11,959	-486	-0.1756	10,208	1,265	0.4991
1970	10,950		12,929	-1,979	-0.7144	11,394	-444	-0.1751
1980	9,969		13,898	-3,929	-1.4184	12,651	-2,681	-1.0583
1990	9,185		14,867	-5,682	-2.0516	13,980	-4,795	-1.8925
2000	9,466		15,837	-6,371	-2.3001	15,380	-5,914	-2.3343
2010	20,421		16,806	3,615	1.3052	16,853	3,568	1.4083
2014	19,941	19,941	17,194	2,747	0.9919	17,462	2,479	0.9785
2020		20,971	17,775	3,196	1.1537	18,397	2,574	1.0158
2030		21,624	18,745	2,879	1.0395	20,013	1,611	0.6358
2040		23,179	19,714	3,465	1.2511	21,700	1,479	0.5836

The polynomial regression projection reaches 21,700 by 2040 (refer to table 4.6), which is significantly lower than the CCAAP (2009). The results of this fitted-curve regression does represent the general trend of population change and growth in the study area rather well, and could be used for the future. Even though this projection is arguably better than linear regression projection, the CCAAP forecast (2009) appears to be even better in representing the population trends.

c) CCAAP (2009) Population Forecast

The CMAP 2040 population forecast prepared by the Chicago Metropolitan Agency reports the Central Chicago Area population to be 2,895,995 in 2000, 2,838,769 in 2007, and projects the area population to possibly reach 3,194,353 by 2040. For the purposes of RUD Case Study, the CCAAP (2009) population forecast prepared for the Central Chicago Area population provides a reasonable trajectory of possible urban re/developments in the future of River North District through 2040. If the same trends and rate of increase are assumed to take place in the study area, the population of the RUD Case Study area can be estimated to reach 20,971 in 2020 and 21,624 in 2030 to 23,179 by 2040 (CCAAP, 2009) (refer to Table 4.6).

Based on this population trajectory forecast (see Figure 4.18), an estimate of the Trajectory Forecast (TFORE) scenario for anthropogenic CO_2 emissions can be produced by multiplying the average per capita rate of 21.2103 tons/yr with the projected study area population in Table 4.6. The trajectory below projects the annual emissions at 517,581 tons/yr in 2020, reaching 533,699 tons/yr by 2030, and finally 491,637 tons/yr by the year 2040 (see Figure 4.19).

Figure 4.18 Projected population of study area is based on CCAAP (2009) forecast

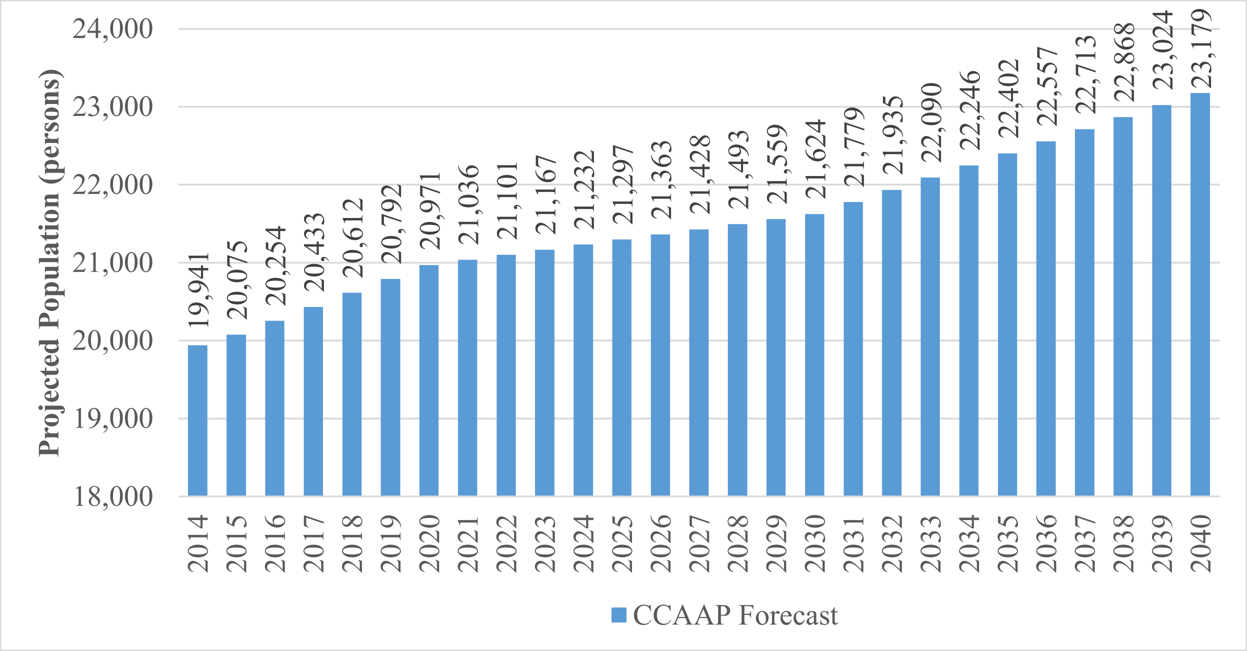


Figure 4.19 Trajectory Forecast (TFORE) scenario is established by projected population

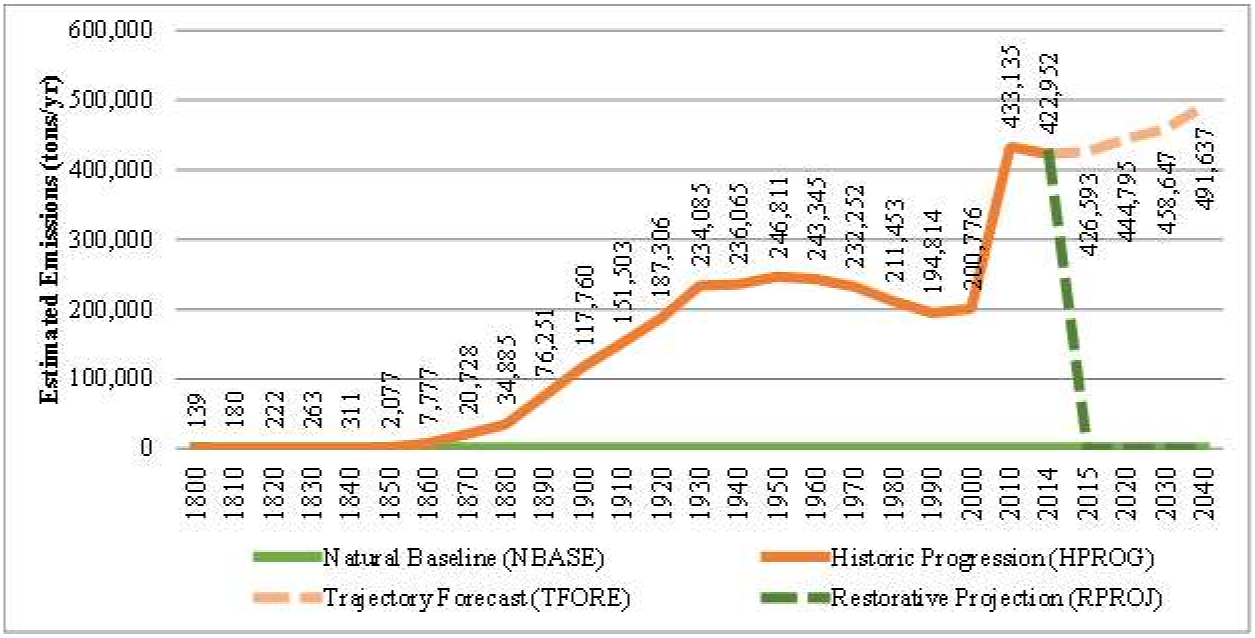
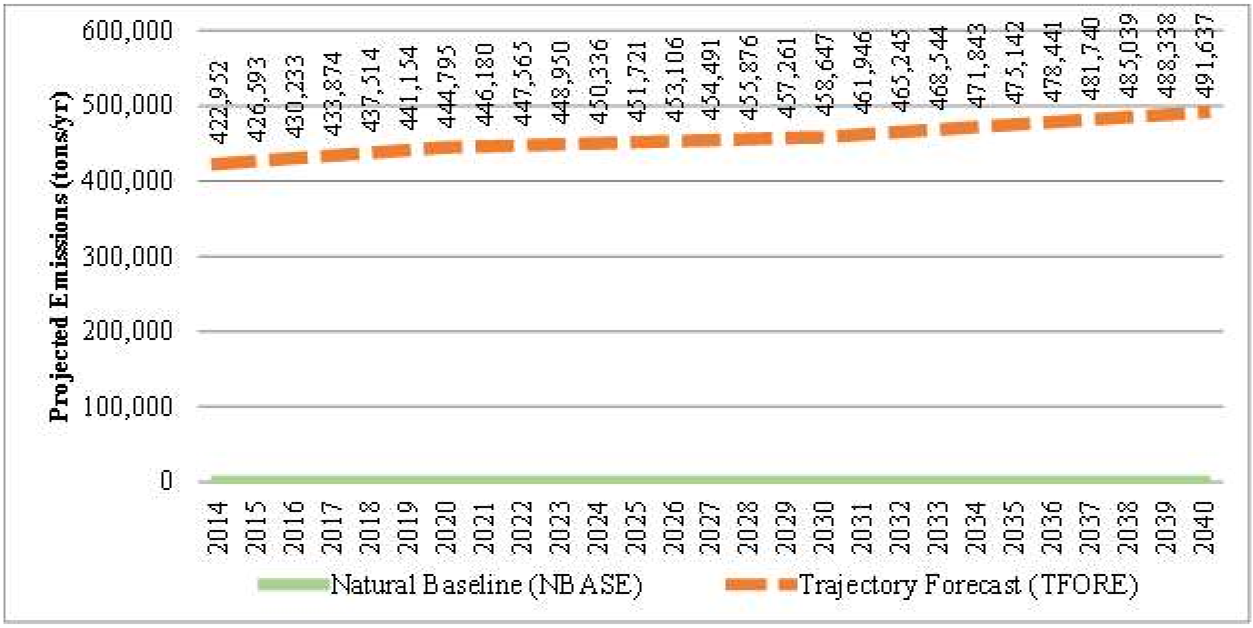


Figure 4.19 presents a composite summary of all major scenarios that make up the RUD Case Study. The figure shows the Natural Baseline (NBASE) scenario to be zero in the case of anthropogenic CO_2 emissions, which is a natural functional condition that can be targeted for restoration. The Historic Progression (HPROG) scenario is also clearly indicated as a line of increasing values through time, following the human population trends in the study area, which ultimately reaches the current estimated level of 422,952 tons/yr for the study area.

From there the Trajectory Forecast (TFORE) scenario indicates that the annual anthropogenic CO_2 emissions can be expected to increase in parallel with the increase in the human population reaching up to 491,637 tons/yr by the year 2040 (see Figure 4.20). The Restorative Projection (RPROJ) scenario in this figure shows that the mitigation of the anthropogenic CO_2 emissions is theoretically immediate since adequate amount of offsite mitigations need to be provided in order to achieve the goal of zero emissions annually almost immediately.

Figure 4.20 Total annual emission generation is forecasted based on area population



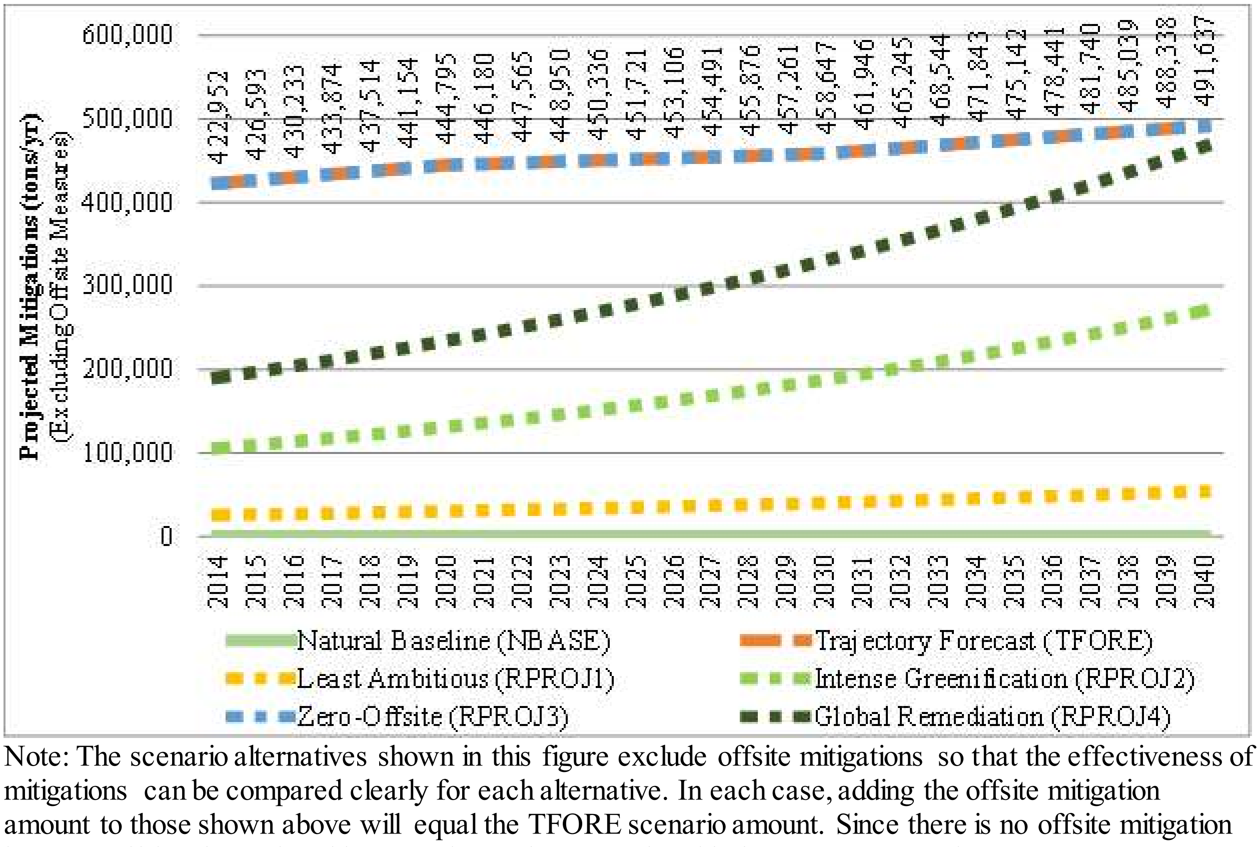
The Trajectory Forecast (TFORE) scenario itself may be subject to fluctuations and changes influenced by a number of real-world conditions. First and foremost, the population and demographics of the study area may change due to migration of people in and out of the area effecting the expansion or contraction of office, retail, and/or residential uses. Second, the forces in the capital market such as employment, services, and investments may drastically shift the demographics of the district. Third, there could be fluctuations or changes in the per capita emissions due to potential improvements in different system and technologies related to building heating and/or cooling, electricity generation, private and public transportation modes. Any and all of these systems and technologies can change the course of trajectory forecast. Finally, there is always the possibility of various acts of nature to completely change course for the entire area, which are obviously not accounted for in this study. Beyond these possibilities the Trajectory Forecast (TFORE) scenario estimates the emissions to be mitigated by the Restorative Projection (RPROJ) scenario at the end of the evaluation and optimization process.

4. Exploring Restorative Conditions: Restorative Projection (RPROJ)

At this point in the scenario-comparison process, the baseline, historical, present, and trajectory conditions are established for the purposes of evaluating and optimizing restorative scenario alternatives. From this point forward the estimations are concentrated on determining the key factors of mitigative efforts and choosing between the various directions mitigations may take toward the achieving baseline design conditions. Since each contributing factor may show an inherent range of variation, the complexity as well as flexibility in these evaluations may be considerably high.

As described in Chapter 3, the design assumptions of the restorative scenario are intended to be refined repeatedly – creating different scenario alternatives – in order to arrive at urban re/development strategies that most closely align with the natural baseline conditions. With varying levels of mitigation measures onsite and/or offsite it becomes theoretically as well as practically possible not only to neutralize the current environmental impacts of an urban area but also to register advances toward the remediation of the natural balances, which are critically needed at this time in history. Depending on the intensity of mitigations there are various possible paths – or scenario alternatives – to achieve the natural baseline conditions by 2040 within the study area (see Figure 4.19).

Figure 4.21 Case study forecasts a number of possible restorative scenario alternatives



Note: The scenario alternatives shown in this figure exclude offsite mitigations so that the effectiveness of mitigations can be compared clearly for each alternative. In each case, adding the offsite mitigation amount to those shown above will equal the TFORE scenario amount. Since there is no offsite mitigation in Zero-Offsite alternative this scenario overlaps exactly with the TFORE scenario.

The estimated total of anthropogenic CO_2 emissions likely to be generated between 2014 and 2040 in the case study area i.e. the Trajectory Forecast (TFORE) scenario remains constant and the same throughout all scenario alternatives as shown on the figure below as well as Tables I.1, J.1, K.1, and L.1 in Appendices I through L. All of the annual emissions in the future estimated in the TFORE scenario need to be entirely mitigated in order to reach the NBASE scenario conditions i.e. net zero emission balance or better. The alternatives are evaluated toward determining a single set of restorative conditions that achieve net zero emissions – or even perhaps some global remediation – by the year 2040.

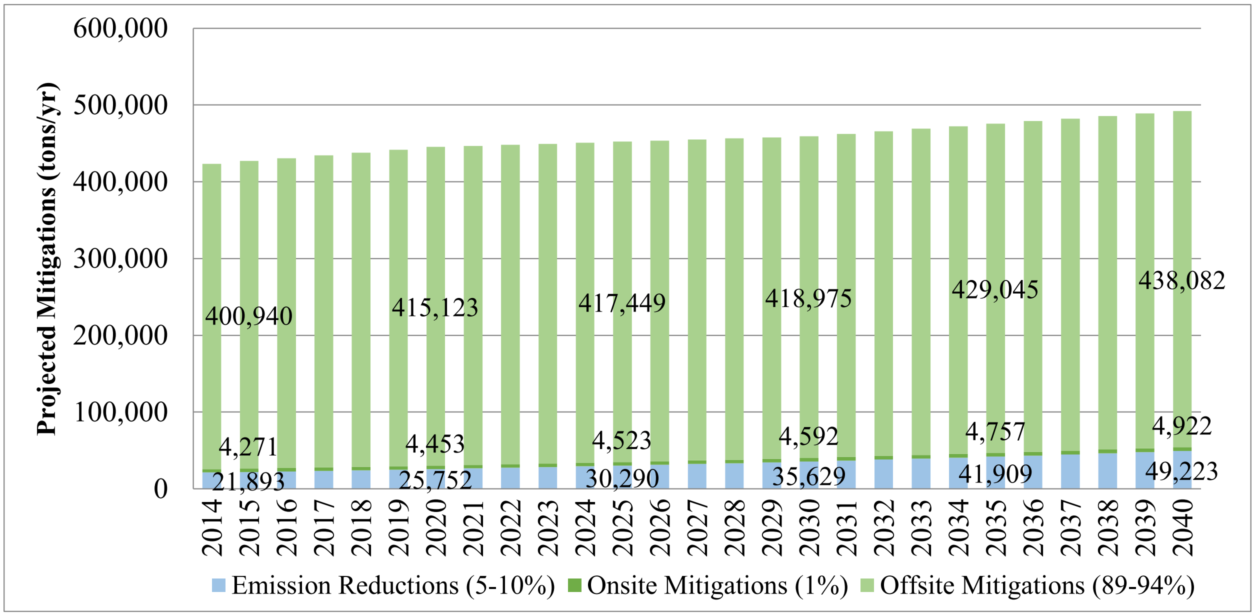
During the optimization process, a number of key alternative restorative projection scenarios are generated in order to examine how the design assumptions may vary resulting in different restorative measures. The alternatives may also be used to evaluate feasibility and viability of restorative measures in achieving different end results. The basic design assumptions used in the construction of each restorative projection scenario alternative are: Energy Reductions; Non-CO_2 Emitting Energy; Onsite Mitigations; and Offsite Mitigations. The reiterative alternatives features a different combination of these design assumptions as suitable and relative to the context of each scenario. The design assumptions in each scenario alternative are used to fully mitigate the emissions estimated by the TFORE scenario through charting a slightly different route. All of these variations need to be evaluated in order to determine which combination of possible onsite and offsite mitigation measures could potentially be a more optimal restorative application for the study area. Depending on the intensity of design assumptions the required amount of mitigation measures also varies.

The first alternative scenario is the least ambitious of the alternatives and includes no onsite mitigations as shown on Figure 4.19. In this scenario, the forecasted emissions are mitigated largely through offsite mitigations with minimal emission reduction measures onsite. Offsite mitigations are integrated into each scenario alternative as necessary. The second scenario introduces more intense greenification measures with a moderate level of onsite mitigations, primarily via improving the energy efficiency of buildings and transportation systems in the district, but still requiring a relatively large amount of mitigations offsite. The third alternative scenario, zero offsite mitigation scenario, explores the hypothetical circumstances under which estimated CO_2 emissions are entirely mitigated through onsite measures. Finally, the global remediation is the most aggressive, in that, in addition to fully mitigating anthropogenic CO_2 emissions from the study area, it also aims to remediate the existing excess carbon already present in the atmosphere by sequestering up to 20% more CO_2 than full mitigation.

a) Restorative Projection Scenario Alternative 1 – Least Ambitious (RPROJ1)

The first scenario alternative, Least Ambitious (RPROJ1), explores the design assumptions for the least ambitious environmentally restorative measures implemented onsite to mitigate CO_2 emissions generated within the RUD Case Study area. It assumes no significant changes made in the trajectory of growth and expansion or the inventory of existing buildings or onsite conditions within the study area through 2040. The trajectory of urban developments in this scenario between now and 2040 are assumed to take place at business-as-usual pace and as an extension of historical status quo patterns without any significant changes (see Figure 4.22).

Figure 4.22 Least ambitious scenario alternative represents minimal onsite mitigations



Note: The total amount of annual mitigations for each year in this figure equals to that of the TFORE scenario for that year.

This scenario incorporates a steadily increasing level of emission reductions starting from 5% (21,173 tons/yr) in 2014 to 10% (49,223 tons/yr) through the year 2040 as the existing building standards, systems, and technologies are highly likely to improve gradually over time (refer to Table I.1 in Appendix I). During the next 25 to 30 years within the study area building renovations and additions are also likely to replace some portion of the older inventory as normal cycle of demolition and new construction continues. Assuming a steady increase in emission reductions – reaching up to 10% by the year 2040 – appears to be reasonable for this scenario. This range can be considered as representing the lower end of environmental performance improvements that can be targeted and actually achieved by the buildings and vehicles in the study area.

The existing green cover in the study area is estimated to have an approximate total area of 3.514 ha (35,140 m^2). The amount of anthropogenic CO_2 to be sequestered and stored by this green cover is estimated at 3,009 tons/yr, which equals little more than 0.5% of total emissions generated onsite. This is the only onsite mitigation estimated as part of this least ambitious scenario alternative, which is represented as 1% in Figure 4.22.

The remaining amount of emissions, then, needs to be mitigated offsite, which are estimated to be about 94 to 89% (438,082 to 398,052 tons/yr) of the required anthropogenic CO_2 emission mitigations (refer to Table I.1 in Appendix I). The minimum size of offsite mitigation forest to fully sequester and store the amount of anthropogenic CO_2 emissions is estimated to be 540 ha (5.401 km^2) in 2014, steadily increasing to 594 ha (5.944 km^2) by 2040 (refer to Figure 4.29 and Table N.1 in Appendix N).

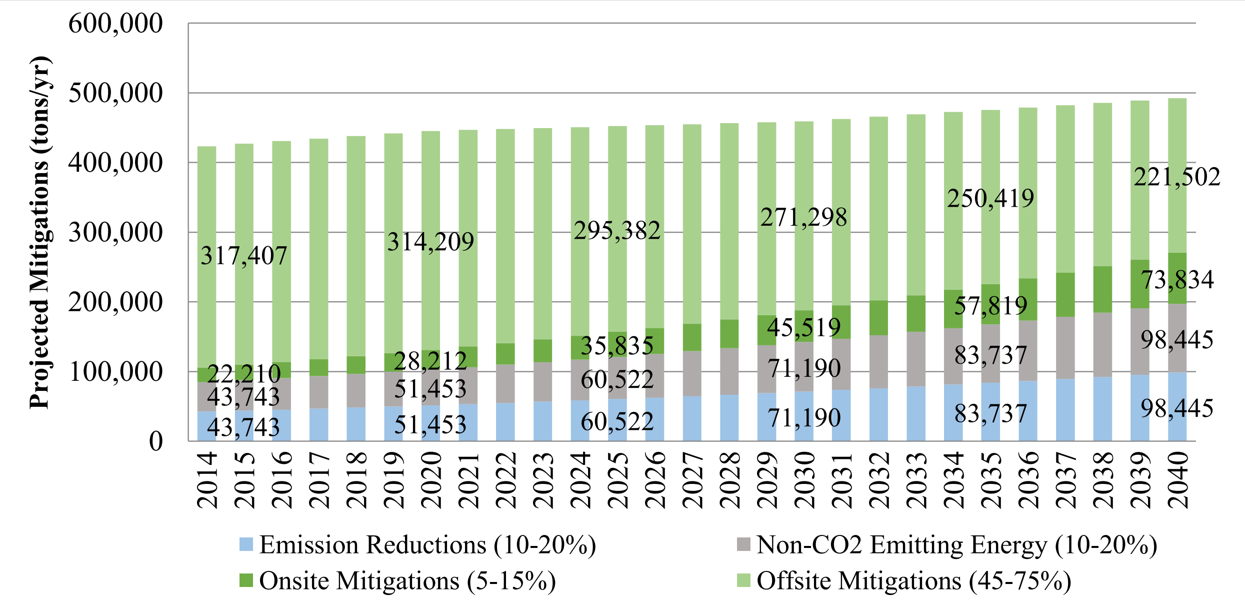
While this scenario is arguably the least encouraging projection from the perspective environmental restoration, sadly, it is perhaps highly realistic from the perspective of its potential to happen if one assumes that the current regulatory conditions and development practices do not change. When the onsite mitigations are limited only to the increase of natural green cover, the implementation of onsite mitigations in highly dense urban environments becomes extremely challenging due to many reasons. Two of the primary issues are noted here. First, dense urban areas are typically substantially developed with asphalt, concrete, glass, and steel where nearly all areas are utilized for some built use. Conversion of buildings and parking lots to open or green spaces is often very difficult, costly, and may be nearly impossible in many situations. Second, only a limited range of created/restored natural systems and constructed “green installations” can be made on existing pavements, roofs and walls. Each of these typically requires substantial renovation and maintenance costs.

In order for these installations to be effective from a CO_2 sequestration and storage standpoint, considerable modifications need to be made to existing structural, insulation, and/or irrigation systems. In the absence of legal requirements and/or regulations, the necessary onsite mitigations remain only voluntary and are often conveniently overlooked or ignored. Thus negative impacts are passed on to the larger environment where CO_2 and other impacts continue to accumulate.

b) Restorative Projection Scenario Alternative 2 – Intense Greenification (RPROJ2)

The Intense Greenification (RPROJ2) scenario alternative introduces an increased number and/or intensity of restorative mitigation measures into the re/development of the study area between 2014 and 2040 (see Figure 4.23). This alternative assumes that moderate to high level of onsite mitigations are implemented throughout the study area through 2040.

Figure 4.23 Intense greenification scenario alternative presents optimal onsite mitigations



Note: The total amount of annual mitigations for each year in this figure equals to that of the TFORE scenario for that year.

The assumptions behind intense greenification start with a constantly rising level of emission reductions from 10 to 20% (42,346 to 98,445 tons/yr) by the year 2040 (see Table J.1 in Appendix J), which would be achieved mainly through the increased energy efficiency of existing or new buildings as well as private transportation in the study area (refer to Table J.1 in Appendix J). Even though these reductions require moderate levels of improvements in the building materials, heating and cooling equipment as well as types of cars in operation they are reasonably easy for thoughtful designers and engineers to accomplish.

The scenario also introduces a heightened level of integrating non-CO_2 emitting energy resources (10 to 20%, or 49,346 to 98,445 tons/yr) as shown on Table J.1 in Appendix J. These types of energy generation systems essentially rely on renewable resources such as solar or wind. The non-CO_2 emitting energy can either be generated by the systems installed onsite in various locations throughout the study area or come from offsite sources in the form of green power. Installation of a central heating and power plant relying on non-CO_2 emitting energy resources is perhaps the most efficient way to take advantage of neighborhood or district scale efficiencies.

The onsite CO_2 sequestration and storage mitigations introduced by the Intense Greenification scenario alternative rely primarily on installation of new green spaces, green roofs and green walls in the most opportune locations throughout the study area. The proposed green roofs are estimated to cover about 13.857 ha (138,569 m^2) whereas the opportunities for green walls are estimated at 1.482 ha (14,819 m^2). Even though the Intense Greenification scenario aims to maximize the possible onsite mitigations it is estimated to be sufficient only for mitigation of 5 to 15% (21,173 to 73,834 tons/yr) of the total anthropogenic CO_2 emissions (refer to Table J.1 in Appendix J).

The remainder of the required mitigations need to take place offsite as indicated on Figure 4.23. The estimated amount of the required offsite CO_2 emissions varies by each year, declining from 75% (317,595 tons/yr) in year 2014 down to 45% (221,502 tons/yr) by 2040. The size of offsite mitigation forest to fully sequester and store the amount of anthropogenic CO_2 emissions is estimated to range from 431 ha (4.309 km^2) in 2014 to 301 ha (3.005 km^2) by 2040 (refer to Figure 4.29 and Table N.1 in Appendix N).

This scenario is considerably more ambitious and costly, and thus potentially much more complicated to achieve than the previous scenario, yet it is theoretically within reach. Difficult as it may be it is achievable and feasible with the appropriate alignment of resources. The application of green roofs and green walls on existing and future buildings in River North District is likely to offer significant opportunities and challenges in the way of re/development. The current technologies of green wall and green roof systems often necessitate considerable modifications to the existing structures and finishes of buildings. For the buildings that are historic and/or preserved, or that are likely to remain structurally unaltered through 2040, the restorative greenification applications are challenging at best. Many restorative opportunities are with those buildings that are relatively newer, stronger, and/or structurally in need of sizable alterations.

Based on the recent history and current conditions of the study area, it is safe to assume that between 2014 and 2040 a certain portion of the existing buildings will be completely demolished and redeveloped in more dense and compact manner. Such projects are excellent opportunities for more aggressive mitigation strategies to be implemented.

In addition to the green roofs and green walls, the Intense Greenification (RPROJ2) scenario incorporates a network new green spaces to be added throughout the study area, which is estimated to be 22,817 m^2 (2.282 ha). The reclamation of these green spaces are primarily assumed to take place in the largest surface (on-ground) parking areas within the district. Such land use change may be made possible in part by the construction of new parking structure(s) and in part by increased integration of alternative transportation modes.

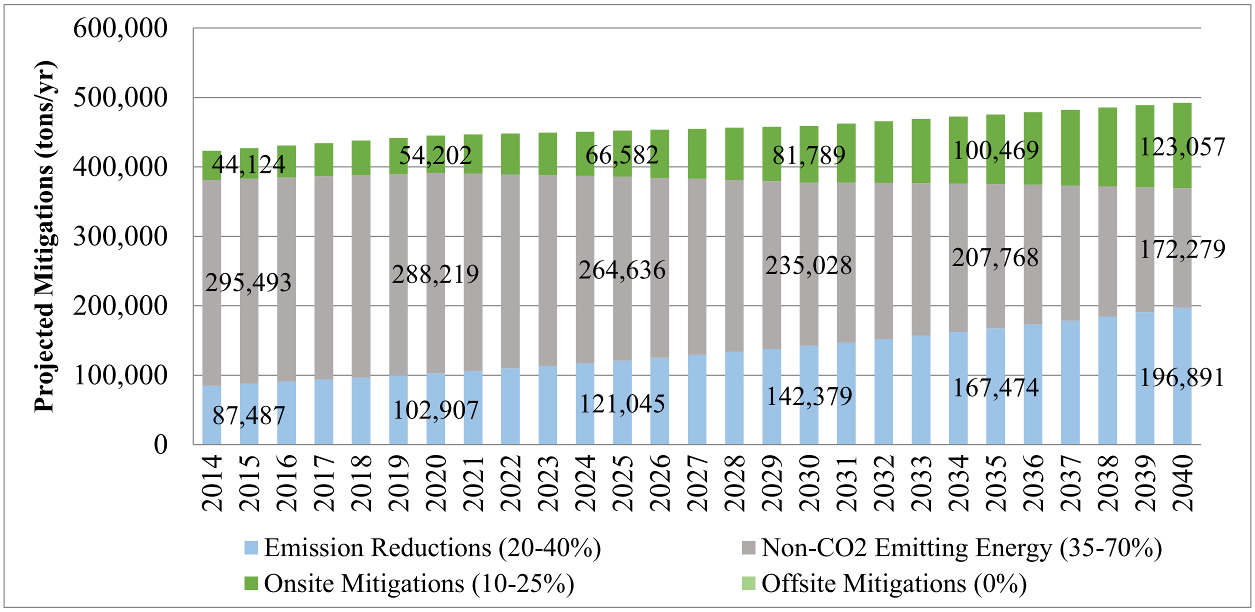
Establishing a district-wide collaboration as well as public/private partnerships among property owners, stakeholders, utility companies, and local governments may enable innovative restorative strategies neighborhood-wide. Local generation of food and energy as well as reclamation of new green spaces can be made possible in the Intense Greenification scenario through a district-wide consensus on necessity for comprehensive environmental restoration. In order to accomplish some of the neighborhood or district-wide strategies and practices, new local zoning and regulations can be activated, perhaps as overlay zoning regulations, so that there are requirements, incentives, and enforcement of restorative measures.

c) Restorative Projection Scenario Alternative 3 – Zero Offsite (RPROJ3)

While the previously discussed restorative scenarios focus on balancing different combinations of onsite and offsite mitigation strategies there is also a hypothetical yet highly desirable possibility of zero offsite mitigations. That is, all of the anthropogenic CO_2 emissions generated by a particular study area need to be addressed through onsite mitigation strategies and measures, requiring no offsite mitigations at all. This is, of course, a theoretical scenario and an extremely difficult one to achieve with respect to the re/development standards and regulations that exist today. Nevertheless, it is a useful exercise to illustrate the amount and nature of CO_2 emission mitigations that would be required with the scenario. For global remediation purposes, the total amount of estimated mitigations need to be increased even further.

A restorative scenario alternative that explores zero offsite mitigations has to concentrate on mitigating all of the forecasted anthropogenic CO_2 emissions through reducing energy use and emissions, increasing energy efficiency, relying on non-CO_2 emitting energy sources, and maximizing onsite mitigations. All of the natural onsite sequestration and storage strategies such as rain-gardens, green roofs, green walls, and associated networks of other new green spaces would need to be incorporated (see Figure 4.24).

Figure 4.24 Zero offsite scenario alternative relies on the rest of design assumptions



Note: The total amount of annual mitigations for each year in this figure equals to that of the TFORE scenario for that year.

The Zero Offsite Mitigation (RPROJ3) scenario alternative starts with maximized emission reductions, which are assumed to rise from 20% (84,692 tons/yr) in 2014 to 40% (196,891 tons/yr) by 2040 (refer to Table K.1 in Appendix K). As discussed previously in RPROJ2, achieving 30% reductions in the emissions solely through energy efficiency of buildings and vehicles is extremely ambitious where 40% is perhaps very close to being the upper limit of what most sustainable design strategies can deliver. High efficiency fuels, extra building insulation, automatic controls, and smart systems can significantly increase the environmental performance but the benefits are not limitless.

This scenario also relies on maximizing the onsite mitigations, which are estimated to range from 10% (49,346 tons/yr) in 2014 to 25% (123,057 tons/yr) by 2040 (refer to Table K.1

in Appendix K). The onsite mitigation assumptions are the same as the RPROJ3 scenario because there are not many more mitigations to be accomplished beyond what was already proposed for that scenario. Of course, if there is a massive transfiguration of the district (i.e. demolition and rebuilding of large sections with significantly innovative restorative strategies to mitigate emissions) then there could be the possibility of achieving greater than 40% mitigation onsite.

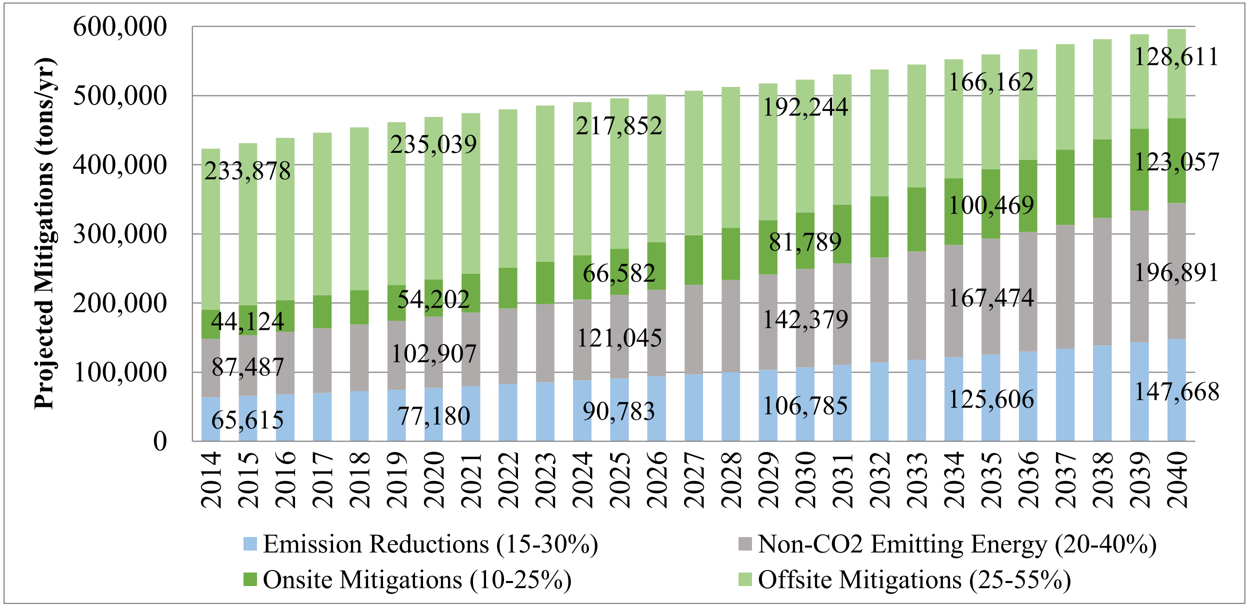
Since there are no offsite mitigations in this scenario, the remainder of the estimated anthropogenic CO_2 emissions are to be mitigated by using non-CO_2 emitting energy sources. In order to achieve zero offsite mitigations, the amount of emissions to be mitigated is estimated to range from 70% (296,422 tons/yr) in 2014 down to 35% (172,279 tons/yr) by the year 2040 (refer to Table K.1 in Appendix K). Seventy percent or 296,067 tons/yr is a very significant amount, which drives home not only the magnitude of emissions to be mitigated but also the important role that the non-CO_2 emitting renewable energy resources must play in this scenario.

The Zero Offsite Mitigation scenario alternative clearly illustrates that – even when the onsite mitigation potentials such as emission reductions, consumption efficiencies, and greenification strategies are completely exhausted – it is extremely challenging for restorative projection scenarios to accomplish all required mitigations onsite unless extremely innovative non-CO_2 emitting energy resources are utilized. By extension, this scenario also demonstrates the vital contributions that buildings, neighborhoods, districts, and cities relying on renewable energy resources can make toward the mitigation of anthropogenic CO_2 emissions. As ambitious as it is, this alternative still does nothing to remediate the excess carbon in the atmosphere.

d) Restorative Projection Scenario Alternative 4 – Global Remediation (RPROJ4)

If the application of the RUD model only aimed to "neutralize" or mitigate the anthropogenic CO_2 emissions from a particular study area then the application would have catered no benefit beyond bringing the net emissions to zero. This, however, would do little or nothing toward remediation of excess CO_2 gas that has already been released and residing in the global atmosphere. In order to contribute appropriately the global remediation, restorative scenario alternatives need be more rigorous in the way of mitigations (see Figure 4.25) (refer to Table L.1 in Appendix L).

Figure 4.25 Global remediation scenario alternative mitigations exceed full mitigation



Note: The total amount of annual mitigations for each year in this figure is greater than that of the TFORE scenario for that year.

Hence, the Global Remediation (RPROJ4) scenario alternative goes beyond neutralizing CO_2 emissions from the study area and explores even more intensive strategies to achieve sequestration and storage up to 104,000 tons/yr more than the projected amount of CO_2 emissions to be mitigated for the RUD Case Study area by the year 2040 (refer to Table L.1 in Appendix L).

To achieve the global remediation goals, this restorative scenario assumes emission reductions primarily through increasing energy efficiency improvements from 15% (63,519 tons/yr) in 2014 to 30% (147,668 tons/yr) by 2040. This is indeed a very aggressive but nevertheless feasible goal to achieve, in that, maximizing building energy performance by 15 to 30% only using energy efficiency strategies is deemed to be moderately difficult under rating systems such as LEED-NC&MR (2009), BREEAM (2011) or ILBI (2010). This goal is perhaps easier to achieve for new construction and major renovation projects but not as readily feasible for existing buildings. Needless to say, some buildings are expected to perform more efficiently than others, therefore, in order to reach the neighborhood-wide goals the performance of each building would need to be evaluated individually and then variations would be reconciled at the district level.

By the year 2040, the Global Remediation scenario alternative assumes that the buildings and systems within the study area rely on non-CO_2 emitting energy sources or technologies, estimated to mitigate from 20% (84,692 tons/yr) in 2014 up to 40% (196,891 tons/yr) of the forecasted emissions in the trajectory by 2040 (refer to Table L.1 in Appendix L). It is assumed that the availability and integration of green power (i.e. energy from renewable energy resources such as solar, wind, geothermal and so on) would steadily increase in the course of the next few decades since it has been steadily increasing in the recent years. Depending on the timing and magnitude of change in the integration of green power in the study area the non-CO_2 energy goals may be achieved and even surpassed by 2040. Local generation of heat and power exclusively from renewable energy resources is successfully practiced in many eco-districts throughout the world such as: Eco-Viikki, FIN; Kronsberg, DEU (Coates, 2009); Vauban Eco-District – Freiburg, DEU (Coates, 2013); Hammarby Sjöstad – Stockholm, SWE; Malmö. SWE; Sherwood Energy Village – Boughton, UK; Masdar City – Abu Dhabi, UAE. In the United States, there are also a number of examples such as: Civano – Tucson, AZ (Farr, 2008); Davis City, CA (Barton, 2000); Glenwood Park – Atlanta, GA (Farr, 2008); Holiday Neighborhood – Boulder, CO (Farr, 2008); and Lloyd Crossing Sustainable District – Portland, OR (Brickman, 2009). It is hoped that reliance on the non-CO_2 emitting energy sources reaches well beyond 40% by the year 2040.

The onsite mitigation measures for the restorative re/development of the study area under this scenario includes natural means of sequestration and storage such as green roofs, green walls and other plantings. By the year 2040, there may very well be technologies and methods developed to sequester and store the excess atmospheric carbon dioxide, however, the Global Remediation scenario does not take those possibilities into account. The onsite mitigations in the study area are assumed to range from 10% (42,346 tons/yr) in 2014 up to 25% (123,057 tons/yr) of forecasted emissions by the year 2040 (refer to Table L.1 in Appendix L). These onsite goals are also extremely ambitious to achieve. They include all of the greenification strategies and associated assumptions introduced in the RPROJ2 scenario and require provision of densely re/developed urban green spaces.

The remainder of the unmitigated anthropogenic CO_2 emissions are estimated to range from 55% (232,903 tons/yr in 2014) down to 25% (128,611 tons/yr), which represents a significant portion of the projected CO_2 emissions that need to be fully mitigated through implementation of offsite measures (refer to Table L.1 in Appendix L). Theoretically, there can be many different forms of offsite mitigation strategies. These strategies are conceived to restore the health and longevity in threatened, stressed, or even extinct naturally living conditions outside of the urban areas. The estimated size of offsite mitigation forest for this scenario ranges from 316 ha (3.160 km^2) in 2014 to 175 ha (1.745 km^2) by the year 2040 (refer to Figure 4.29 and Table N.1 in Appendix N).

Even though the locations of offsite mitigations are not predicated by the RUD model or Case Study there are perhaps practical and logistical reasons why they are preferably located near the urban areas from which they are generated. Perhaps one of the most immediate reasons is so that the improvements made to the surrounding natural environment can be directly benefited and enjoyed by nearby urbanites. In certain circumstances, wild habitats and core area species need to be fostered far from the immediate reach of humans. Otherwise, it is conceivable that, in most cases, offsite mitigation sites could be located in or adjacent to existing natural reserves in need of ecological restoration/reclamation. These "restored natural areas" could be locally, regionally, or even nationally established and managed by governmental or other appropriate entities.

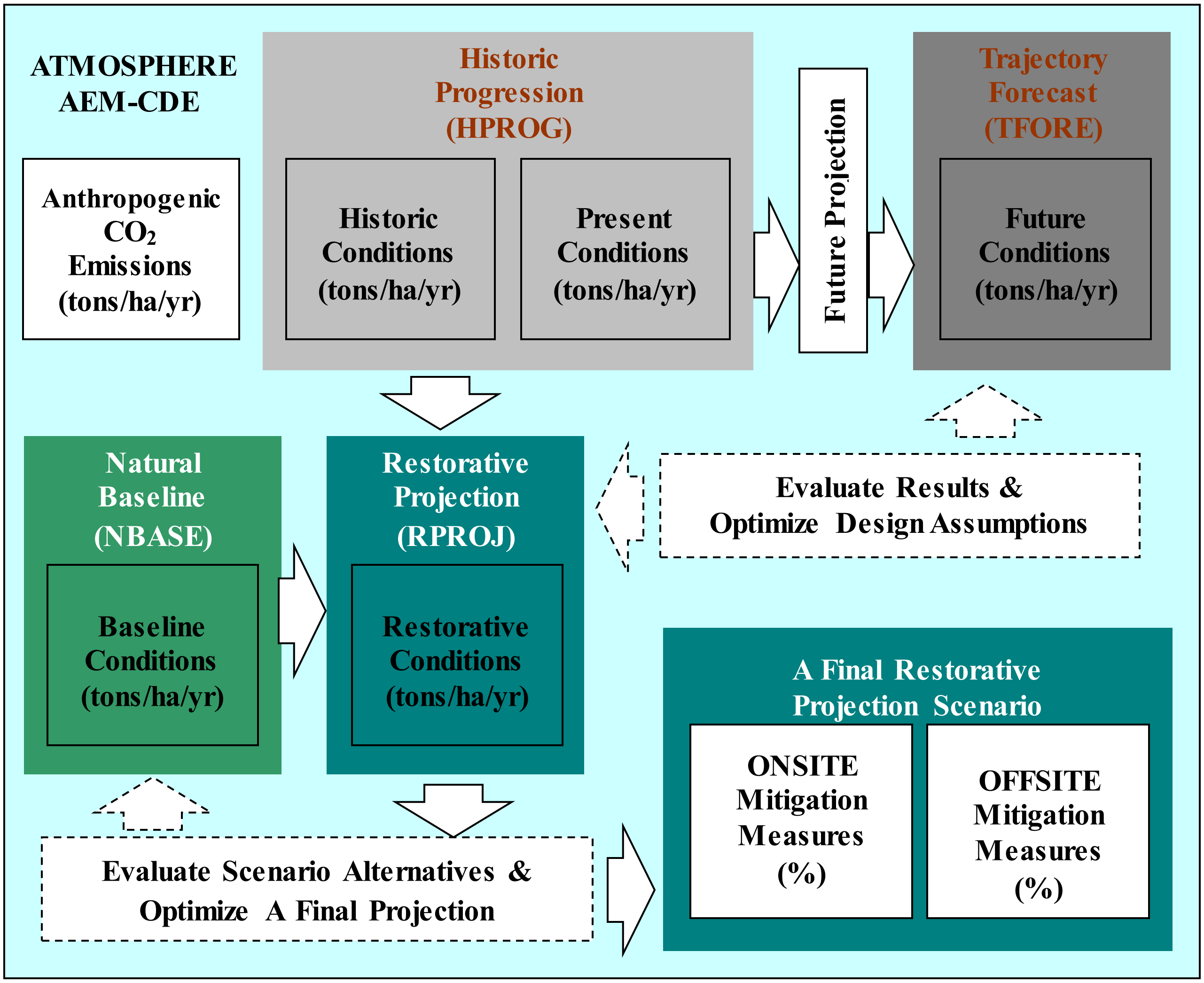
Nonetheless, it is a key objective of the restorative research to point out the urgent need and to facilitate the restorations of the natural environment. To that end, the intent and scope of offsite mitigations are to reestablish healthy ecosystems and forests, to rehabilitate degraded or disturbed wetlands, and to rejuvenate wildlife habitats and species in exurban areas. Clearly, the implementation of such re/developments depend on the cultivation of proper social values, necessary political will, required legal regulation and instruments including conservation easements and potentially the transfer of development rights as well as economic/financial support.

F. Evaluating Alternatives & Optimizing Design Assumptions

All of the possible restorative scenarios explored in the RUD model aim to fully mitigate the urban impacts through combination of onsite and/or offsite measures, plus perhaps making a certain amount of contribution to the global remediation as desired. One of the most critical parts of the restorative research is the evaluation and optimization of the design assumption on each indicator category using the TFORE and RPROJ scenario conditions. Since the end goal of the

RUD model is to recommend a single set of design strategies for urban re/development the performance of these two scenarios are reiteratively compared and critically evaluated in order to determine which aspects of the RPROJ scenario can be further optimized so that the expected results most closely approximate the NBASE scenario (refer to Figure 4.26).

Figure 4.26 Evaluating and optimizing a final projection is a reiterative process



The optimization of restorative strategies involves careful examination of a series of important components while making certain assumptions and decisions about the pattern of urban re/developments in order to achieve the desired environmental restorations. The success of restorative projections depend on the effectiveness of mitigation strategies aimed at counterbalancing the urban impacts.

While providing some hope for future, the field of mitigation technologies and standards related to sequestration and storage of anthropogenic CO_2 emissions is advancing rather slowly. Makhijani (2007) identifies a series of emission mitigation techniques as The Clean Dozen, which includes: emission limits, caps, and allowances; elimination of subsidies to fossil fuels and nuclear power; central solar power and heat stations; government purchase and distribution of critical technologies; banning new coal-fired power plants; federal level standards of higher efficiency on appliances, buildings, and vehicles; emission reduction incentives; and enactment of a new commission under EPA on Energy and Climate. While it will take some time for these techniques to become fully operational, currently for restorative purposes, conventional re/development strategies should include planting more trees, and increasing vegetation cover, green infrastructure and integrated plant communities (Pickett & Cadenasso, 2008). Providing a greater mixture of land use, integrating mass transportation, and spreading the use of renewable resources are arguably more accessible, achievable, convenient and effective re/development patterns (Barton, 2000; Ritchie & Thomas, 2009; Condon, 2010).

The process of evaluating and optimizing a final restorative projection for the RUD Case Study requires, among other considerations, estimating the following types and amounts of mitigations to be implemented in the study area through the year 2040.

1. Emission Reductions: Achieving Up To 40% Reduction in CO_2 Emission

As discussed in Chapter 1 and earlier in Chapter 4, even though there are many other major sources of anthropogenic CO_2 emissions, the RUD Case Study focuses only on four main sources that are directly related to the study area i.e. private transportation, public transportation, heating (natural gas and fuel oil), and electricity consumption (Glaeser, 2008). For the purposes of the RUD Case Study, emission reductions are primarily the decreased amounts of anthropogenic CO_2 emissions to be achieved from the performance improvement of buildings and transportation modes in the study area.

The Least Ambitious (RPROJ1) restorative projection scenario alternative supposes the reduction of forecasted emissions to increase from 5% (21,173 tons/yr) in 2014 to 10% (49,223 tons/yr) in 2040, which is very easily achievable. The Intense Greenification (RPROJ2) scenario alternative assumes reductions from 10 to 20 % (49,223 to 84,590 tons/yr) by the year 2040, which are significantly higher goals. The Zero Offsite (RPROJ3) scenario alternative assumes that reductions to rise from 20% (84,590 tons/yr) up to 40% (196,655 tons/yr) by 2040. And finally, the Global Remediation (RPROJ4) scenario alternative supposes the forecasted generation of CO_2 emissions to be reduced by 15% (63,443 tons/yr) to 30% (147,491 tons/yr), which is much more aggressive yet within reach of re/development. As discussed previously, achieving 40% reductions in the CO_2 emissions solely through energy efficiency of buildings and vehicles requires reaching the upper limits of what these technologies can deliver. High efficiency fuels, extra building insulation, automatic controls, and smart systems can significantly increase the environmental performance but they have real limits.

Since buildings are estimated to be the largest contributors of current CO_2 emissions from the study area (263,026 tons/yr or 62.19% of the total emissions) the majority of emission reductions need to be accomplished by the buildings (see Figure 4.15). All buildings in the United States, including existing buildings in the study area, are built to perform at least at the minimum performance standards established by the regulatory codes of building materials, mechanical systems, and energy performance. The minimum performance standards in the current codes are not very difficult to achieve, which is partly the source of current environmental problems. Hence, substantially improving on environmental performance beyond the minimum requirements is practically possible. The prominent areas of improving energy performance in the buildings includes changing types of mechanical systems and/or fuels, increasing building insulation, and installing automatic mechanical controls and smart systems to manage energy consumption. When performance enhancement strategies contained in various rating systems such as LEED-NC&MR (2009), BREEAM (2011), CASBEE (2010), and ILBI (2010) are applied to conventional buildings and systems typically energy savings up to 50% are within reach, mainly by making different selection choices on mechanical systems and utilities in addition to making systematic improvements to building envelopes. All of these improvements tend to increase initial costs but significantly lower the overall amount of lifecycle expenses (Melby & Cathcart, 2002; Yeang, 2006).

Not all types of mechanical systems and fuels are equal when it comes to CO_2 emissions. Certain types are much more efficient and/or versatile than others. The amount of fuel consumption, efficiency rates of generation and conversion, as well as the efficiency of conveyance play important roles in the generation of unit carbon dioxide emission per unit energy produced (Torcellini et al., 2006; Evans, 2007).

The requirements of wall and roof insulation provide one of the most critical venues to influence emission reductions. Even in the newly revised International Energy Conservation Code (IECC, 2012) the minimum requirements are easily achievable by integrating a layer of standard insulation, which is not sufficient to provide extraordinary efficiency. Small incremental increases in the insulating characteristics of building walls and roofs are often sufficient to make considerable changes in the amount of energy needed to keep the indoor spaces comfortably heated, cooled, and conditioned throughout the year. Detailed modeling and energy performance calculations can help designers and engineers estimate exactly how much decrease in energy consumption is possible, which translates to emission reductions where fossil fuels are currently utilized as energy resource (Kulman & Schurke, 2001).

The efficiency level of building and transportation systems in the study area are likely to improve significantly over time if the consumption of unnecessarily wasted energy can be minimized. One of the most effective ways to minimize energy consumption in buildings is to incorporate passive (or natural) design strategies and technologies (Brown & DeKay, 2001). Beyond these measures, the automatic mechanical controls prove to be very effective active design tools for reducing energy consumption and/or wastes. The artificial controls can be configured to provide optimum amount and timespan of lighting, heating, cooling, and ventilation for the users. The computerized, automated, and smart system control technologies are critically important in making up to 40% energy savings possible (AIA/COTE, 2005; CASBEE-NC, 2010).

Through 2040, a significant portion of the existing building inventory in the study area is likely to be replaced by sporadic renovations, alterations, additions, as well as completely brand-new reconstruction. The re/development process is likely to incorporate more of the smart building systems and technologies that monitor exterior and interior environment conditions, making energy-smart conditioning decisions based on the time of the day as well as the number and location of occupants. Quantifying the potential as well as actual CO_2 emission reductions by these systems would necessitate detailed energy modeling and simulation.

To achieve the higher goals of restoring the natural environment, the Global Remediation and Zero Offsite mitigation projection scenarios demonstrate the intense level of rigor that is necessary for urban re/developments need to exhibit. The varying levels of emission reductions are certainly possible to achieve up to a maximum of about 40%, which means that majority of existing and new buildings would have to perform at the upper ranges of rating systems such as LEED-NC&MR (2009), BREEAM (2011), CASBEE (2010), and ILBI (2010).

The current CO_2 emissions from private transportation is estimated to be 130,613 tons/yr, 30.88% of the total emissions for the study area. Achieving up to 40% CO_2 emission reductions in transportation depends on a number of different variables also. Reduction of use or reducing the need to rely on vehicles is perhaps one of the most fundamental goals of sustainable urban design practices as discussed in Chapter 2. These goals are more long-term than immediate. While automobiles are convenient, widely available, and frequently seen as "fun" or "enjoyable" for drivers and passengers, restorative efforts need to keep focus on walkable and bikeable neighborhoods where different modes of public transportation need to be available. Buses and other mass transit systems need to be provided where the overall population and urban densities are high enough to warrant these systems (Cervero et al., 2002).

Emission reductions from increasing fuel and performance efficiency of private vehicles are currently limited to only a few basic options. With the projected new technologies and federally mandated minimum fuel efficiency requirements, the 40% total combination of energy savings, efficiency increase, and emission reductions by the year 2040 is perhaps very hard to achieve but not entirely impossible.

2. Non-CO2 Emitting Energy: Achieving Up To 40% Reliance on Renewables

A second area of consideration for the purposes of restorative mitigations in the study area is the reliance on non-CO_2 emitting energy resources, which are estimated to play vital roles in decreasing the amounts of anthropogenic CO_2 emissions from buildings and transportation.

The Least Ambitious restorative (RPROJ1) scenario alternative integrates no significant amount of non-CO_2 emitting energy resources. The Intense Greenification (RPROJ2) scenario alternative assumes an increasing reliance on non-CO_2 emitting renewable energies from 10% to 20% (49,223 to 84,590 tons/yr) by the year 2040, which are moderately high goals for typical urban re/developments. The Zero Offsite mitigation (RPROJ3) scenario alternative is estimated to rely on the most amount of CO_2 emission mitigations from 70% down to 35% (296,067 to 172,073 tons/yr) by 2040. As discussed previously, achieving the mitigation of 70% of estimated CO_2 emissions through non-CO_2 emitting renewables is definitely a tall order, which needs to be satisfied in order to reach zero offsite mitigation. And last but not least, the Global Remediation

(RPROJ4) scenario alternative supposes the mitigations by non-CO_2 emitting energies to increase from 20% (84,590 tons/yr) in 2014 up to 40% (196,655 tons/yr) in 2040, which are considerably more aggressive yet attainable if properly designed.

As the buildings are estimated to contribute 62.19% (263,026 tons/yr) of the total CO_2 emissions the majority of the non-emitting mitigations need to be accomplished by the buildings of the study area. The technologies of non-CO_2 emitting renewable energy resources in the United States – and in much of the rest of the world – can still be considered to be in their infancy. The existing minimum performance standards and regulations on industries such as agriculture, construction, transportation, and energy generation still favor – and subsidize – the use of the fossil fuels over renewable alternatives. Even though they are relatively difficult to implement, district-wide central heat and power generation stations are being planned in many eco-districts, eco-villages, and eco-cities in order to provide locally generated non-CO_2 emitting energies more efficiently as discussed in Chapter 2. Generating the equivalent of 40% of the projected emissions is not only theoretically possible but also tremendously preferable taking advantage of economy of scale in district-wide restorative mitigations.

As far as the non-CO_2 emitting technologies are concerned, solar, wind, and geothermal systems are currently available for installations in buildings, however, the overall capacity of these renewable systems typically tend to be limited in comparison to conventional systems. In the case of solar panels for electricity or hot water generation, for example, the total area of panels – especially for larger and denser projects – becomes a critical and often times a prohibitive factor.

In order to achieve higher goals of restoring the natural environment, the Zero Offsite mitigation and Global Remediation projection scenarios demonstrate the rigorous nature and intensity of required urban re/developments. The goals of providing up to 40% (and even 70%) emission mitigations through non-CO_2 emitting energy resources may be achievable but the success in implementation depends largely on the available technologies. The RUD Case Study estimates are based on the current solar, wind, and geothermal systems available for mitigations today.

As far as private transportation, achieving up to 40% emission mitigations with non-CO_2 emitting energy resources predicates significant technological transformations, which are perhaps outside of the immediate scope of restorative research. However, it can only be hoped that by 2040 non-CO_2 emitting renewable energy-based technologies become available and common practice for private as well as public transportation modes.

3. Estimating Magnitude of Onsite Mitigations

Estimation of the anthropogenic CO_2 emissions can be done in a variety of different ways, each inevitably requiring certain data and assumptions to be integrated from the findings of other studies and reports. The accuracy and reliability of any estimation varies with the accuracy and reliability of observations and research on which it is based. The RUD model relies on published data used in estimating CO_2 emission amounts as well as the sequestration and storage rates used in estimating the amounts of onsite and offsite mitigations required. Once the amount of onsite mitigation is determined for a restorative projection scenario the remainder of the unmitigated CO_2 emission need to be accounted for through offsite measures.

The amount of onsite mitigations depends on the physical area, layout, and configuration characteristics of the study area as well as the kinds of mitigations to be implemented on parcels. Since the RUD Case Study relies largely on greenification, onsite mitigation opportunities are somewhat limited by the possibilities and sizes of plant installations. Needless-to-say, the amount of plants that can be appropriately installed and successfully maintained in dense urban parcels is rather restricted. The mitigations depend on the ratio of available open spaces to the overall parcel sizes, which becomes a function of building footprints onsite.

The literature on the estimation of carbon dioxide emissions is as expansive as the sources of emissions themselves. The focus of the RUD Case Study is simply not to determine which emission figures in the literature are most accurate or reliable with respect to the other research and studies but to use a set of average figures in the process of demonstrating how the RUD model is applied to a study area. In doing that, the RUD Case Study assumes that the primary method of CO_2 storage and sequestration is through increasing natural plant cover i.e. planting trees and green cover inside and outside of urban areas in addition to other optimization strategies implemented in different scenarios.

> The simplest means of doing this [Sequestering Carbon] is the establishment or growth of vegetation that absorbs CO2 from the atmosphere. To achieve a carbon balance, an equivalent amount carbon and greenhouse gases need to be removed from the atmosphere. Areas of reforestation or other planting act as carbon sinks, offsetting a project's carbon emissions. On-site planting can be designed to provide additional local benefits such as habitat cooling, water and air filtration,

> noise reduction, shielding buildings from roadways, improved aesthetics, or even producing cash crops. (Sarte, 2010, p. 196)

The restorative mitigation measures can include: reforestation of large open spaces, existing grazing lands, and riparian areas; growth of tropical dry forest; restoration of natural ecosystems; onsite vegetative sequestration; offsite vegetative sequestration; onsite green energy projects; offsite energy conservation projects; and carbon credit purchases (Sarte, 2010).

a) Researching Average Sequestration Rates: Tree Cover

The estimation of mitigations depends on the combinations of different species and densities of natural materials to be used. While the growth, carbon sequestration, and storage rates of each grass, shrub, and tree are different the restorative research reviews a range of specific studies in the literature and establishes certain averages to be used for the purposes of the RUD Case Study. Some of the key assumptions for using the natural elements in onsite and offsite mitigations include the following (see Figure 4.27):

i. The RUD Case Study relies exclusively on natural elements for carbon mitigation purposes since carbon sequestration by vegetation (phytosequestration) and carbon storage by natural plant cover are among the most effective and long-lasting ways to mitigate anthropogenic CO_2 emissions depending on size, location, and type of installations (Jansson et al., 2010).

ii. Offsite mitigations as required by the RUD model can be used effectively to rehabilitate or reestablish well-functioning, adaptive forests, meadows, grasslands, wetlands, and marshlands since these are among the largest basins of CO_2 storage in the natural environment (EIA, 1998).

iii. The Calculation and References publication of EPA (EPA-REFS, 2014) indicates the rate of total annual CO_2 sequestration by urban trees to be 0.039 tons/yr per urban tree planted [23.2 lbs C/tree x (44 units CO_2 ÷ 12 units C) x 1 ton ÷ 2,204.6 lbs]. Assuming a 60% tree coverage, this average predicates a sequestration rate of 23.400 tons/ha/yr.

iv. Urban whole tree carbon storage densities average 7.69 kg/cm^2 [76.9 tons/m^2/yr or 769,000 tons/ha/yr] of tree cover and sequestration densities average 0.28 kg/cm^2 [2.8 tons/m^2/yr or 28,000 tons/ha] of tree cover per year (Nowak et al., 2013, p. 229).

v. Total tree carbon storage in U.S. urban areas (c. 2005) is estimated at 643 million tons ($50.5 billion value; 95% CI = 597 million and 690 million tons) and annual sequestration is estimated at 25.6 million tons ($2.0 billion value; 95% CI = 23.7 million to 27.4 million tons)" (Nowak et al., 2013, p. 229).

vi. Average carbon storage per square meter of tree cover varies by sampled city and state, with overall carbon storage averaging 7.69 kgC/m^2, gross carbon sequestration rate averaging 0.277 $kgC/m^2/yr$, and net carbon sequestration rate averaging 0.205 kgC/m^2 (see Table 4.7) for Chicago, IL (Nowak et al., 2013, p. 231). This rate translates to 0.752 $kgCO^2/m^2/yr$, which is equivalent to 7.516 tons/ha/yr.

Table 4.7 The CO_2 storage and sequestration rates (Nowak, 2002, p. 385)

Estimated C storage (tC)	**Gross annual sequestration (tC/y)**	**Estimated gross annual C sequestration (kgC/ha)**	**Number of trees**	**Density (trees/ha)**
854,800	40,100	14,190	4,128,000	68

vii. 18% tree cover sequesters 6.030 kgC/m^2 of Carbon, which equates to 22.110 kg/m^2 (221.100 tons/ha) of CO_2 (Nowak, 2013) (see Table 4.8). Based on this figure, at 60% tree cover a denser forest is hypothetically estimated to sequester and store up to 737.00 tons/ha CO_2 a year.

Table 4.8 The CO_2 sequestration rates (Nowak et al., 2013, Table 2, p. 232)

Estimated C storage (kgC/m^2)	**Gross sequestration (kgC/m^2)**	**Net sequestration (kgC/m^2)**	**Tree cover (%)**
6.03	0.212	0.149	18.0

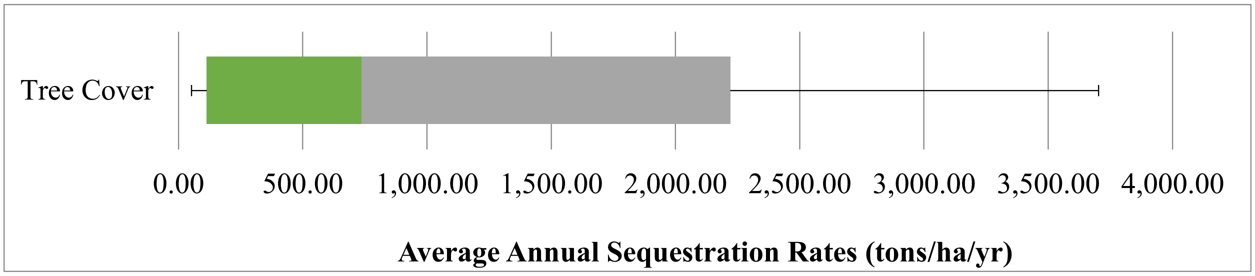
viii. EPA Calculation and References publication the Conversion Factor for Carbon Sequestered by 1 Acre of Average U.S. Forest is 1.22 ton CO_2 sequestered annually (EPA-REFS, 2014). This means that, on average 0.332 hectare of U.S. forest sequesters 1 metric ton CO_2 annually. In other words, a hectare of an average forest in the U.S. sequesters about 3.015 tons of CO_2 each year, indicating that the actual

Carbon sequestration or mitigation occurs at an average rate of 0.8221 tons/ha per year.

ix. The average ranges of carbon sequestration and storage are estimated to be 25.6 to 34.0 tonsC/ha/yr for new green land cover, aspen and poplar forests, and 0.4 to 2.6 tonsC/ha/yr for grasslands, wetlands, and marshlands depending on species, soil zone, stand age, and other factors (Wylynko, 1999, p. 13). The range of averages in this research translates to 93.86 to 124.66 tons/ha/yr CO_2 sequestration.

Figure 4.27 below summarizes the variation in the researched data in the literature.

Figure 4.27 Median values are used to establish the average tree sequestration rates



Sequestration (tons/ha/yr)	Min.	Max.	Median	Standard Deviation	Sources
Tree Cover	52.03	2,800.00	737.00	1,194.06	Wylynko (1999); Nowak (2002); Nowak et al.(2013); EPA-REFS (2014)

b) Researching Average Sequestration Rates: Green Wall & Green Roofs

The average sequestration rates for green wall and green roofs also depend on the various possible mixture of species and their size. Even though these strategies can contribute to sequestration and storage of carbon dioxide within the urban areas they tend not to be nearly as convenient or effective as tree and plant cover strategies. These applications in existing buildings tend to be far more limited than those integrated into the design and construction of new buildings. Whittinghill et al. (2014, p. 47) summarizes some of their findings on sequestration rates as follows (see Figure 4.28):

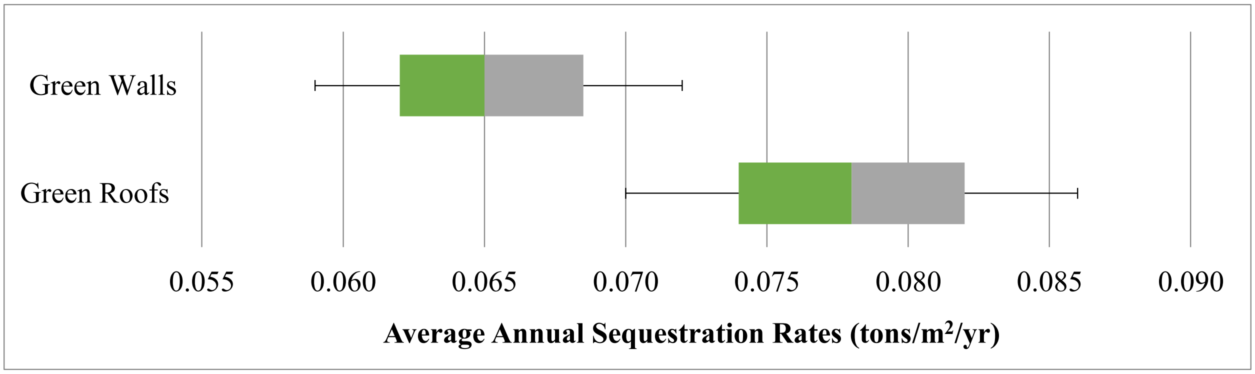
i. In-ground broad leaf evergreen shrubs: 78.70 kgC/m^2/yr (0.079 tonC/m^2/yr)

ii. In-ground herbaceous perennials and grasses: 68.70 kgC/m^2/yr (0.069 tonC/m^2/yr)

iii. Herbaceous perennials and grasses on the green roof: 67.70 kgC/m²/yr (0.068 tonC/m²/yr)
iv. In-ground deciduous shrubs: 65.70 kgC/m²/yr (0.066 tonC/m²/yr)
v. Needle leaf evergreen shrubs: 62.91 kgC/m²/yr (0.063 tonC/m²/yr)

Figure 4.28 below summarizes the variation in the researched data in the literature, the median values of which have been used to establish average rates for the RUD Case Study.

Figure 4.28 Median values are used to establish the average sequestration rates



Sequestration (tonC/m²/yr)	Min.	Max.	Median	Standard Deviation	Sources
Green Roofs	0.070	0.086	0.078	0.008	Whittinghill et al. (2014); EPA-REFS (2014)
Green Walls	0.059	0.072	0.065	0.007	Whittinghill et al. (2014); EPA-REFS (2014)

c) Establishing Average Sequestration Rates on Generation

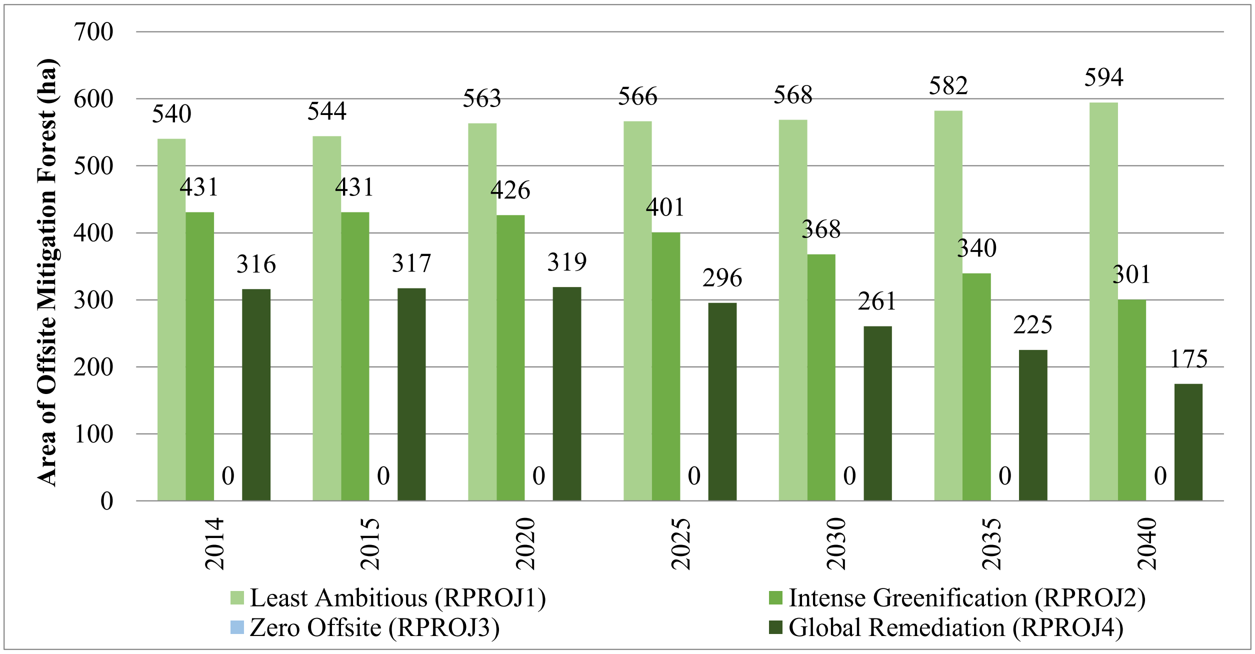
Based on the research in the preceding sections, the RUD Case Study assumes the following carbon dioxide sequestration and storage rates for the purposes of estimating the magnitude of anthropogenic CO_2 emission mitigations. Since the primary components for mitigation purposes are natural elements such as trees and shrubs the implementation areas and installation types are prone to restrictions by physical as well as practical limitations:

i. Average annual CO_2 sequestration by a hectare of forest: 737.000 tons/ha/yr
ii. Average annual CO_2 sequestration by green roofs: 78.00 kgC/m²/yr (7.80 tons/ha/yr)
iii. Average annual CO_2 sequestration by green walls: 65.00 kgC/m²/yr (6.50 tons/ha/yr)

4. Offsite Mitigation Forest

Based on the CO_2 sequestration rates indicated in the previous section and Tables 4.7 and 4.8, the RUD Case Study proposes that all of the remaining anthropogenic CO_2 emissions that are not mitigated within the study area be mitigated offsite. While the precise calculation of offsite mitigations may be accomplished in various different ways, for simplicity in calculations, the restorative research assumes the primary method of offsite mitigations to be forestation and/or reforestation in dedicated non-urban areas. As pointed out earlier, the mitigation forest for the purposes of the RUD Case Study assumes a minimum of 60% tree coverage, capable of sequestering 201.00 tons/ha/yr carbon a year (see Table 4.8). This means that the average annual CO_2 sequestration of the offsite mitigation forest is assumed to be 737.00 tons/ha/yr. Using these sequestration rates, it is possible to hypothetically determine the size of offsite CO_2 mitigation forest required for each scenario, which shows significant variation through time (refer to Appendix N). Figure 4.29 below illustrates the variation in the size of the offsite forest throughout the RUD Case Study timeline.

Figure 4.29 Area of offsite mitigation forest varies based on onsite implementations



Note: Zero Offsite (RPROJ3) scenario alternative has no offsite mitigation forest.

The initial size of the mitigation forest in the RPROJ1 scenario, for instance, is calculated to be 540 ha (5.401 km^2 or 2.085 mi^2), which steadily needs to expand to 594 ha (5.944 km^2 or

2.295 mi^2) (see Figure 4.29 and refer to Table N.1 in Appendix N). Since the Least Ambitious scenario relies exclusively on offsite mitigation measures and does very little in the way of onsite mitigations, the size requirement for the offsite mitigation forest is the largest, which grows over time following the growth of forecasted anthropogenic CO_2 emissions from the study area. The required size of forest for Intense RPROJ2 shrinks from 431 ha (4.309 km^2 or 1.664 mi^2) to 301 ha (3.005 km^2 or 1.160 mi^2). The size for RPROJ4 reduces from 316 ha (3.160 km^2 or 1.220 mi^2) down to 174 ha (1.745 km^2 or 0.674 mi^2).

It is possible that, in the absence of appropriate mitigations of increasing anthropogenic emissions, the existing – and often shrinking – natural ecosystems like forests, wetlands, and marshlands have been mitigating but increasingly being overwhelmed by these impacts. Only through providing the appropriate amount of offsite mitigation can the mounting anthropogenic CO_2 emissions be comprehensively neutralized.

5. Optimizing A Final Restorative Projection

In the last phase of the evaluation and optimization process toward a final restorative projection in the RUD Case Study, the Global Remediation (RPROJ4) scenario alternative was mathematically optimized. For the optimization of final scenario, a series of data analysis tools in Microsoft Excel such as the solver, scenario manager, and scenario summary functions were used. The data analysis tool used for the computational optimization of final projection was the Solver add-in function in Excel 2014. The Solver is part of "What-If" scenario analysis tools that are used to "find an optimal (maximum or minimum) value for a formula in one cell — called the objective cell — subject to constraints, or limits, on the values of other formula cells on a worksheet" (EXCEL, 2014). The Solver data analysis tool simply works with "a group of cells, called decision variables" (or simply variable cells) that are plugged into a formula in the "objective" and "constraint cells" in a spreadsheet. The Solver automatically calculates the values in the "decision variable cells" in order to satisfy the limitations on the "constraint cells," and produces an analysis summary, which contains the mathematically calculated "optimal" results for the objective in the "result cells" (refer to Table 4.9).

Table 4.9 summarizes the three reiterations of quantitative optimization where a total seven variables were constrained in the solver parameters. These constraints were:

i. Em_Red_min >= 5.00% (Emission Reductions)

ii. Non_CO2_min >= 10.00% (Non-CO^2 Emitting Energy)
iii. Onsite_min >= 1.00% (Onsite Mitigation)
iv. Em_Red_max <= 40.00% (Offsite Mitigation)
v. Non_CO2_max <= 70.00% (Offsite Mitigation)
vi. Onsite_max <= 25.00% (Offsite Mitigation)
vii. Offsite_max <= 94.00% (Offsite Mitigation)

In the first iteration, the objective in the solver parameters was set to the value of 1.00 so that the scenario can be optimized for full (100%) mitigation. The result of this computation indicated 14.28% emission reductions, 21.86% non-CO2 emitting energy, 18.86% onsite, and 45.00% offsite mitigations as shown on Table 4.9 (refer to Appendix M).

Table 4.9 Final optimization aims at 10% global remediation beyond full mitigation

Data Optimization Analysis Summary	**Initial Values**	**Full Mitigation**	**+10% (Global Remediation)**	**+20% (Global Remediation)**
Changing Cells:				
Em_Red_min	5.00%	5.00%	5.00%	5.00%
Non_CO2_min	10.00%	10.00%	10.00%	10.00%
Onsite_min	1.00%	10.00%	10.00%	10.00%
Em_Red_max	40.00%	14.28%	14.95%	15.53%
Non_CO2_max	70.00%	21.86%	23.42%	24.85%
Onsite_max	25.00%	18.86%	20.02%	21.07%
Offsite_max	94.00%	45.00%	51.61%	58.56%
Result Cells:				
Min_EmRed	21,173	21,173	21,173	21,173
Min_NonCO2	42,346	42,346	42,346	42,346
Min_Onsite	4,235	42,346	42,346	42,346
Max_EmRed	84,692	70,293	73,571	76,437
Max_NonCO2	296,067	107,598	115,279	122,316
Max_Onsite	143,022	92,832	98,549	103,692
Max_Offsite	509,159	221,502	254,051	288,228

Note: Initial Values column represents the values of changing cells at the time Date Optimization Analysis Summary was created. Changing cells for each scenario are highlighted in gray.

If the design assumptions for the final restorative projection are just set for full mitigation (see Figure L.1) of emissions, there would technically not be any global remediation because the excess athropogenic carbon emissions already in the atmosphere would not be mitigated through these measures implemented in the study area. For that reason it is desirable to set the design assumptions such that the final restorative projection of the RUD Case Study can mitigate some percentage (e.g. 10 to 20) more emissions than the estimated generation in the case study area.

Hence, in the second reiteration of the data optimization analysis (refer to Table 4.9), the Global Remediation (RPROJ4) scenario alternative was further optimized for 10% more mitigation than to 20% more than full (100%) mitigation by setting the solver parameter objective to the value of 1.10. The result of this computation indicated 14.95% emission reductions, 23.42% non-CO2 emitting energy, 20.02% onsite, and 51.61% offsite mitigations.

In the third and last reiteration of the Global Remediation (RPROJ4) scenario alternative optimization, the solver parameter objective was set to the value of 1.20. The solver computed the optimized conditions under which the design assumptions would be 20% more than full (100%) mitigation and indicated 15.53% emission reductions, 24.85% non-CO2 emitting energy, 21.07% onsite, and 58.56% offsite mitigations as shown in Table 4.9.

Figure 4.30 Final projection aims at 10% global remediation beyond full mitigation

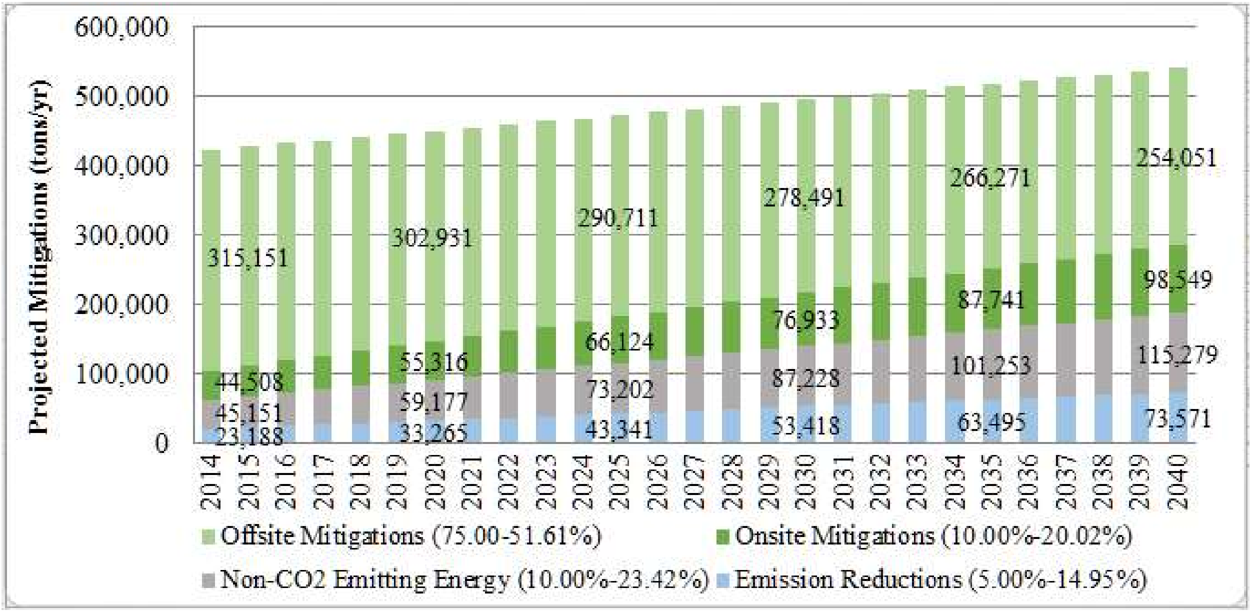


Figure 4.30 shows the final restorative projection, which targets at mitigating 10 percent more emissions beyond the design assumptions for full mitigation. In order to achieve these goals, the final projection assumes that the emission reductions in the final scenario start at a minimum of 5.00% (21,173 tons/yr) of 2014 estimation in the TFORE scenario and increase up to 14.95% (73,571 tons/yr) by the year 2040. The non-CO_2 emitting energy mitigations are

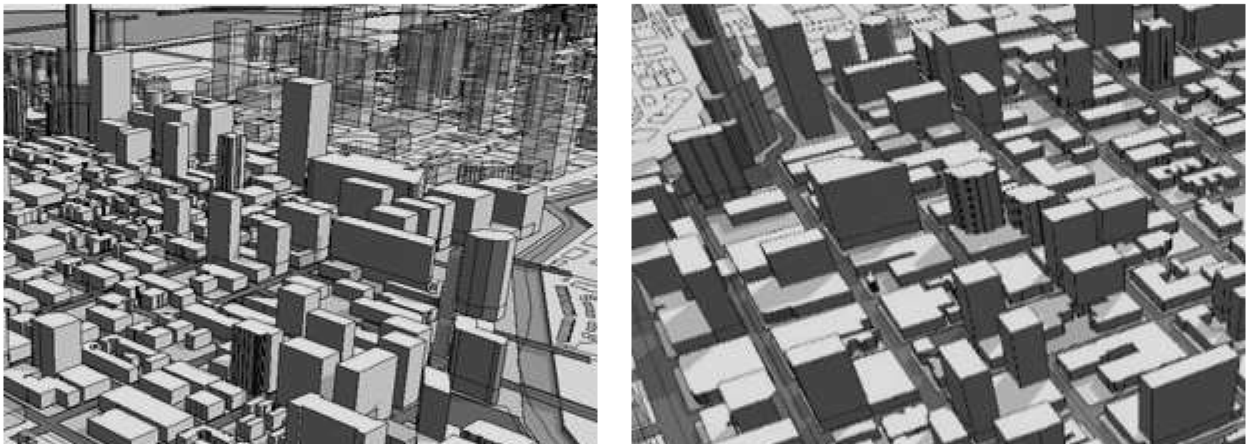
assumed to rise from 10.00% (42,346 tons/yr) in 2014 to 23.42% (115,279 tons/yr) by 2040. The final restorative design projection assumes that the onsite mitigation measures in 2014 mitigate 10.00% (42,346 tons/yr) of the estimated emissions in 2014 reaching 20.02% (98,549 tons/yr) by 2040. And, finally, the offsite mitigations are assumed to play a major role in global remediation contributing 75.00% (317,595 tons/yr) in 2014 and steadily falling down to 51.61% (254,051 tons/yr) by 2040. The size of the offsite mitigation forest for the optimized final restorative scenario is estimated to range from 431 ha (4.309 km^2) in 2014 to about 345 ha (3.447 km^2) by 2040 (refer to Appendix N).

G. Visualizing Restorative Conditions

The restorative research advocates environmental data modeling for evaluating and hypothetically comparing the effectiveness of urban re/development principles and strategies for restoration purposes. The environmental data used in the optimization process can also be used to visualize different scenarios using three-dimensional building information modeling (BIM), simulation and visualization tools, which offer significant benefits in analysis as well as presentation of findings for decision-making processes. With increasing data analysis and visual presentation capabilities, programs such as REVIT, UrbanSIM, CommunityViz, and ArcGIS 3D Analyst are being used increasingly to represent urban growth and re/development data models in three and four dimensions (Campagna, 2000; Batty et al., 2009; Jat et al., 2009; Nour, 2011).

Figure 4.31 below illustrates the RUD Case Study area, which features a very limited amount of open or green space within asphalt, concrete and glass cover (refer to Appendix Q).

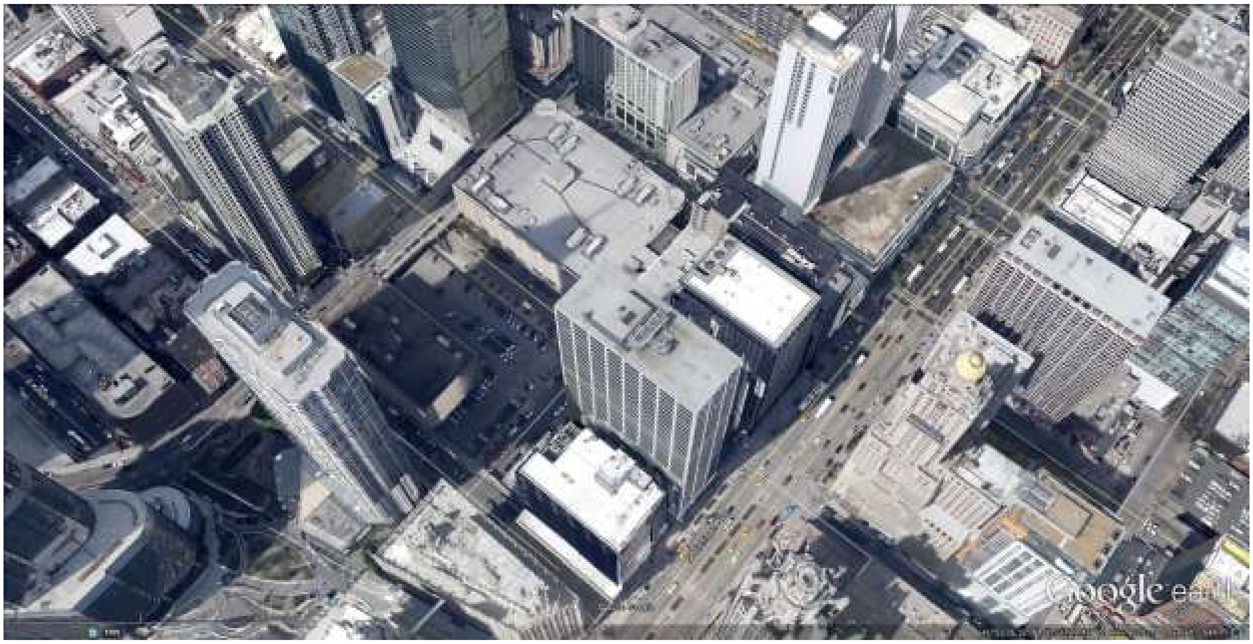
Figure 4.31 Virtual (BIM) model of the existing buildings in and around the study area



1. Green Roofs & Green Walls

Estimating the size of green roofs and green walls can be highly subjective, yet it can be done in a methodological manner as part of the optimization of restorative scenarios. For the purposes of the RUD Case Study, the entire study area has been examined in great detail, parcel by parcel and building by building. For each individual parcel and building the possible locations and probable size of green roof and green wall installations have been estimated from a physical space point of view (see Figure 4.32).

Figure 4.32 A view of existing building, roof, and surface conditions (©2014 Google Earth)

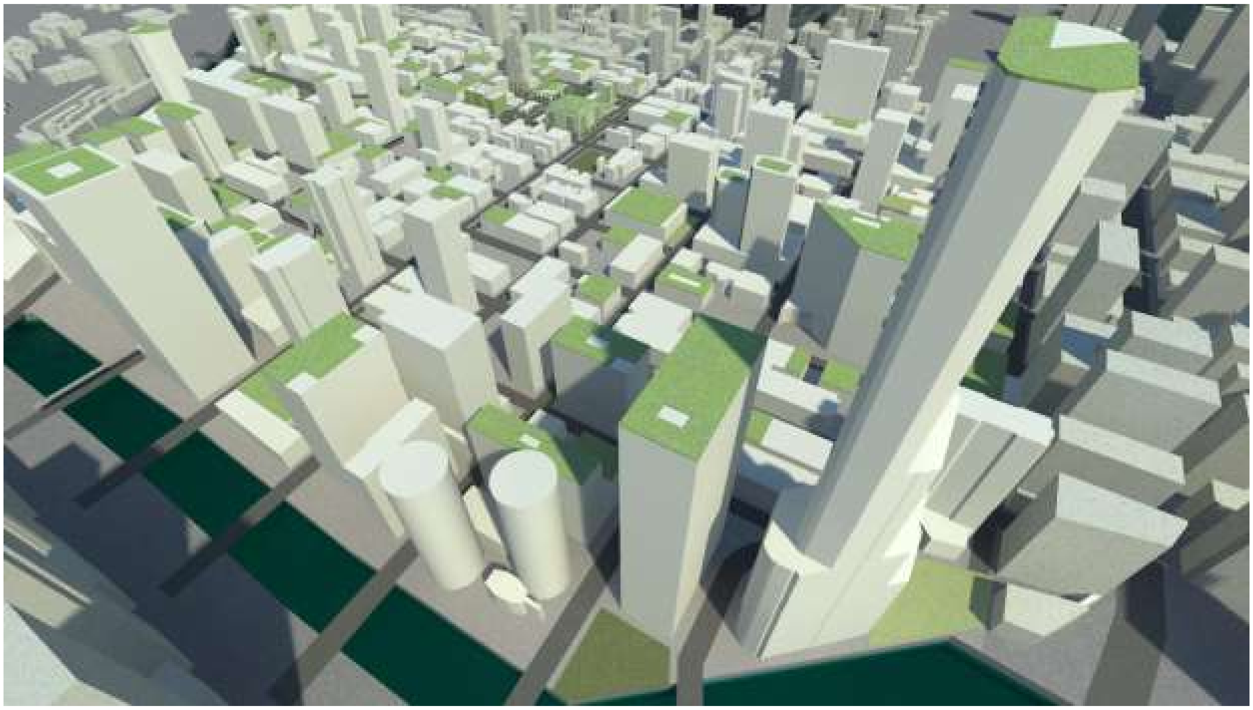


For the green roof allocations, the primary consideration has been given to the overall size of suitable spaces on roofs that are uninterrupted by other building features or equipment. While there could be opportunities for sloped roofs also, only the flat roofs in the study areas have been incorporated in the restorative estimations. Some of the technical factors such as the age and types of construction on the existing structures as well as the logistic aspects like the kinds of building use or ownership structures are excluded from these investigations. Furthermore, there has been no consideration given to any economic factors like the initial costs of installation or the associated maintenance expenses, which are critically important for these implementations in the real world. Yet, these exclusions allow the RUD Case Study to isolate and focus solely on environmental aspects.

The overall total of roof areas (i.e. building footprints) in the study area is estimated to be 67.606 ha (676,058 m^2). The portion of possible green roof installations in the Final Restorative Projection (RPROJ) scenario is assumed to be 13.857 ha (138,569 m^2) or 20.50% for 2014, increasing in parallel with the population, urban growth, and greener re/developments to 25.613 ha (256,131 m^2) or 37.89% by 2040 (see Figure 4.33). By applying the assumed average annual CO_2 sequestration rate for green roofs, the total amount of carbon dioxide sequestration and storage by the green roofs in the RUD Case Study is estimated to range from 10,808 tons/yr in 2014 to 19,978 tons/yr in 2040 as part of RPROJ4 scenario alternative.

In the Final Restorative Projection (RPROJ) scenario the amount of possible green roof installations are estimated to cover 23.095 ha (230,948 m^2) or 34.16% of the existing building footprints in 2014, sequestering and storing 18,014 tons/yr CO_2. The total area of green roofs in the study area is projected to rise up to 63.14% (42.288 ha or 426,884 m^2) by the year 2040, which would sequester and store 33,297 tons of CO_2 annually.

Figure 4.33 Green roof installations proposed by the Final Restorative Projection



As far as green wall applications, installation techniques available today are much less advanced and much more restricted than the green roofs. However, new systems and technologies are continually being developed tested and improved for performance. Even though some of these systems are only experimental in high-rise structures (i.e. over 22.86 m or 75 feet in height) the restorative green wall applications in the study area have been restricted to low to mid-rise buildings in the range of 5 to 22 meters (one to six stories in height). The green wall systems are mainly assumed to be installed on the building facades that do not face due north and that have larger portions of solids than openings.

The total area of green walls in the Final Restorative Projection (RPROJ) scenario is estimated to be 1.482 ha (14,819 m^2) for 2014, increasing with the urban growth and technological developments to 6.125 ha (61,248 m^2) by 2040. According to these estimations the sites suitable for applications are expected to yield about 138,596 m^2 (13.859 ha) of additional green cover (vegetation) onsite (see Figure 4.34).

Figure 4.34 A view of new green roof and green wall installations in the final projection

Unfortunately, the installation of green wall technologies available today are not going to make a very significant difference in the amount of carbon dioxide that needs to be sequestered. By applying the assumed average annual CO_2 sequestration rate, the total amount of sequestration and storage by the green walls in the final projection scenario of the RUD Case Study is estimated to range from 963 tons/yr in 2014 to perhaps 3,981 tons/yr in 2040 as these technologies advance.

The total area of green walls presumed for the RPROJ4 scenario in 2014 amount to 4.619 ha (46,189 m^2), which sequesters and stores 3,002 tons/yr carbon dioxide. The estimated area for the year 2040 is 38.200 ha (382,005 m^2) with 24,830 tons/yr. These numbers are significantly higher than the RPROJ2 alternative and likely to necessitate a greater level of innovation, commitment, incentives, and regulations to make them happen in the real world.

2. Network of New Green Spaces

The Intense Greenification (RPROJ2), the Global Remediation (RPROJ4), and the Final Restorative Projection (RPROJ) scenarios rely heavily on introducing a network of new green spaces throughout the RUD Case Study area in order to reach higher levels of environmental restoration from the stand point of anthropogenic CO_2 emission mitigations. The new green space network is based mainly on conversion of large expanses of underutilized land areas such as surface parking lots, alley ways, easements, and sidewalks into green spaces. The amount of conversions as well as carbon dioxide that can be sequestered and stores shows variation in each scenario (see Figure 4.35).

Figure 4.35 An Aerial view of the proposed new green spaces network and green roofs

The green spaces network estimated for the Final Restorative Projection (RPROJ) scenario features a total of 17.417 ha (174,174 m^2), sequestering and storing 12,837 tons of CO_2

in 2014. The new green network would occupy about 46.63% of the land area that is not taken up by the existing buildings and roads. In order to reach 15% onsite mitigation goal in the final projection (RPROJ) scenario (refer to Figure 4.30), the size of the new green spaces network needs to reach 28.230 ha (280,230 m^2) or 75.02% of the available land area outside of buildings and roads by the year 2040. These are indeed more intense greenification efforts within the RUD Case Study area.

Furthermore, the Final Restorative Projection (RPROJ) scenario introduces even further-reaching measures on creating a new network of green spaces in order to reach up to 25% onsite mitigations in the study area (refer to Figure 4.25). This projection assumes not only the greenification of 75% of available land area outside of buildings and roads but also much denser green areas, up to four times the average annual sequestration rates assumed for the rest of the RUD Case Study i.e. 737.00 tons/ha versus 3045.00 tons/ha. The total amount of onsite carbon dioxide sequestration and storage by the network of new green spaces in this scenario is estimated to range from 28,200 tons/yr in 2014 to 85,313 tons/yr by 2040.

3. A Summary of Onsite Mitigations at City Block Scale

Specifically on carbon dioxide reduction, there are a number of sustainable urban design applications at city block scale that target reducing a significant portion of anthropogenic CO_2 emissions through onsite mitigations. Some examples from the United States include: 2030 District Block 10 – Seattle, WA; Lloyd Crossing – Portland, OR; Greenways Xero Energy – San Francisco, CA; New Railroad Square – Santa Rosa, CA; and Super Sustainable City Block – Dallas, TX (AIA/COTE, 2005; JG, 2009; Architecture 2030 Challenge, 2014). Other examples from other developed countries around the world include: Dockside Green – Victoria, BC, CAN; Z-Squared – London, UK (zero-carbon, zero-waste) (Farr, 2008). While most of these sustainability efforts aim at reduction of human impacts on air, water, land, and ecology only a few are focused on complete neutralization or global remediation.

An effective way of summarizing the restorative mitigations proposed by the RUD Case Study is to visualize the various strategies on a three-dimensional model at the city block scale. Predictably, the extent and amount of onsite restorative mitigations show a wide range of variation across the study area, where some blocks are more conducive to improvements than others, simply due to shape, size and configuration of existing features (refer to Appendix P).

Figure 4.36 Restorative mitigations to increase green cover at the city block scale

Figures 4.36 and 4.37 illustrate a small section of the study area comprised of four city blocks i.e. F7, F8, G7, and G8 for the Final Restorative Projection (RPROJ) scenario (see Figure 4.11 and refer to Appendix O).

Figure 4.37 Another view of restorative mitigations at the city block scale

The onsite mitigations at the city block designated as F7 (see Figure 4.11) features 0.342 ha (3,416 m^2) of green roof primarily on the retirement center building (refer to Appendix F). Proposed green wall installations are located on east, west, and south facades totaling 0.200 ha (2,002 m^2) up to four stories high. The block F8 accommodates approximately 0.054 ha (539 m^2) of green roofs and 0.233 ha (2,331 m^2) of green walls. The block G7 is estimated to host 0.097 ha (937 m^2) of green roofs and 0.177 ha (1,772 m^2) of green walls. And, finally, the total area of green roofs on city block G8 is estimated at 0.290 ha (2,899 m^2) – with 0.087 ha (874 m^2) that already exists – while the new green walls sum up to 0.234 ha (2,336 m^2).

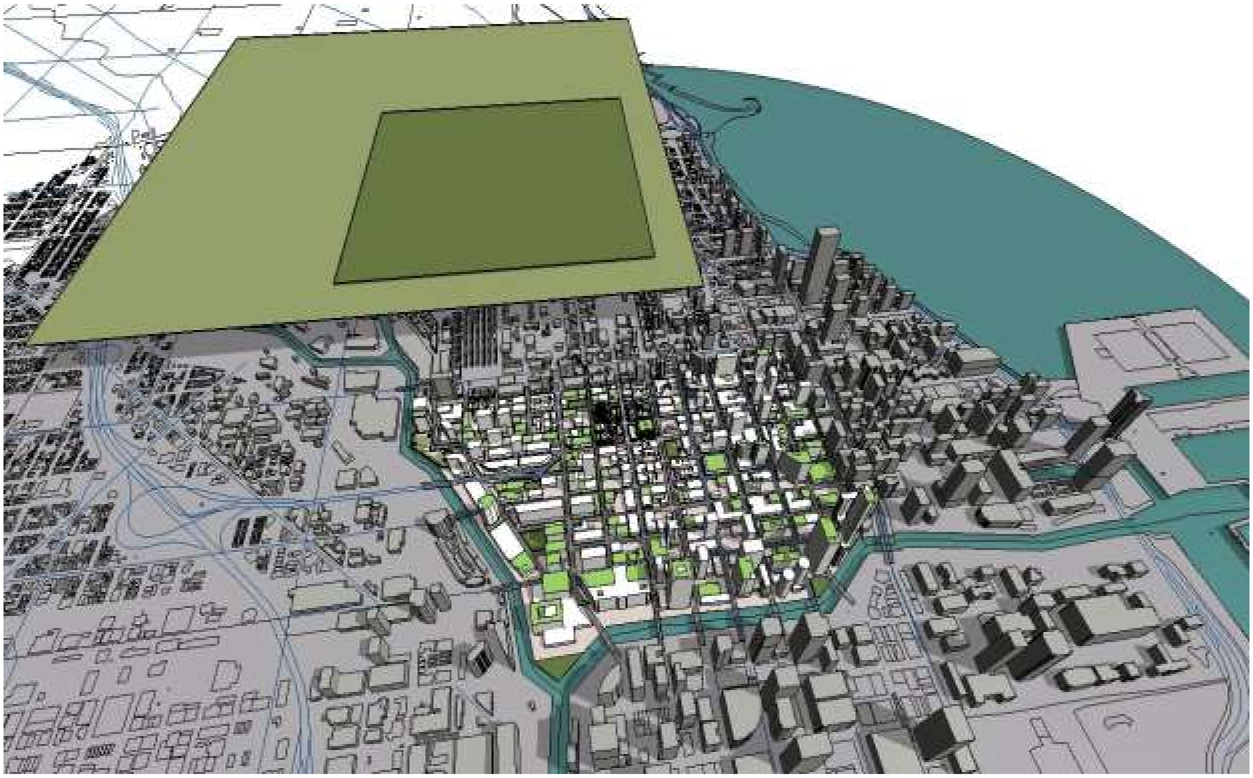
4. The Size of Offsite Mitigation Forest

Above and beyond the various onsite mitigation strategies, each restorative scenario alternative appears to require a large offsite CO_2 mitigation forest. The size of this forest varies with the changing design assumptions throughout the restorative timeframe. Based on the calculated amounts of anthropogenic CO_2 emissions and mitigations as discussed in the previous sections the RUD Case Study results suggest that the minimum area of an offsite mitigation forest is 175 ha (1.745 km^2 or 0.674 mi^2) in the Global Remediation (RPROJ4) scenario in 2040, which is roughly 123% of the River North District land area. Whereas the maximum is 594 ha (5.944 km^2 or 2.295 mi^2) in the Least Ambitious (RPROJ1) scenario for 2040, which is approximately 419% (see Figure 4.38).

The minimum area of the offsite mitigation forest for the Final Restorative Projection (RPROJ) scenario is estimated to be 345 ha (3.447 km^2 or 1.331 mi^2), which is approximately 243% of the overall RUD Case Study area (see Figure 4.38). The maximum area of the forest is estimated to be 431 ha (4.309 km^2 or 1.664 mi^2), nearly 304% of the River North District land area.

If assumed to be square shaped, the side length of the minimum offsite mitigation forest area in the Final Restorative Projection (RPROJ) scenario – needed to naturally offset the entire anthropogenic CO_2 emissions of the River North District – is approximately 1.857 km (1.154 mi). The maximum square shaped forest area requires the side length to be 2.076 km (1.290 mi), which is significantly larger than the size of former length. If circular shaped, the radius of the minimum forest area is approximately 1.047 km (0.651 mi), whereas, the maximum forest area requires a radius of 1.171 km (0.728 mi).

Figure 4.38 Minimum and maximum forest sizes (circular and square-shaped)



H. Summary of Case Study Findings

The RUD Case Study starts with the determination of existing conditions for the study area, for which basic historical, demographic, physical, and geospatial information is gathered. Firstly, the Natural Baseline (NBASE) scenario conditions are established as a reference state preceding human settlements, which is exemplified by a nearby forest reserve (Catherine Chevalier Woods, O'Hare, IL). The historical population trends since 1800 through 2014 are used in the case study to estimate the future Trajectory Forecast (TFORE) through 2040 assuming the population growth as well as per capita CO_2 emissions in the region would not changes significantly. Once the difference between the natural baseline and trajectory forecast values are estimated, and urban re/development scenario alternatives for mitigations are explored, the size and magnitude of mitigations are optimized under different Restorative Projection (RPROJ) scenario alternatives (see Figure 4.19).

In conclusion, the RUD Case Study:

i. Focuses on a well-developed urban area of 1.417 km^2 (0.547 mi^2)
ii. Estimates current total population of 19,491, projected to reach 23,179 by 2040
iii. Features current total building area of 5,651,621 m^2, comprised of 1,406,918 m^2 office, 135,281 m^2 retail, and 4,109,422 m^2 residential uses
iv. Projects the current total anthropogenic CO_2 emissions to be 422,952 tons/yr
v. Forecasts unmitigated anthropogenic CO_2 emissions to reach 491,637 tons/yr by 2040
vi. Proposes and analyzes few different restorative projection scenario alternatives as follows.

The Least Ambitious (RPROJ1) scenario alternative (see Figure 4.22):

i. Forecasts 5 to 10% (21,173 to 49,223 tons/yr) reduction in anthropogenic CO_2 emissions from increased energy efficiency and performance of the building systems as well as transportation activities through 2040 (refer to Appendix I)
ii. Assumes no reliance on non-CO_2 emitting technologies or energy resources
iii. Incorporates onsite mitigation via existing green spaces estimated at 3.514 ha (35,140 m^2), which contributes little more than 0.5% (4,230 tons/yr)
iv. Estimates onsite mitigations to range within 1% (4,230 tons/yr in 2014 to 4,916 tons/yr by 2040) (refer to Appendix I)

v. Estimates the offsite mitigations to range from 89 to 94% (398,052 to 438,082 tons/yr), which translates to an offsite CO_2 emission mitigation forest ranging from 540 ha (5.401 km^2) in 2014 to 594 ha (5.944 km^2) by 2040.

The Intense Greenification (RPROJ2) scenario alternative (see Figure 4.23):

i. Projects 10 to 20% (49,346 to 98,445 tons/yr) reduction in anthropogenic CO_2 emissions from increased energy efficiency and performance of the building systems as well as transportation activities through 2040 (refer to Appendix J)
ii. Assumes 10 to 20% (49,346 to 98,445 tons/yr) reliance on non-CO_2 emitting technologies and energy resources such as solar, wind, geothermal by 2040
iii. Incorporates a moderately intense amount of onsite mitigations such as green roof and green wall installations, as well as a network of new green spaces, estimated to rise from 5 to 15% (21,173 to 73,834 tons/yr) by 2040
iv. Estimates the size of required offsite CO_2 emission mitigation forest to range from 431 ha (4.309 km^2) in 2014 to 301 ha (3.005 km^2) by 2040.

The Zero Offsite (RPROJ3) scenario alternative (see Figure 4.24):

i. Assumes 20% to 40% (84,692 to 196,891 tons/yr) reduction in anthropogenic CO_2 emissions from increased energy efficiency and performance of the building systems as well as transportation activities through 2040 (refer to Appendix K)
ii. Maximizes the amount of onsite mitigations estimated to range from 10% (49,346 tons/yr) in 2014 to 25% (123,057 tons/yr) by 2040
iii. Projects from 70% down to 35% (296,422 to 172,279 tons/yr) reliance on non-CO_2 emitting energy resources and technologies such as solar, wind, geothermal by the year 2040
iv. Relies on no offsite mitigation forest.

The Global Remediation (RPROJ4) scenario alternative (see Figure 4.25):

i. Assumes 15% to 30% (63,519 to 147,668 tons/yr) reduction in anthropogenic CO_2 emissions from increased energy efficiency and performance of the building systems as well as transportation activities through 2040 (refer to Appendix L)
ii. Projects 20% to 40% (84,692 to 196,891 tons/yr) reliance on non-CO_2 emitting technologies and energy resources such as solar, wind, geothermal by 2040

iii. Includes a maximum estimated onsite mitigation – by new green spaces as well as green roof and green wall installations – to range from 10% (42,346 tons/yr) in 2014 up to 25% (122,057 tons/yr) by 2040

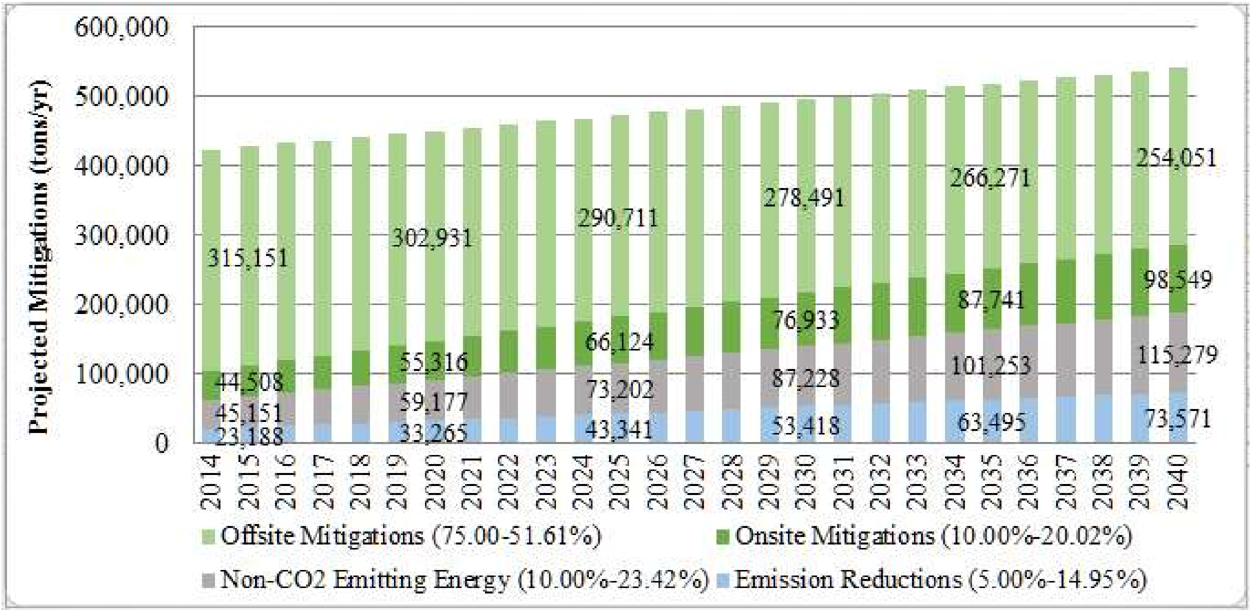
iv. Estimates the offsite mitigations to contract from 55% (232,903 tons/yr) in 2014 down to 25% (128,611 tons/yr) by 2040

v. Calculates the Global Remediation amount to steadily reach 21% (104,000 tons/yr) by 2040 (refer to Appendix L)

vi. Determines the size of required offsite CO_2 emission mitigation forest to contract from 316 ha (3.160 km^2) in 2014 to about 175 ha (1.745 km^2) by 2040.

And finally, the Global Remediation (RPROJ4) scenario alternative is optimized in order to determine the Final Restorative Projection (RPROJ) (see Figure 4.39). In its final form, the RPROJ scenario aims to mitigate 10% more emissions than those projected to be generated in the study area by 2040.

Figure 4.39 Final projection aims at 10% global remediation beyond full mitigation



The Final Restorative Projection (RPROJ):

i. Assumes the design of emission reductions to start from 5.00% (21,173 tons/yr) in 2014 and to reach 14.95% (73,571 tons/yr) by 2040 (refer to Appendix M)

ii. Relies on the non-CO_2 emitting technologies and energy resources such as solar, wind, geothermal to mitigate 10.00% (49,346 tons/yr) of the emission in 2014, rising up to 23.42% (115,279 tons/yr) by 2040

iii. Includes extensive amount of new green spaces as well as green roof and green wall installations onsite similar to the assumptions of the Global Remediation (RPROJ4) scenario alternative before the optimization, starting at 10.00% (42,346 tons/yr) in 2014 and reaching 20.02% (98,549 tons/yr) level by 2040

iv. Estimates the offsite mitigations to contract from 75% (317,595 tons/yr) in 2014 down to 51.61% (254,051 tons/yr) by 2040

v. Calculates the Global Remediation amount to gradually reach 10% (49,233 tons/yr) by 2040 (refer to Appendix M)

vi. Estimates a sizable offsite mitigation forest that needs to start from an area of 316 ha (3.156 km^2) in 2014 and gradually shrink to about 174 ha (1.745 km^2) by 2040 (refer to Appendix N).

A key outcome of the RUD Case Study on the anthropogenic CO_2 emissions is the visualization of extent and magnitude of mitigations necessary to fully mitigate a single indicator of the RUD model. A large portion of offsite mitigations for emissions in this case is achieved by re/forestation, which naturally provides mitigation for many other indicators in the RUD model that are not specifically analyzed in this dissertation. The size of the offsite forest is, of course, subject to change based on the assumptions to be made in terms of type and density of species of carbon sequestering and storing natural mechanism contained within. Nonetheless, through the process of analyzing conditions, evaluating design assumptions, and optimizing mitigation strategies the restorative approach seeks to inform the planning and design of a restorative urban re/development in the study area.

The comprehensive restoration of the global natural environment can ultimately be achieved as a cumulative result of the restorative urban re/developments throughout the world, however, it will take significant collaborative efforts, well beyond what we currently see happening in most cities, regions, and nations.

Chapter 5 - Conclusions

This chapter offers an overview of the entire process and conclusions of the research, which are directly linked to the primary and secondary research questions in Chapter 1. The broader impacts and implications of restorative research are discussed briefly in the following sections.

The restorative research is possibly the very first of its kind, in that, currently there appear to be no urban methodologies that exclusively focus on the comprehensive restoration of the natural environment. This inquiry intends to raise the public awareness, the academic pursuit of knowledge, and the professional efforts toward the environmental restoration related to urban design and planning. It is hoped that in the near future research, development, advancement and application of restorative technologies become more prevalent in the design, planning as well as re/development processes of urban areas.

> Make no little plans; they have no magic to stir men's blood and probably themselves will not be realized. Make big plans; aim high in hope and work, remembering that a noble, logical diagram once recorded will never die, but long after we are gone will be a living thing, asserting itself with ever-growing insistency. Remember that our sons and grandsons are going to do things that would stagger us. Let your watchword be order and your beacon beauty [Daniel H. Burnham]. (Moore, 1921, p. 147).

A. An Overview of The Restorative Research

Current degradation, deterioration and depletion in the natural environment is manifesting evidence that preservation and conservation strategies fall short of necessary environmental regeneration and rehabilitation. The paradigm of sustainability has been beneficial in proving some remediation to the multidimensional issues that the human interventions have created in the natural environmental. It is, however, time to think beyond sustainability (Toros, 2010).

Just as healthy and fully-functioning natural systems can improve health and longevity of humans, deterioration of health and diversity in the biosphere is supposed to be equally alarming to the stewards and caretakers of the terrestrial environment. History shows that the contemporary values and technologies of human civilizations need to align and work in harmony with natural cycles and balances in order to avoid unpleasant yet unavoidable corrections (Register, 2006). Through a restorative frame of planning and design the built environment can be transformed into harmonious relationships with nature.

The essence of nature in the human environment, activities, and processes need to be restored. In order to facilitate the process of restoration in urban design and planning, the principles of restorative design are examined in this research. Such restorative urban design efforts must necessarily spring out of and expand beyond a solid foundation of smart, sustainable, green, regenerative, and resilient ecological strategies.

A considerable portion of sustainable urban design strategies reviewed in this research have varying levels of intrinsic restorative significance associated with them. Especially critical are the management of urban populations and their expansion across the landscape, the use of appropriate technologies for urban agriculture, reforestation, biodiversity, and green infrastructure. Each are critically important in minimizing human impacts on natural systems, and letting them regenerate more rapidly. Re/development practices to promote integrated land use mixtures, transit-orientation, and widespread reliance on renewable energy and materials help increase environmentally benign, neutral, regenerative, and ecologically resilient urban patterns.

The Restorative Urban Design (RUD) model is conceived to evaluate the restoration of natural cycles and balances represented in five primary environmental assessment dimensions: Atmosphere (emissions, pollutants, air quality, ozone depletion); Hydrosphere (stormwater, domestic water, water quality, wastewater); Lithosphere (land use, land cover, soil quality, urban agriculture); Ecology (habitat resilience, biodiversity, human population, biophilia, resource management); and Energy (renewability, reduction and efficiency, transportation). In order to model and test the effectiveness of restorative strategies within a particular area of study a scenario-based comparison method is proposed based on four basic scenarios: Natural baseline (NBASE); Historic progression (HPROG); Trajectory forecast (TFORE); and Restorative projection (RPROJ).

The RUD Case Study in this research is designed and constructed to illustrate the application of the RUD model to a single assessment category i.e. anthropogenic CO_2 emissions within a given study area through a given period of time.

B. Restorative Research Outcomes & Discussions

One of the key outcomes of the restorative research is the recognition of a high level of complexity involved in defining, appropriately quantifying, modeling, analyzing, as well as adequately addressing the necessary environmental impact mitigations. Despite the exclusion of social, cultural, political, and economic factors associated with the urban issues under focus, the scope and extent of the environmental issues to be covered by the RUD model remain intertwined and complex. The overarching result is that in spite of the complexities the comprehensive environmental restoration is not only possible but also highly achievable if proper principles and strategies for planning, design as well as implementation are employed.

The restorative research is designed to advocate heightening of the contemporary goals behind the ecologically responsive and environmentally responsible design practices of the future. Yet another important outcome is perhaps initiating the formal development of a viable methodology that quantifies, analyzes, tests, models, and visualizes the different possible scenarios of environmentally restorative urban growth and re/developments.

To be effective, restorative implementations have to facilitate a significant urban re/developments including management of urban growth and expansion, increase infusion of renewable materials and energy, and expansion of open spaces in addition to resource conservation policies. Despite expected constraints and limitations related to modeling, data type, availability, and interpretation issues such a comprehensive methodology is perhaps the only viable framework through which the natural environment can be restored over time.

1. Beyond Sustainability: Toward A Restorative Methodology

Moving beyond the mindset of preservation, conservation, minimal impact, sustainability or increased regeneration and entering into the paradigm of comprehensive environmental restoration requires a simple – but rather sobering – realization that significant degradation, deterioration, and depletion in the natural environment have already taken place, and that deterioration in many aspects is simply beyond the regenerative capabilities of natural growth cycles (Toros, 2010).

The restorative research (as well as the RUD model) springs from a conceptual framework of environmental restoration rather than sustainability or regeneration. While recognizing the interdependence – rather than independence – between the natural habitat and its inhabitants it seeks to restore the diminishing balances – the severed harmony – with nature through an ecologically responsible design agenda. The restorative framework acknowledges that the emerging era of urban evolution is inevitably one of restoration where the primary objectives in development transcends beyond the concerns of simple sustainability into the oft-neglected domain of proactive, on-the-ground environmental repair and rehabilitation.

The framework of regenerative design is intended to offer significant improvements beyond the lessening of human and urban impacts. In fact, the central emphasis of restorative concerns stems from the urge to live according to and within natural laws and to have positive environmental contributions along the way. John Lyle's core vision behind regenerative principles still hold true today: Only by restoring the natural habitat, and then reintegrating human activities within the regenerative natural systems and processes, can the civilization achieve substantial advances toward overcoming the current crises and the potential future ones. In order for humans – as integral members of natural ecology – to neutralize their unnatural impacts within the biosphere urban lifestyles, systems, mechanisms, and processes need to be transformed to operate in keeping with natural laws and functions. The struggle remains to be the refinement of human activities, and the battleground is the urban landscape and its supporting systems (Lyle, 1994; Melby & Cathcart, 2002; DeKay, 2010; Edwards, 2010).

a) Scenario-Comparison Process

The scenario-comparison process is an effective planning and design instrument, enabling planners and designers to estimate, analyze, evaluate, and evaluate environmental performance quantitatively in the application of the RUD model. Especially during the process of optimizing restorative scenarios, running through different alternatives, and estimating the amount of impact mitigation for each alternative projection scenario, the scenario-comparison process allows greater flexibility and control for adjustments and refinement. As some of the emerging urban growth modeling, 3D visualization and temporal simulation technologies mature further in the near future the restorative research with scenario-comparison is likely to be become more streamlined and integrated into environmental design and planning.

b) Exclusive Focus on Urban Ecology

This restorative research advocates that the efforts of re/development need to maintain an exclusive focus on refinement of contemporary urban design principles and strategies toward the comprehensive restoration of the natural environment. As the number, extent, and impacts of human-made environments continue to increase, the study of these environments as well as their impacts on nature give rise to new areas of knowledge and technologies that were not conceivable or necessary just a few decades ago. One of these exciting and rapidly maturing new areas is urban ecology, which increases the understanding of urban areas as ecosystems (Fitter, 1945; Breuste et al., 1998; Beatley, 2000; Radovic, 2009; Palazzo & Steiner, 2011). Within that framework, the ecological approach to design and planning of urban areas in general aims not only to learn from and mimic with the natural processes and systems, but also to create harmonious patterns as well as interdependent relationships with them (Gill & Bonnett, 1973; Spirn, 1984; Douglas et al., 2011).

Improving on the existing theory, knowledge, and technologies of sustainable urban design and planning, this restorative research aspires to make transformative contributions toward the comprehensive restoration of the rapidly deteriorating natural environment. The RUD model promotes a multidisciplinary environmental design and planning approach in order to achieve simultaneous multidimensional improvements by:

i. <u>Identifying Significant Urban Sources of Degradation, Deterioration, and Depletion in Nature</u>

   A rigorous survey of interdisciplinary literature on urban design and planning reveals the complexities and extents of environmental challenges before the rehabilitative and restorative efforts.

vi. <u>Forming An Agenda of Ecologically Responsive and Environmentally Responsible Design</u>

   Based on qualitative as well as quantitative assessment of human impacts a set of ecologically responsive and environmentally responsible design goals are established for restorations within urban ecology.

vii. <u>Quantifying Negative Human Impacts Originated from Urbanized Areas</u>

   In order to quantify human impacts associated within urban areas, this research proposes a system of analyses on selected indicators on all five major dimensions of RUD model (i.e. air, water, land, ecology, energy). Through analyzing an adequate number of select environmental performance assessment indicators, the necessary impacts should be systematically quantified, estimated, and mitigated.

viii. Mitigating Impacts of Human Activities within Urban Areas

A critical step in mitigation of negative human impacts on nature is to determine a multidisciplinary set of urban re/development principles and strategies that can be implemented in an orderly, timely, and effective manner to appropriately counteract past, present, and expected degradation.

ix. Modeling Restorative Alternatives for Urban Re/development Scenarios

The central feature of this research is a virtual model of geospatial data where restorative concepts, strategies, and scenarios can be effectively represented and evaluated. The Restorative Urban Design (RUD) model is conceived and designed for the urban ecology, using similar principles as those employed in ecological studies and restoration models.

x. Developing A Methodological Approach Based On Scenario-Comparison

Scenario-comparison is an effective process employed in modeling and analyses of complex spatiotemporal phenomena from urban growth and ecological restoration to management practices for emergencies, environmental crises, risks, and threats. The RUD model establishes, analyzes, and evaluates the restorative advantages and disadvantages among four scenarios in urban development i.e. Natural Baseline; Historic Progression; Trajectory; and Restorative Projection.

xi. Evaluating and Optimizing Restorative Design Strategies

The RUD model proposes an effective way to analyze, evaluate and optimize specific urban design and planning strategies with respect to their restorativeness.

xii. Reporting Through Geospatial Models and 3D Visualization Techniques

Among the end results of this research are data and input that can be used for visualization of various scenarios as evaluated in the analyses of selected indicators. The new visualizations are partially to be incorporated in the report section.

2. The RUD Case Study Findings, Outcomes & Discussions

The theoretical application of the RUD model in the River North District within Chicago Metropolitan Area serves as an illustration of how complicated the simultaneous implementation of all restorative strategies would likely get within urban cores and well-developed areas. The River North District application reveals not only the extent of anthropogenic CO_2 emissions but also the complications preventing or constraining appropriate onsite mitigations primarily due to the high density of existing developments.

As introduced in Chapter 1 and discussed in Chapter 4, adequately answering the specific research questions driving the RUD Case Study provides specific insights on the application of the RUD model on the rest of the restorative indicators. The following discussions focus on the findings, outcomes, and interpretation of case study results.

a) Current Amount of Anthropogenic CO_2 Emissions

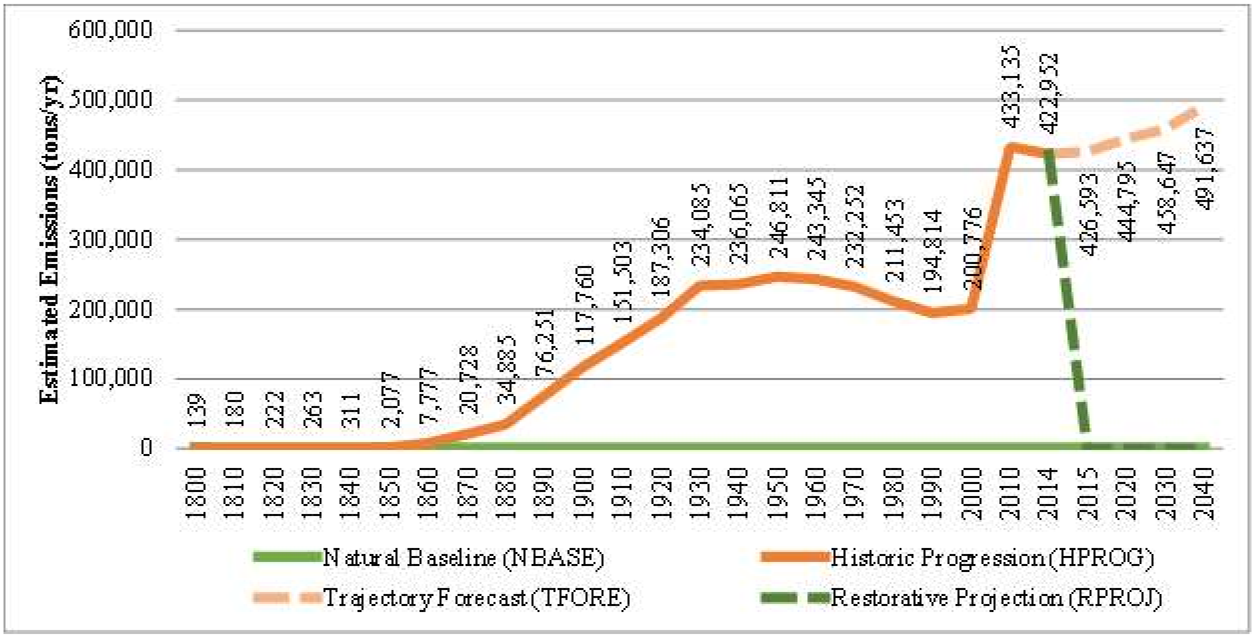
The current amount of major anthropogenic CO_2 emissions of a given urban area for restorative purposes may be estimated in various different ways. For the purposes of this research, four main sources of CO_2 generation are used: private transportation, public transportation, heating (natural gas and fuel oil), and electricity consumption (Glaeser, 2008). While examining the emissions generated within urban areas is useful in understanding the present amount and volume of human impacts from that area it may not be the whole picture. This because, often times, even larger amounts of anthropogenic CO_2 emissions are generated outside of these areas in order to support the systems and activities in these areas. Some of the most significant emission sources are often located outside the urban areas i.e. power generation, agriculture, industrial operations, manufacturing, commercial and freight transportation as discussed earlier. By default, the impact of these kinds of emission sources are excluded from the RUD Case Study estimations, however, they do need to be incorporated, estimated, and mitigated appropriately in reality.

That said, the first research question was: What is the total estimated annual amount of current anthropogenic CO_2 emissions in the study area (tons/yr) as of year 2014? The originally expected results estimated that the current anthropogenic CO_2 emissions in the study area (tons/yr) as of year 2014 were likely to be within the range of: a) High: 498,500 tons/yr (assuming 25% lower efficiency and/or more reliance on fossil fuels usage than regional averages), b) Median: 398,800 tons/yr (assuming about 20 tons/yr per person on average), and c) Low: 299,100 tons/yr (assuming 25% higher efficiency and less reliance on fossil fuels).

At the end, the RUD Case Study finds the current anthropogenic CO_2 emissions in the study area to be 422,952 tons/yr (see Figure 5.1, and refer to Table 4.5), which is comprised of 263,026 tons/yr from buildings, 130,613 tons/yr from private transportation, and 29,313 tons/yr from public transportation (refer to Figure 4.15).

This total estimate is at the higher end of variation range (498,500 for high and 299,100 tons/yr for low), which was based on a 25% deviation from an average per capita carbon generation rate for the United States (20 tons/yr CO_2 or of 2.3 tons/yr) (Rowntree & Nowak, 1991, p. 273; TLGDB, 2001, p. 219). Especially in densely populated urban areas such as the RUD Case Study area, the concentration of environmental impacts like emissions are naturally expected to reach significantly high levels.

Figure 5.1 Summary of four major scenarios in the RUD Case Study

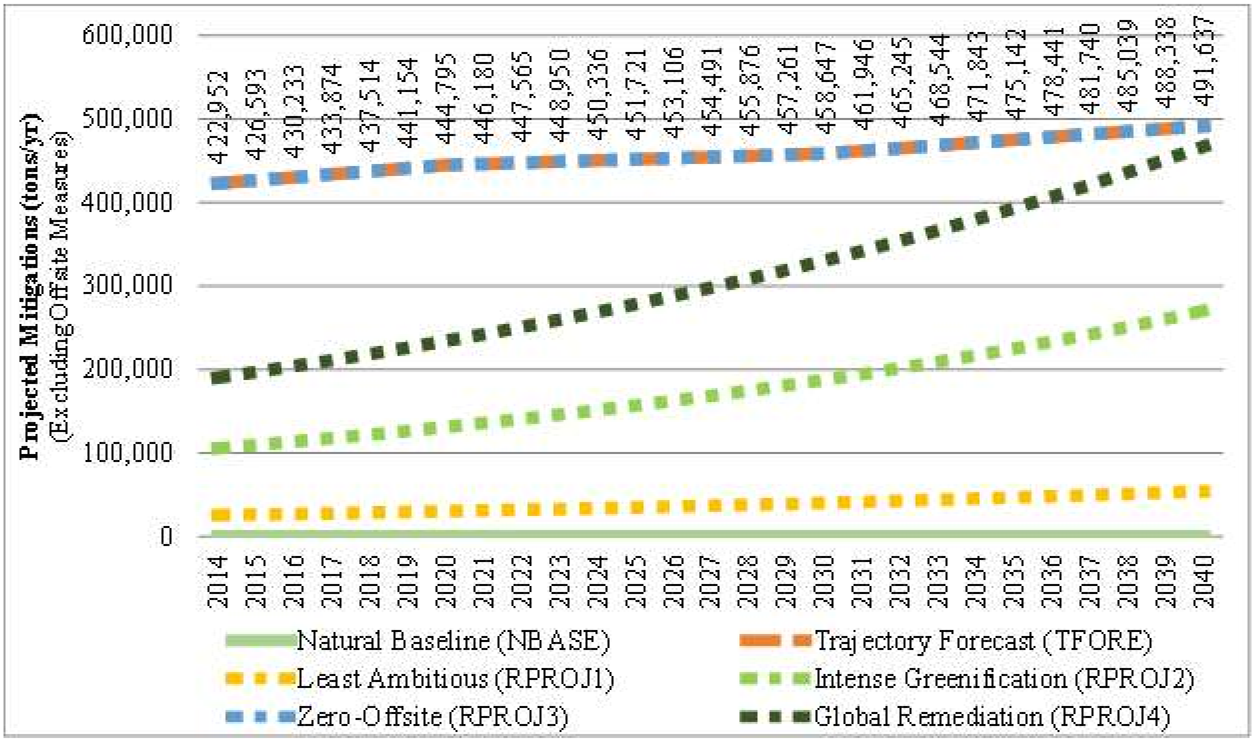


The annual emission amount of 422,952 tons/yr marks the starting point for the future trajectory forecast as well as the restorative projection, where the latter needs to be configured to fully mitigate the former. It is perhaps more helpful to visualize the magnitude of this rate by using the offsite mitigation forest used in the RUD Case Study, which is specified to sequester an average of 737.00 tons CO_2 of per hectare annually. If not mitigated through any other means, this generation rate would require a forest that is 573 ha (5.738 km^2 or 2.215 mi^2), which would be about 405% or 4 times the study area.

b) Trajectory Forecast on Anthropogenic CO_2 Emissions

The second research question was: What is the total annual amount of anthropogenic CO_2 emissions (tons/yr) to be restoratively mitigated by year 2040 in the study area? It was expected that the total annual amount of anthropogenic CO_2 emissions in the study area (tons/yr) as of year 2040 – depended largely on population and consumption patterns but – was likely to fall within a range of: a) High: 579,300 tons/yr (25% above historical patterns), b) Median: 463,500 tons/yr (based on historical population growth patterns), and c) Low: 347,600 tons/yr (25% below historical patterns). The RUD Case Study forecasts that, assuming no significant changes in the historic population growth or emission patterns, the carbon dioxide generation is likely to reach 491,637 tons/yr by 2040 (see Figure 5.1, and refer to Table I.1). This finding is very close to the median of expected range, which simply means more intensified mitigations would be required.

Figure 5.2 Summary of evaluated restorative projection scenario alternatives



c) Onsite Mitigations in Restorative Projections

The next restorative research question aimed to predict the onsite mitigations: In an optimized restorative projection scenario, what percentage of the estimated annual amount of anthropogenic CO_2 emissions is likely to be mitigated through strategies implemented onsite by 2040? Since the percentage range of projected restorative mitigations within the study area as of year 2040 is influenced by a series of factors such as population, growth, and design assumptions the possible answers were grouped into three categories: a) High: 55% (assuming a relatively lower level of future growth and development in the study area than CCAAP (2009) projection, with relatively high level of mitigation measures for anthropogenic CO_2 emissions by the year 2040), b) Median: 30% (assuming an average level of growth and development in the study area as compared to CCAAP (2009) by the year 2040, as well as moderate mitigation measures), and c) Low: 5% (assuming a much higher level of growth and development in the study area by the year 2040, with the least amount of onsite mitigations).

To conclude, the RUD Case Study demonstrates that there are multiple possible restorative projection scenario alternatives, through which current and forecasted anthropogenic CO_2 emissions can be mitigated onsite as much as possible (refer to Figure 5.2). The study determines that the projected amount of onsite mitigations could be as low as 1% (RPROJ1) or as high as 25% (RPROJ4 in 2040). As discussed in Chapter 4, the amount and percentage of onsite mitigations is a function of available open spaces, building facades, and roof areas in the land parcels when natural elements such as trees, plants, and vegetation are used. While parcels with smaller building footprint ratios are more conducive to bigger green installations in general the larger building footprints tend to constrain the size of efficient onsite applications. Even though larger building footprints – and surface area – may offer greater opportunities for bigger green roof – and green wall – applications they may not always feasible due to a number of limitations such as physical space, structure systems, local climate, plant species, or maintainability issues.

On individual parcels, especially ones with smaller building footprints, lesser density, smaller estimated impacts, and larger available open spaces, exceeding beyond 25% onsite mitigations becomes more feasible. By the same token, larger building footprints together with larger estimated impacts often result in smaller available open spaces, which directly translates to significantly reduced amount of possible onsite mitigations. Therefore, in densely developed urban areas, aided by the limited sequestration capacities of current green roof and green wall technologies, it becomes considerably more challenging to surpass 25% onsite mitigations on a neighborhood scale. The maximum level of 25% onsite mitigations emerges as a plateau or ceiling, which is slightly below the median prediction as discussed in the research questions. Additionally, unless the overall emission levels are drastically reduced, implementing onsite mitigations at 55% neighborhood-wide remains an extremely hard-to-achieve goal for most densely developed urban areas.

Yet another potentially key advantage of district scale urban re/developments lies in the possibility of recomposing urban landscape in order to generate more available open spaces and green areas as a large-scale onsite mitigation strategy. There are few instances in the RUD Case Study where the existing paved areas and parking lots are converted into green areas. Perhaps through new regulations, legal instruments, and ownership structures the land assemblies and restorative urban re/developments may become economically more desirable and environmentally more beneficial in the near future.

d) Offsite Mitigations in Restorative Projections

Finally, the last research question driving the restorative research was: In an optimized restorative projection scenario, what percentage of the estimated annual amount of anthropogenic CO_2 emissions is likely to be offset by mitigation strategies implemented offsite by 2040? In most parcels of the RUD Case Study area, it was expected that the estimated range of anthropogenic CO_2 emissions cannot be fully mitigated onsite, and therefore, some offsite mitigations were likely to be implemented offsite. The percentage of offsite mitigated emissions were predicted at: a) High: 95% (assuming a relatively high level of growth and development in the area with relatively low level of onsite mitigation measures for emissions), b) Median: 70% (assuming an average level of growth and development in the study area as compared to CCAAP (2009) by the year 2040, as well as a moderate level of onsite mitigation measures), c) Low: 45% (assuming a lower level of growth and development in the study area by the year 2040, with the most amount of onsite mitigations).

To conclude, the restorative projection scenario alternatives of the RUD Case Study illustrate that the restorative offsite mitigations can vary from 25% (RPROJ4 in 2040) to 94% (RPROJ1 in 2040) (refer to Figures 4.25 and 4.22 respectively). The anthropogenic CO_2 sequestration amounts for these percentages are respectively 128,611 tons/yr (refer to Table L.1 in Appendix L) and 438,082 tons/yr (refer to Table I.1 in Appendix I), which is a considerable range of variation. Even though relying on offsite mitigation strategies is not the core intent of the restorative research these mitigation measures are critical in fully addressing the estimated urban impacts on the natural environment. When the RUD model is applied to the remaining indicators in all dimensions the offsite mitigations are likely become even more critical to the comprehensive restoration of the natural environment. If regulated, organized and executed appropriately the offsite mitigations have the potential to act as the local instruments of remediation that are effective on a global scale.

3. Extrapolating Implications for The RUD model

Similar to the RUD Case Study, the full application of the RUD model within a neighborhood or an entire city is likely to require a certain portion of restorative mitigations implemented offsite while some of the air, water, and energy related impacts may be addressed more conveniently onsite.

a) Type, Size & Intensity

Depending largely on the particular type, size, and intensity of urban re/developments, the ratio of onsite mitigations to offsite strategies is likely to show a wide variation from one parcel or neighborhood to another. For developments of lesser density and larger available open space, restorative onsite improvements – such as production of food, harvesting and treatment of water, infusion of biodiversity, management of emissions, sequestration of pollutants, generation of renewable energy, and so forth – can be achieved relatively easier. Whereas, for developments of higher densities or impacts, a more significant portion of restorative measures can be expected to take place offsite.

b) Synergies & Efficiencies

Some of the possible restorative measures have been indicated in Table 3.1 in Chapter 3 earlier. A key technique for achieving successful restoration is to carefully optimize and balance the various mitigation strategies to be implemented simultaneously, making sure that overlaps and counterproductive or conflicting measures are accounted for. Understanding the synergies and efficiencies among restorative measures and taking a reconciliatory approach is important. The required size and number of mitigation measures can greatly be reduced by choosing a combination of appropriate techniques that are likely to deliver most benefits simultaneously in multiple environmental assessment dimensions.

c) Multiple Benefits of Greenification

Planting trees and increasing highly-integrated plant communities that function well within urban settings, for instance, is perhaps a prime example of possible restorative measures that can deliver multiple benefits simultaneously. In general the trees and plant communities simultaneously: purify the air and water; create new and stabilize the existing soil; enrich the ecosystems; harbor and nourish flora and fauna; provide shelter and food for the animals, insects, as well as microorganisms; provide useful materials, fiber and energy; help regulate the local microclimate as well as humidity; provide shade and help reduce the ambient temperatures; produce and provide oxygen that all living beings rely on; sequester and store atmospheric carbon content; support life, die, return to soil, and fuel new growth. The long list of environmental benefits makes increasing the non-invasive tree cover and functional plant communities among the most effective and preferable strategies toward the environmental restoration.

The use of natural materials such as trees, plants, and vegetation comes with its own limitations depending on location and climate. For instance, the harsh winters in the case study area is likely to make maintenance and survival of vegetation difficult in green wall applications. CO_2 sequestration related to green walls and green roofs are limited by their type and longevity under the local conditions. Keeping vegetation healthy in dense urban areas – especially when there is limited or degraded soil involved – poses many challenges. Healthy living soils will help create healthy living plants but excellent design, installation, and ongoing maintenance are vital.

d) Complex Multidisciplinary Collaboration

As the RUD model must consider and address a large set of environmental performance assessment indicators, the process of modeling and running actual calculations quickly becomes complicated, which inherently necessitates corresponding levels of multidisciplinary collaboration and teamwork. Synchronizing the knowledge and technologies from different fields of expertise is not only beneficial but also essential in successfully determining the most efficient measures for environmental restoration. The restorative approach is likely to be most productive and effective when adopted by the local authorities or organizations focusing on urban planning and design, and implemented through the legal processes and partnerships in the environmental design and planning processes.

e) Technical Difficulties in Data & Computations

Through the RUD Case Study it becomes clearer that there can be significant potential difficulties and limitations on the availability, retrieval, or recomposition of historical data. On some indicators such as emissions, wastewater, waste generation, locating and accessing recorded local data may be more challenging simply due to incompatibility, insufficiency, unavailability or lack of recording. In many instances, some of the missing data may be reconstructed, interpolated and/or extrapolated using published regional or national averages as appropriate. Other factors such as documented trends in human population or land cover changes may be used as proxies to bridge the gaps or estimate the missing information. Likewise, the RUD Case Study applies the regional historic trends and future trajectory projections documented by CMAP (2012) to the population change in the study area as discussed earlier in Chapter 4.

4. Opportunities & Challenges of Restorative Implementations

Environmental restoration is not a new idea or practice, however, the overall scale and rate of current degradation in the natural environment has been pushing it to the forefront of the environmental design and planning agenda (Berger, 1990; Hall, 2005). Since the RUD model is primarily driven by environmental concerns it places little emphasis on the social, economic, and political aspects of the issues, which are certainly vital to implementations. Lack of primary emphasis on these aspects does not mean that they are unimportant or irrelevant but rather that the environmental concerns can be brought into better focus for assessment purposes. The social, economical, and political considerations are in fact critical factors that may greatly influence how restorative goals are actually adopted and restorative objectives achieved during the implementation process.

The implementation of future restorative methods in existing urban areas is likely to present many significant social, political, economic opportunities as well as challenges. While this research elucidates what needs to be done for restoration from strictly an environmental and physical standpoint, the implementation depends on the dynamics and synergy of other real life forces in today's urban communities. Since, in most instances, the current development standards and regulations are not geared to deliver comprehensive restoration, transformation and change within planning and policy-making arenas are inevitably necessary.

a) Regulatory & Political Environment

Perhaps one of the most important challenges with greatest consequences is the political environment and the regulatory mechanisms of communities, regions and nations. The legal requirements, codes, laws and regulations hold tremendous potential to make extraordinary urban transformations at large scales. Here, it should be noted that environmental performance assessment and rating systems such as BREEAM (2007), LEED-ND (2009), ILBI (2010), or CASBEE-UDe (2007) are gaining widespread recognition and increasingly being adopted as part of local urban design and planning regulations. Generally speaking, the rigor and extent of these adoptions are in direct proportion with the strength of values and convictions within those communities. The sustainability design guidelines and practices are often self-imposed and adopted voluntarily by a minority of communities and cities where concerned citizens, professionals, landowners, developers, and/or stakeholders lead these efforts. For the majority of urban areas, however, these systems appear to be unrecognized, irrelevant or impractical.

b) Encouraging Precedents

The expanding number of precedents for ecologically responsive and environmentally responsible design practices continue to minimize urban impacts on nature in many communities. In these communities the urban re/development patterns are transformed voluntarily in order to set higher standards for environmentally responsible lifestyles. There are many communities around the world, which have taken even more aggressive environmentally responsible initiatives such as: Kibbutz, Israel; Camphill Village, NOR; Findhorn Ecovillage – Findhorn, SCO; Lebensgarten – Steyerberg, DEU; Crystal Waters, AUS; EcoVille – St. Petersburg, RUS; Gyurufu, Hungary; Ladakh Project – Kashmir, IND; and Ecotop, DEU. In these communities, the founding ideals are to religiously preserve and restore the natural settings while seamlessly integrating low density human settlements within those settings (Bang, 2005).

In the United States, some of the environmentally responsible urban re/development examples include: Arcosanti – Mayer, AZ; Village Homes – Davis, CA; Emeryville Marketplace – Emeryville, CA; Marin Solar Village – Novato, CA; Lyle Center for Regenerative Studies – Pomona, CA; The Manitou Institute, CO; Stapleton – Denver, CO; New Alchemy Institute – Cape Cod, MA; Twinbrook Station – Rockville, MD; EcoVillage at Ithaca, NY; Ti O'Spaye Village Project – Pine Ridge Reservation, SD; Albert Bates, TN; The Farm (EcoVillage Training Center), TN (Jackson & Svensson, 2002). While intuitive efforts in some of communities are commendable from a sustainable design viewpoint other examples such as Arcosanti and the New Alchemy Institute are, in principal, close to achieving a framework of comprehensive environmental restoration or total mitigation of urban impacts. Although their scale is much smaller than most urban neighborhoods, sensitive environmentally conscientious planners and designers need to learn from both their vision and specific practices.

c) Enabling Legislation: A Federal Act for Environmental Restoration

The restorative urban design principles and strategies put forth by the RUD model could be adopted and required by any governing body at local, regional, state, or national levels. Needless to say, these regulations would complement some of the existing requirements and introduce some new mitigation considerations. The legal footing of restorative measures can be firmly instituted by an enabling legislation – as in the case of comprehensive plans or zoning regulations – or a federal act, perhaps similar to the National Environmental Policy Act of 1969. Such a federal act can establish a hierarchy of funding mechanisms, agencies, regulations, and standards of environment restoration similar to those of environmental protection (Bass & Herson, 1993; Syms, 2002; Norton, 2005).

Otherwise, individual local jurisdictions may have to exercise their own legislative authorities – as it is commonly practiced today on sustainability efforts – to seek public consensus like in environmentally conscious, sensitive, and progressive communities like Portland, OR, Boulder, CO, in order to adopt self-imposed initiatives for restoration of the natural environment, in much similar manner to the adoption of growth management programs in many jurisdictions as discussed earlier (Kelly, 2004; Porter, 2008; Calthorpe, 2011).

d) Adoption & Implementation by Local Governments

In a hypothetical scenario of a local or regional jurisdiction choosing to adopt and implement an environmentally restorative re/development framework like the RUD model, necessary provisions and requirements would need to be codified into the regulatory instruments such as comprehensive plan, zoning regulations and ordinances as appropriate. A strong foundation for the restorative efforts would need to be legally established by the federal, state, and local statutes and laws in accordance with the constitution (Scott, 1969; Leung, 2003; Levy, 2003; Morris, 2009).

The regulatory environment supporting the growth management regulations has been going through litigious evolution for decades where through many court cases valuable lessons have been learned and rulings established. When a sizable new development is proposed in a community there are real impacts associated with providing public services – i.e. water, sewer, roads, parks, schools, emergency and police – to these added uses in order to maintain the same level of service, which create physical and economic burdens upon the limited resources and infrastructure of existing communities (Juergensmeyer & Roberts, 2003; Kelly, 2004; Porter, 2008). The offsite mitigation requirements is perhaps a key area that requires further development, can be potentially contentious and controversial to implement through real world regulations. However, it would be reasonable to expect that as the restorative strategies and technologies become more mainstream the offsite mitigation measures would receive wider acceptance and become routine practices in urban re/developments. Transformation of our agricultural landscapes to ecologically restorative and productive systems will be vital as offsite mitigations are contemplated. This is also true for other landscapes that are mined by people for the resources they provide.

e) Estimation of Full Extent of Urban Impacts

Perhaps one of the greatest opportunities and challenges of the restorative research is the willingness or ability to estimate the full extent of urban impacts in the real-world. The current set of environmental performance assessment and rating systems available today evaluate only the most significant portion of these impacts that can be readily addressed prominently individual project sites. However, the impacts of urban developments are typically well beyond these estimations. For instance, in estimating only the carbon dioxide emitted from a building or a car on site is only the top of the iceberg. If the restorative investigation includes all the resources, energy, costs, and impacts embedded in the production and maintenance of that building or car the picture would be more complete. That is to say, annual carbon dioxide emission of a car or a building should theoretically include the carbon dioxide that was generated in the extraction, transportation, manufacturing, production, assembly, sales and maintenance of that car or building as well as other factors that make it possible for them to function for a year.

For this reason, the compounding complexity in estimation of the urban impacts is often avoided by simplification, and the representation in impact models tend to fall short of some of the real concerns. The restorative research is no exception to this rule, in that, the offsite impacts have been excluded in Chapter 4. However, in order to fully address the urban impacts the estimations need to be rigorous and include full extent of urban impacts.

5. Onsite & Offsite Mitigations of Urban Impacts

In theory, every piece of the urban puzzle has potential contributions to the problems and solutions in the natural environment. Urbanized areas are widely recognized as the origins or sources of cumulative environmental degradation, deterioration, and depletion in nature (Meyer, 1996; Goudie, 2006; UNEP, 2002; Lloyd Crossing Plan, 2004; MITHUN, 2009). It is fairly logical that the problems have to be resolved or mitigated by its originators and contributors. The best solution to any environmental problem would be to not create it in the first place. Beyond that, the mitigation of associated urban re/development impacts onsite and/or offsite is the core focus of restorative research. The RUD model and scenario-comparison process have the potential to form a powerful approach to analyzing, estimating, and mitigating major urban impacts of urban re/developments in the planning and design stage. Once appropriately quantified, mitigating maximum amount of urban impacts onsite needs to be the most critical objective for any urban re/development project adopting the restorative approach.

a) Balancing The Project Scope & Site

The sizes of projects matter. Although there is a wide selection of possible strategies available for just about any given re/development situation the full mitigation of impacts onsite is even harder to achieve for larger and denser developments. Those kinds of projects need to carefully establish a balance between total impacts and mitigation techniques onsite. Reducing the project scope or changing location to a more suitable site must be a consideration.

Depending on the accessibility, ease, and feasibility of mitigations, certain adjustments may have to be made on the size and density of projects in order to achieve more ecologically responsive and environmentally responsible results. From that standpoint, the concerns about feasibility should not overtake the concerns about environmental health. Unmitigated or environmentally irresponsible re/development proposals – which cannot be appropriately mitigated on a given site – need to be reconsidered and recalibrated carefully before proceeding into implementation.

Since mitigations rely on creating functional natural systems, the lack of available land area onsite is likely to become a serious limitation for most urban re/developments from a restorative design perspective. Addressing the required onsite mitigations on the scale of neighborhoods and districts in an urban area can offer greater advantages over segmented mitigations on each parcel. Designated land areas in urban neighborhoods – acting as natural amenities as well as functional onsite mitigation spaces – would be a good starting point to foster more natural elements and settings within the urban ecologies.

b) Economic & Political Sacrifices

Though transition into restorative practices may initially necessitate significant economic and political sacrifices initially, the environmental benefits and payoffs in the long-term are unparalleled. The urban impacts on environment are not a superfluous set of lofty ideas or concerns but are very much real and present problems with potentially irreversible consequences. Many private organization, communities, public authorities, governments, and countries responsibly treat their impacts or footprints on the environment already with extreme seriousness and care that it deserves i.e. urban re/developments in Norway, Denmark, Sweden, Germany as pointed out (Brown, 1981; Franchi, 2005; Brown, 2011).

From that perspective, the development difficulties of offsite mitigations need to be welcomed and embraced as opportunities to implement environmentally responsible patterns of urban development and redevelopment. Using renewable energies, living within local budgets of sequestered carbon, harvested water, and productive capabilities of soil provides a natural measure of how much human growth should be accommodated. The environmental objectives behind urban growth should include exporting no emissions or pollution in to the biosphere, increasing energy efficiency, biodiversity, and environmental quality through all means possible. Offsite mitigations should be responsibly accepted as offsets of those environmental impacts that could not be neutralized within the confines of any given site. Traditionally, these impacts are thrown away into the atmosphere, sent away into the hydrosphere, or put away into the lithosphere. Well, there is no more “away,” and “away is gone away” (McDonough & Braungart, 2002, p. 27).

c) New Legal Instruments to Enable Mitigations

On the subject of offsite mitigations, transferable development rights or Transfer of Development Rights programs currently practiced in many jurisdictions could be taken as a precedent for regulatory tools around which to organize required mitigations proposed by the restorative research (Porter, 2002; Kelly, 2004; Lloyd Crossing Plan, 2004; Newman & Jennings, 2007). The transfer of development rights programs in zoning practices entail the permanent vacating of rights on one site and adoption by another. While the recorded rights to develop on one site are reduced and restricted permanently the developments on another corresponding site are increased and intensified in the offset amount. Some of the offsite mitigations under the RUD model could be structured to work along similar lines where the urban impacts that could not be mitigated on certain sites – due to various constraints as discussed earlier – could be mitigated on other sites near or away from the place of their origination. Jurisdictions adopting a restorative approach and framework to re/development could manage the offsite mitigations, and even designate areas inside or outside of their urban areas where these could be planned, combined, and implemented in an organized manner. This way, some of the required offsite mitigations might be sold and purchased creating a robust economic market with environmentally positive outcomes. This is certainly an area that deserves further research and experimentation.

Perhaps another viable path to wide-scale urban transformations is federal enabling and local adoption of restorative zoning regulations. Considering the extent of offsite mitigations necessary to offset urban impacts, there appears to be a great need to appropriate new legislation and requirements to organize, facilitate, and regulate a restorative urban re/development process. At a minimum, the urban areas can be transformed by creation of restorative overlay zones, which protect the historic structures and facilitate denser, compact, pedestrian-, and transit-oriented re/developments district-wide. The new overlays can extend special incentives to the property owners, investors, developers and users for land assembly and restorative urban re/developments. The innovative partnerships between local government private enterprises are likely to continue proving invaluable toward the necessary transformations in the human-made environment.

C. Broader Impacts & Implications of Restorative Research

The restorative research proposes an integrated urban design method aiming at the comprehensive environmental restoration, which would be – at least in principle – adopted by public or private entities in any community where social, economical, and political values are driven by mitigation of environmental impacts. The restorative principles and strategies that shape the RUD model hold enormous potentials to provide feedback for policy- and decision-making processes based on scientific analyses while also bringing large-scale transformation in urbanized areas toward facilitating the recovery and the rehabilitation of natural balances within the living biosphere of the Earth.

1. Academic & Professional Collaboration

The RUD model proposed by this research is intended to allow theoreticians and practitioners to develop and test urban re/development scenarios that are evaluated and optimized specifically for significant rehabilitation of the natural environment. Scenario-based urban growth modeling is a rapidly advancing area of urban design research and developments, which continues to increase the collaboration of academicians and professionals.

The restorative line of research has the potential to foster the growth of knowledge and advancement of technologies related to comprehensive rehabilitation of the natural environment also. The promise is likely to be an entire universe of multidisciplinary research, design, and construction possibilities, especially in those areas that are directly associated and involved with the onsite and offsite restorative mitigation measures.

2. Public Awareness & Participation

In preventing further degradation and implementing rehabilitation, the awareness and active participation of the general public as stakeholders are critical factors, which can only be achieved through widespread efforts to continually educate and remind the urban populations on the nature of urban impacts. Some of the educational and participatory goals of restorative efforts can be supported and propagated by the metropolitan non-profit and non-governmental organizations that are already involved in the community re/development at various levels. Many educational, political, environmental and philanthropic organizations can and should adopt a restorative frame of mind, and support fostering and dissemination of the core principles.

3. Multi-Criteria Decision Making (MCDM)

Multiple-criteria decision making (or multiple-criteria decision analysis) explicitly considers multiple criteria in decision-making environments. In professional, academic, and institutional settings, there are often multiple conflicting criteria that need to be evaluated for making decisions. Quality, safety, and costs are usually among the leading considerations. Even though the exact criteria under consideration may vary the fundamental strategy of this evaluation method is to achieve the highest possible returns with lowest risks involved.

In addition to the multi-criteria decision making process, the methods, processes, and practices proposed by this research are intended to be used by governments, governmental agencies, organizations, public and private institutions, which are typically engaged directly with the re/development of urbanized areas.

4. Transformation of Urban Metabolism

Effective transformation of urban metabolism is perhaps the single most important broader impact that restorative research and development can have on the built environment. Such an evolutionary track may provide the impetus for development of new academic fields, discovery and application of new technologies, new opportunities for research and education, as well as creation of economic opportunity, employment, and revenue streams.

Urban design and planning, in particular, are among the most potent collaborative disciplines for facilitating future transformations within the urbanized areas. Integrated developments and coordinated redevelopments of the built environment are vitally important portals leading to comprehensive environmental restoration. The restorative research seeks to provide a stepping-stone in the aforementioned direction by introducing an alternative approach based on scenario modeling at the service of urban designers, planners, and decision-makers, who are shaping the world of tomorrow (Rogers, 2003).

5. National Laws & International Policies

It is hoped that the recognition of current and projected degradation in the natural environment promptly triggers formulation of legislation in the developed countries, similar to the Environmental Protection Act of 1969 in the United States. Federally enacted laws and/or internationally mandated policies on environmentally restorative developments could not only institute a series of resolute organizations headed by an Environmental Restoration Agency but also provide a solid legal foundation for a broad spectrum of industrial and urban impact mitigations. Long-standing concerns regarding authoritarian rule-making and policing must be addressed by ensuring meaningful local autonomy and adaptation to any over-arching legislation and policy-making. This is yet another realm for focused research and pro-active, decision-oriented dialogue.

D. On Future Research Toward Global Remediation

The existing literature – focusing specifically on comprehensive environmental restoration or global remediation that embraces urban areas – is limited to studies and initiatives in disciplines such as restoration ecology and landscape design, and related fields. The restorative literature on urban ecology is even narrower and primarily focused on redevelopment of infrastructure, recreation facilities, and parks within urban areas (Laurie, 1979; Spirn, 1984). While major sources of environmental degradation, deterioration, and depletion on Earth are irrefutably embedded in urban areas there appears to be an unjustifiable absence of research and development aiming for the comprehensive restoration of natural environment through improved urban design and planning.

The larger Restorative Urban Design methodology is conceived to address a critical yet absent aspect of current sustainable planning and design practices, i.e. an exclusive focus on the restoration and remediation of natural environment through urban growth and redevelopment practices. While this model is not the only possible venue to implement such broad based and widespread environmental restoration efforts it does form a theoretical foundation not only for other urban research and developments to follow but also for countless other restorative efforts to transform the current urban reality.

It is hoped that there is more research and development in the area of comprehensive environmental restoration and remediation through urban design and planning in the near future. Perhaps one of the most important research and development areas is the advancement of better onsite mitigation technologies to be used in the environmentally restorative design solutions. Offsite mitigation techniques are another significant area that need to advance in order for the restorative strategies to be effective on larger scales. Restoring the conditions for thriving natural life and beauty is not only theoretically possible but also practically feasible even under the most unfavorable circumstances or the most prohibitive environments on earth. Learning from natural systems based green infrastructure planning/design and the field of ecological restoration will be vital to the effort to achieve truly restorative urban conditions.

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Appendix A - Abbreviations

Abbreviations used in the restorative research include:

Abbreviation	Full Name, Phrase, or Title
ABA	American Bus Association
ABM	Agent-Based Models
AIA	American Institute of Architects
APA	American Planning Association
APTA	American Public Transportation Association
AUS	Australia
BEL	Belgium
BIM	Building Information Model
BRA	Brazil
BREEAM	British Research Establishment, Environmental Assessment Method
CA	Cellular Automata
CAN	Canada
CASBEE	Comprehensive Assessment System for Building Environment Efficiency
CCAAP	Central Chicago Area Action Plan
CH_4	Methane
CHN	China
CMAP	Chicago Metropolitan Agency for Planning
CO_2	Carbon Dioxide
CTA	Chicago Transit Authority
CNU	Congress for New Urbanism
DEU	Germany
EPA	Environmental Protection Agency
EU	European Union
FIN	Finland
FRA	France

GIS	Geographic Information System
HPROG	Historic Progression
HUN	Hungary
ILBI	International Living Building Institute
IND	India
IPCC	Intergovernmental Panel on Climate Change
ITA	Italy
JPN	Japan
LEED	Leadership in Energy and Environmental Design
MEA	Millennium Ecosystem Assessment
NBASE	Natural Baseline
NCARB	National Council of Architectural Registration Boards
NO_2	Nitrogen Oxide
NOR	Norway
NO_x	Mono-Nitrogen Oxides
NZD	New Zealand
OECD	Organization for Economic Cooperation and Development
RTA	Regional Transportation Authority
RPROJ	Restorative Projection
RUD	Restorative Urban Design
RUS	Russia
SAF	South Africa
SCO	Scotland
SERI	Society for Ecological Restoration International
SLEUTH	Slope, Land use, Excluded, Urban area, Transportation, Hillside area
SPA	Spain
SWE	Sweden
TFORE	Trajectory Forecast
TOD	Transit-Oriented Development
UAE	United Arab Emirates

UCS	Union of Concerned Scientists
UIA	Union Internationale des Architectes
UK	United Kingdom or Great Britain
ULI	Urban Land Institute
UNEP	United Nations Environment Programme
WCED	World Commission on Economic Development

Appendix B - Environmental Indices

Table B.1 Restorative significance of environmental indicators in USI (1998)

USI (1998) – Urban Sustainability Indicators	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
Global Climate Indicator (GCI)	5	1	1	1	1	tons
Air Quality Indicator (AQI)	5	1	1	1	1	days/yr
Acidification Indicator (AI)	4	4	4	1	1	lt/ha
Ecosystem Toxification Indicator (ETI)	4	4	4	1	1	kg/person
Urban Mobility Indicator (UMI)	1	1	1	4	5	km/yr
Waste Management Indicator (WMI)	1	1	5	5	5	tons/ha
Energy Consumption Indicator (ECI)	1	1	1	1	5	tons/yr
Water Consumption Indicator (WCI)	1	5	1	1	1	m^3/yr
Nuisance Indicator (DI)	1	1	1	3	1	%
Social Justice Indicator (SJI)	1	1	1	3	1	%
Housing Quality Indicator (HQI)	1	1	1	3	1	%
Urban Safety Indicator (USI)	1	1	1	3	1	%
Economic Urban Sustainability Indicator (ESI)	1	1	1	4	1	\$/yr
Green, Public Space & Heritage Indicator (GPI)	1	1	1	3	1	%
Citizen Participation Indicator (CPI)	1	1	1	3	1	%
Unique Sustainability Indicator (USI)	1	1	1	2	1	%

Table B.2 Restorative significance of environmental indicators in USI (2010)

USI (2010) – Urban Sustainability Index	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
BASIC NEEDS						
Water supply	1	4	1	1	1	%
Housing	1	1	1	3	1	m^2/capita
Health	1	1	1	3	1	#/capita
Education	1	1	1	2	1	#/teacher
RESOURCE EFFICIENCY						
Power	1	1	1	1	5	kWh/GDP
Water Demand	1	4	1	3	1	lt/capita
Waste Recycling	4	4	4	4	4	%
% HI-GDP	1	1	1	3	1	#/teacher
ENVIRONMENTAL CLEANLINESS						
Air Pollution	5	1	1	1	1	mg/m^3
Industrial Pollution	5	5	5	1	1	lt/capita
Waste Water Treatment	1	5	1	1	1	%
Waste Management	1	1	4	4	1	tons/capita
BUILT ENVIRONMENT						
Urban Density	1	1	1	5	1	$\#/km^2$
Mass Transit Usage	1	1	1	4	4	lt/capita
Public Green Space	1	1	5	5	1	m^2/capita
Building Efficiency	1	1	4	4	1	%
COMMITMENT TO FUTURE SUSTAINABILITY						
Green Jobs	1	1	1	3	1	#/capita
Investment on Environmental Protection	5	5	5	5	1	$/GDP

Table B.3 Restorative significance of environmental indicators in CDI (1997)

CDI (1997) – City Development Index	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
Infrastructure (Water + Sewer + Electric + Phone)	1	4	1	1	1	#
Water (Treated + Disposed)	1	4	4	1	1	%
Health (Life Expectancy + Child Mortality)	1	1	1	3	1	yr
Education (Literacy)	1	1	1	3	1	%
Product (City Product)	1	1	4	4	1	#

Table B.4 Restorative significance of environmental indicators in EUPI (1994)

EUPI (1994) – Ecosistema Urbano Performance Index	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
Accessible Urban Green Areas						
Air Quality: NO_2	5	1	1	1	1	tons/yr
Air Quality: PM10	1	1	1	5	1	#
Bike Paths	4	4	4	4	4	%
Circulating Cars	1	1	1	2	1	ha/person
Eco Management Of Local Authority						
Fuel Consumption	1	1	1	1	5	%
Households Electricity Consumption	1	4	1	3	1	min/mo
ISO 14100 Certified Industries	4	4	4	4	4	#
Limited Traffic Areas	1	1	1	3	1	ha/person
Pedestrian Areas	5	1	1	1	1	#/10,000
Production of Solid Waste						
Public Transport Demand	5	5	5	1	1	#
Quality Of Drinking Water – Nitrate	1	5	1	1	1	#/1,000
Unauthorized Building	1	1	4	4	1	#/10,000

Table B.5 Restorative significance of environmental indicators in CSI (2001)

CIS (2001) – Compass Index of Sustainability	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
Well-being (Human Health and Happiness - Individual)	1	1	1	2	1	#
Society (Human Institutions and Systems)	1	1	1	2	1	%
Economy (Extraction, Production, Transaction, and Value-Creation Processes)	1	1	1	2	1	yr
Nature (Resources and Ecosystem Services)	5	5	5	5	5	%

Table B.6 Restorative significance of environmental indicators in SCI (2010)

SCI (2010) – Sustainable Cities Index	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
ENVIRONMENTAL PERFORMANCE						
Air Quality	5	1	1	1	1	tons/yr
Biodiversity	1	1	1	5	1	#
Household Waste	4	4	4	4	4	%
Ecological Footprint	1	1	1	2	1	ha/person
QUALITY OF LIFE						
Employment	1	1	1	1	5	%
Transport	1	4	1	3	1	min/mo
Health	4	4	4	4	4	#
Green Space	1	1	1	3	1	ha/person
Education	5	1	1	1	1	#/10,000
FUTURE-PROOFING						
Climate Change	5	5	5	1	1	#
Recycling	5	1	1	1	1	%

Table B.7 Restorative significance of environmental indicators in SDI (2002)

SDI (2002) – Sustainable Development Index	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
ECONOMIC INDICATORS						
GDP per capita	1	1	1	2	1	$/capita
Employment	1	1	1	3	1	#
Electricity intensity	1	1	1	1	5	kWh/mi^2
Environmental Assets	5	5	5	5	5	#/teacher
SOCIAL INDICATORS						
Education (Literacy)	1	1	1	3	1	#
Health (Child Mortality)	1	1	1	3	1	%
Poverty	1	1	1	3	1	%
Potable Water Availability	1	4	1	1	1	tons/yr
Sewage Infrastructure	1	4	4	1	1	m^3/yr
Electricity Availability	1	1	1	1	5	kWh/yr
NATURAL INDICATORS						
Hydrologic Balance	1	5	1	1	1	m^3/yr
Water Quality	1	4	1	1	1	mcg/m^3
Air Quality	5	1	1	1	1	ppm
Vegetation Covering Change	1	1	1	5	1	%
Soil Use	1	1	5	1	1	%
Erosion	1	1	5	1	1	tons/yr
Ecological Habitat	5	1	1	5	1	km^2
Protected Areas	5	5	5	5	1	km^2

Table B.8 Restorative significance of environmental indicators in LPI (1997)

LPI (1997) – Living Planet Index	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
TERRESTRIAL BIOME						
Realms	1	1	1	5	1	#
Species	1	1	1	5	1	#
Populations	1	1	1	5	1	#
FRESHWATER BIOME	1	1	1	5	1	#
MARINE BIOME	1	1	1	5	1	#

Table B.9 Restorative significance of environmental indicators in EI (2010)

EI (2010) – Eco-Index	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
Facilities Systems	2	2	2	1	2	#
Materials	1	1	1	2	1	#
Packaging	1	1	1	2	1	#
Product Manufacturing & Assembly	4	4	4	4	4	#
Transportation	1	1	5	5	5	#
Use	3	3	3	3	1	#

Table B.10 Restorative significance of environmental indicators in SSISC (1998)

SSISC (1998) - Sustainable Seattle - Indicators of Sustainable Community	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
ENVIRONMENT						
Ecological Health	1	1	1	5	1	#
Soil Erosion	1	1	5	1	1	turbidity
Air Quality	5	1	1	1	1	NAAQS
Pedestrian- and Bicycle-Friendly Streets	1	1	1	4	1	miles
Impervious Surfaces	1	4	4	1	1	%
POPULATION & RESOURCES						
Population	1	1	1	5	1	#
Water Consumption	1	4	1	1	1	gal/day
Solid Waste Generated and Recycled	4	4	4	4	1	lbs/capita
Pollution Prevention	5	5	5	5	1	lbs/day
Vehicle Miles Traveled and Fuel Consumption	1	1	1	1	4	miles
Renewable and Nonrenewable Energy Use	1	1	1	1	5	BTU
ECONOMY						
Energy Inputs Per Dollar of Personal Income	1	1	1	1	4	BTU/$
Employment Concentration	1	1	1	3	1	#
Unemployment	1	1	1	1	1	%
YOUTH & EDUCATION						
High School Graduation	1	1	1	1	1	#
Ethnic Diversity of Teachers	1	1	1	1	1	#
Adult Literacy	1	1	1	1	1	#
HEALTH & COMMUNITY						
Voter Participation	1	1	1	1	1	#
Gardening Activity	1	1	1	5	1	ha
Neighborliness	1	1	1	1	1	#/ha

Table B.11 Restorative significance of environmental indicators in ESI (2005)

ESI (2005) – Environmental Sustainability Index	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
AIR QUALITY						
Urban Population NO_2 Concentration	5	1	1	1	1	mcg/m^3
Urban Population SO_2 Concentration	5	1	1	1	1	mcg/m^3
Urban Population TSP Concentration	4	1	2	3	4	mcg/m^3
Indoor Air Pollution	3	1	1	1	1	%
BIODIVERSITY						
Threatened Ecoregions	1	1	1	5	1	%
Threatened Bird Species	1	1	1	5	1	%
Threatened Mammal Species	1	1	1	5	1	%
Threatened Amphibian Species	1	1	1	5	1	%
National Biodiversity Index	1	1	1	5	1	#
LAND						
Low Anthropogenic Impact	1	1	5	1	1	%
High Anthropogenic Impact	1	1	5	1	1	%
WATER QUALITY						
Dissolved Oxygen Concentration	1	5	1	1	1	mg/lt
Electrical Conductivity	1	5	1	1	1	mSI/cm
Phosphorus Concentration	1	5	1	1	1	mg/lt
Suspended Solids	1	5	1	1	1	mg/lt
WATER QUANTITY						
Freshwater Availability Per Capita	1	5	1	1	1	m^3/capita
Internal Groundwater Availability Per Capita	1	5	1	1	1	m^3/capita
REDUCING AIR POLLUTION						
Coal Consumption Per Populated Land Area	1	1	1	1	5	kJ/km^2
Anthropogenic NOx Emissions	5	1	1	1	1	tons/km^2

ESI (2005) – Environmental Sustainability Index (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
Anthropogenic SO2 Emissions	5	1	1	1	1	tons/km^2
Anthropogenic VOC Emissions	5	1	1	1	1	tons/km^2
Vehicles in Use per Populated Land Area	1	1	1	3	1	#/km^2
REDUCING ECOSYSTEM STRESS						
Average Forest Cover Change Rate	1	1	5	5	1	%
Acidification Exceedance	1	1	4	1	1	%
REDUCING POLLUTION PRESSURE						
Percentage Change in Projected Population	1	1	1	3	1	%
Total Fertility Rate	1	1	1	3	1	#
REDUCING WASTE & CONSUMPTION PRESSURES						
Ecological Footprint per Capita	1	1	1	5	1	ha/capita
Waste recycling rates	1	1	1	5	1	%
Generation of Hazardous Waste	1	1	1	3	1	tons
REDUCING WATER STRESS						
Industrial Organic Water Pollutant (BOD) Emissions per Available Freshwater	1	5	1	1	1	tons/km^3
Fertilizer Consumption per Hectare of Arable Land	1	4	1	1	1	100g/ha
Pesticide Consumption per Hectare of Arable Land	1	4	1	1	1	kg/ha
Percentage of Country Under Severe Water Stress	1	3	1	1	1	%
REDUCING WATER STRESS						
Industrial Organic Water Pollutant Emissions	1	1	1	1	1	tons/km^2
Generation of Hazardous Waste	1	1	1	1	1	tons
NATURAL RESOURCE MANAGEMENT						
Productivity Overfishing	1	1	1	4	1	#
Percentage of Total Certified Forest Area	1	1	1	5	1	#

ESI (2005) – Environmental Sustainability Index (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
World Economic Forum Survey On Subsidies	1	1	1	1	1	#
Salinized Area Due To Irrigation	1	1	5	1	1	#
Agricultural Subsidies	1	1	2	3	1	%
ENVIRONMENTAL HEALTH						
Death Rate From Intestinal Infectious Diseases	1	1	1	2	1	#
Child Death Rate From Respiratory Diseases	1	1	1	2	1	#
Children Under Five Mortality Rate	1	1	1	2	1	#
ENVIRONMENTAL GOVERNANCE						
Ratio of Gasoline Price To World Average	1	1	1	1	3	%
Percentage of Total Land Area Under Protection	1	1	1	2	1	%
World Economic Forum Survey on Environmental Governance	1	1	1	2	1	z-score
Local Agenda 21 Initiatives per Million People	1	1	1	4	1	%
ECO-EFFICIENCY						
Energy efficiency	1	1	1	1	5	TJ/$
Hydropower and Renewable Energy Production	1	1	1	1	5	%
PARTICIPATION IN INTERNATIONAL COLLABORATIVE EFFORTS						
Environmental Intergovernmental Organizations	1	1	1	4	1	
International and Bilateral Environmental Projects	1	1	1	4	1	#
Participation in International Environmental Agreements	1	1	1	4	1	#
GREENHOUSE GAS EMISSIONS						
Carbon Emissions per Million US dollars GDP	5	1	1	1	1	tons
Carbon Emissions per Capita	5	1	1	1	1	tons/capita

Table B.12 Restorative significance of environmental indicators in EQI (2008)

EQI (2008) – Environmental Quality Index	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
SOIL CONDITION INDEX						
Soil Erosion	1	1	5	1	1	tons
Tillage Practice	1	1	5	1	1	%
Crop Rotation History	1	1	4	1	1	#
SURFACE WATER HEALTH INDEX						
Lake Clarity	1	4	1	1	1	turbidity
Riparian Buffers	1	5	1	1	1	%
LAND HABITAT INDEX						
Habitat Improvement	1	1	1	5	1	acres
T&E Species	1	1	1	5	1	#
Habitat Fragmentation	1	1	1	5	1	%
AIR QUALITY INDEX						
NH3 Emissions	5	1	1	1	1	kg
Particulate Levels	4	1	1	1	1	mg/m^3

Table B.13 Restorative significance of environmental indicators in EPPI (1993)

EPPI (1993) – Environmental Policy Performance Indicator	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
Change of Climate	1	1	1	5	1	%
Acidification	4	4	4	5	1	%
Eutrophication	1	3	1	3	1	%
Dispersion of Toxic Substances	4	4	4	1	1	%
Disposal of Solid Waste	4	4	4	3	1	%
Odor And Noise Disturbance	1	1	1	5	1	#

Table B.14 Restorative significance of environmental indicators in IEF (1996)

IEF (1996) - Index of Environmental Friendliness	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
POLLUTION						
Greenhouse Gases Emissions	5	1	1	1	1	tons
Sulphur Dioxide Emission	5	1	1	1	1	tons
CO_2 Emissions in 2006	5	1	1	1	1	tons
CFC Emission	5	1	1	1	1	tons
Biochemical Oxygen Demand (BOD) Emission	5	1	1	1	1	tons
Quality of the Natural Environment	1	1	1	4	1	
Industrial Waste Discharge Into Water Sources	1	5	1	5	1	tons
Industrial Waste Buried in Landfills	1	1	5	5	1	tons
Water Pollution	1	5	1	5	1	tons
Recycling Rate	1	1	1	5	1	tons
DEPLETION OF NATURAL RESOURCES						
Rate of Deforestation	1	1	1	5	1	%
Electricity Generated from Renewable Sources	1	1	1	5	1	%
Consumption of Oil	1	1	1	1	5	barrels/yr
Ecological Footprint Per Capita	1	1	1	5	1	ha/capita
Unaccounted Water	1	5	1	1	1	km^3
Threatened Species	1	1	1	5	1	%
ENVIRONMENTAL INITIATIVES						
International Environmental Agreements	1	1	1	5	1	#
Research & Development of Renewable Energy	1	1	1	1	4	$/yr
Reforestation Rate	1	1	1	5	1	%
Terrestrial Protected Area	1	1	1	5	1	%
Protected Marine Area	1	1	1	5	1	%
Waste Management	2	4	3	2	1	%

Table B.15 Restorative significance of environmental indicators in EPI (2010)

EPI (2010) – Environmental Performance Index	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
AIR POLLUTION						
Particulate Matter	5	1	1	1	1	mcg/m^3
Indoor Air Pollution	5	1	1	1	1	%
SO_2 per Capita	5	1	1	1	1	SO_2/capita
SO_2 per GDP	5	1	1	1	1	SO_2/GDP
WATER						
Access to Sanitation	1	4	4	4	1	%
Access to Drinking Water	1	5	1	4	1	%
Change in Water Quality	1	5	1	1	1	%
BIODIVERSITY & HABITAT						
Critical Habitat Protection	5	5	5	5	1	%
Biome Protection	1	3	2	4	1	%
Marine Protected Areas	1	3	1	4	1	#
AGRICULTURE						
Agricultural Subsidies	1	1	1	3	1	%
Pesticide Regulation	4	4	4	1	1	%
FORESTS						
Forest Growing Stock	1	1	1	5	1	%
Change in Forest Cover	1	1	1	5	1	%
Forest Loss	1	1	1	5	1	%
CLIMATE CHANGE						
CO_2 per Capita	5	1	1	1	1	kgCO_2
CO_2 per GDP	1	1	1	3	1	kgCO_2
CO_2 per kWh	1	1	1	1	5	grCO_2
Renewable Electricity	1	1	1	1	5	%

Table B.16 Restorative significance of environmental indicators in EVI (2004)

EVI (2004) – Environmental Vulnerability Index	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
WEATHER & CLIMATE						
1 High Winds	2	1	1	1	1	knots//yr
2 Dry Periods	1	4	1	1	1	mm/yr
3 Wet Periods	1	4	1	1	1	mm/yr
4 Hot Periods	3	1	1	1	1	C/yr
5 Cold Periods	3	1	1	1	1	C/yr
6 Sea Temperature	1	3	1	1	1	average/yr
GEOLOGY						
7 Volcanoes	1	1	3	1	1	#
8 Earthquakes	1	1	3	1	1	#
9 Tsunamis	1	3	1	1	1	#
10 Slides	1	1	3	1	1	#
GEOGRAPHY						
11 Land Area	1	1	4	1	1	km^2
12 Country Dispersion	1	1	2	1	1	border/area
13 Isolation	1	1	2	2	1	km
14 Relief	1	1	3	1	1	m
15 Lowlands	1	1	2	1	1	> 50m
16 Borders	1	1	2	2	1	#
RESOURCES & SERVICES						
17 Ecosystem Imbalance	1	1	1	4	1	%
18 Environmental Openness	1	1	1	2	1	$/km^2
19 Migrations	1	1	1	5	1	#
20 Endemics	1	1	1	3	1	#/1000000
21 Introductions	1	1	1	5	1	#/1000km^2

EVI (2004) – Environmental Vulnerability Index (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
22 Endangered Species	1	1	1	5	1	#/1000km^2
23 Extinctions	1	1	1	5	1	#/1000km^2
24 Vegetation Cover	1	1	1	5	1	%
25 Loss of Cover	1	1	1	5	1	%
26 Habitat Fragmentation	1	1	1	4	1	km/km^2
27 Degradation	1	1	1	5	1	%
28 Terrestrial Reserves	1	1	1	5	1	%
29 Marine Reserves	1	1	1	5	1	%
30 Intensive Farming	1	1	5	5	1	tons/km^2
31 Fertilisers	4	4	4	4	1	kg/km^2/yr
32 Pesticides	4	4	4	4	1	kg/km^2/yr
33 Biotechnology	1	1	1	4	1	
34 Productivity Overfishing	1	4	1	4	1	tons/km^2
35 Fishing Effort	1	4	1	1	1	#/km^2
36 Renewable Water	1	5	1	1	1	% used
37 Sulphur Dioxide Emissions	5	1	1	1	1	tons/km^2
38 Waste Production	1	5	5	1	1	tons/km^2
39 Waste Treatment	1	5	5	1	1	%
40 Industry	1	1	1	4	1	toe/km^2/yr
41 Spills	1	4	1	1	1	#/1000km
42 Mining	1	1	4	1	1	tons/km^2
43 Sanitation	1	1	1	3	1	#/km^2
44 Vehicles	1	1	1	3	1	#/km^2
HUMAN POPULATIONS						
45 Population	1	1	1	5	1	#/km^2
46 Population Growth	1	1	1	5	1	%

Table B.17 Restorative significance of environmental indicators in EC (2001)

EC (2001) - Eco-Compass	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
Resource Conservation	5	5	5	5	1	%
Health & Environmental Potential Risk	1	1	1	3	1	#
Mass Intensity	1	1	1	3	1	#
Energy Intensity	1	1	1	1	4	#
Revalorization	1	1	1	4	1	%
Service Extension	1	1	1	2	1	#

Table B.18 Restorative significance of environmental indicators in EI-99 (2000)

EI-99 (2000) - Eco-Indicator 99	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
DAMAGE TO RESOURCES						
Surplus Energy at Future Extraction - Ores	1	1	1	1	3	%
Surplus Energy at Future Extraction - Fossil Fuels	1	1	1	1	3	%
DAMAGE TO ECOSYSTEMS						
Regional Effect on Species Numbers	1	1	1	5	1	#/yr
Local Effect on Species Numbers	1	1	1	5	1	#/yr
Effect on Target Species	1	1	1	5	1	#/yr
Ecotoxicity: Toxic Stress (PAF)	4	4	4	4	1	#
DAMAGE TO HUMAN HEALTH						
Climate Change (Disease + Displacement)	5	1	1	5	1	%
Ozone Layer Depletion (Cancer + Cataract)	5	1	1	5	1	#/yr
Radiation Effect (Cancer)	4	1	1	4	1	#/yr
Respiratory Effects	4	1	1	4	1	#/yr
Cancer	1	1	1	3	1	#/yr

Appendix C - Environmental Rating Systems

The reviewed indicators of environmental rating systems include the following.

Table C.1 Restorative significance of environmental indicators in BREEAM (2011)

BREEAM (2011)	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
MANAGEMENT						
01 Sustainable Procurement	1	1	1	3	3	#
02 Responsible Construction Practices	2	2	2	2	2	%
03 Construction Site Impacts	2	2	2	2	2	%
04 Stakeholder Participation	1	1	1	1	1	%
05 Life-Cycle Cost and Service Life Planning	1	1	1	2	2	#
HEALTH AND WELLBEING						
01 Visual Comfort	1	1	1	2	2	%
02 Indoor Air Quality	4	1	1	1	1	ppm
03 Thermal Comfort	1	1	1	1	3	%
04 Water Quality	1	3	1	1	1	#
05 Acoustic Performance	2	1	1	1	1	%
06 Safety and Security	1	1	1	2	1	#
ENERGY						
01 Reduction of CO2 Emissions	5	1	1	2	1	$kgCO_2/m^2$
02 Energy Monitoring	1	1	1	1	4	#
03 External Lighting	1	1	1	1	2	lumen/W
04 Low and Zero Carbon Technologies	5	1	1	1	1	%
05 Energy Efficient Cold Storage	1	1	1	1	2	%
06 Energy Efficient Transportation Systems	1	1	1	1	4	%
07 Energy Efficient Laboratory Systems	1	1	1	1	3	%

BREEAM (2011) (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
08 Energy Efficient Equipment	1	1	1	1	2	%
09 Drying Space	1	1	1	1	2	%
TRANSPORT						
01 Public Transport Accessibility	1	1	2	4	4	1000m
02 Proximity to Amenities	1	1	5	5	1	500m
03 Cyclist Facilities	1	1	1	3	1	#
04 Maximum Car Parking Capacity	1	1	1	2	1	#/m^2
05 Travel Plan	1	1	1	2	1	%
WATER						
01 Water Consumption	1	5	1	1	1	%
02 Water Monitoring	1	4	1	1	1	#
03 Water Leak Detection and Prevention	1	2	1	1	1	%
04 Water Efficient Equipment	1	3	1	1	1	%
MATERIALS						
01 Life-Cycle Impacts	1	1	1	2	2	%
02 Hard Landscaping and Boundary Protection	1	1	3	3	1	%
03 Responsible Sourcing of Materials	1	1	2	2	2	%
04 Insulation	1	1	1	1	1	%
05 Designing for Robustness	1	1	1	1	1	%
WASTE						
01 Construction Waste Management	5	5	5	5	5	m^3/100m^2
02 Recycled Aggregates	5	5	5	5	5	%
03 Operational Waste	4	4	4	4	4	%
04 Speculative Floor and Ceiling Finishes	1	1	1	2	2	%
LAND USE AND ECOLOGY						
01 Site Selection	1	1	4	1	1	75%

BREEAM (2011) (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
02 Protection of Ecological Site Features	5	5	5	5	1	%
03 Mitigating Ecological Impact	1	1	1	5	1	# x m^2
04 Enhancing Site Ecology	1	1	1	5	1	# x m^2
05 Long Term Impact on Biodiversity	1	1	1	4	1	%
POLLUTION						
01 Impact of Refrigerants	5	5	5	1	1	$kgCO_2/m^2$
02 NOx Emissions	5	5	5	1	1	%
03 Surface Water Run Off	1	4	1	1	1	l/s/ha
04 Reduction of Night Time Light Pollution	2	1	1	1	2	%
05 Noise Attenuation	2	1	1	2	1	db

Table C.2 Restorative significance of environmental indicators in CASBEE-UDe (2007)

CASBEE-UDe (2007)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
QUD1 NATURAL ENVIRONMENT						
1.1 MICROCLIMATES						
1 Mitigation of heat island effect with passage of air	1	1	1	5	5	65%
2 Mitigation of heat island effect with shading	1	1	1	4	4	30%
3 Mitigation of heat island effect with green space	1	5	1	5	5	%
4 Consideration for the positioning of heat exhaust	1	1	1	1	2	%
1.2 TERRAIN						
1 Building layout and shape design that consider existing topographic character	1	1	4	4	1	75%
2 Conservation of topsoil	1	1	5	1	1	30%
3 Consideration of soil contamination	1	1	4	1	1	%

CASBEE-UDe (2007) (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
1.3 WATER ENVIRONMENT						
1 Conservation of water bodies	1	5	1	1	1	%
2 Conservation of aquifers	1	5	1	1	1	%
3 Consideration of water quality	1	5	1	1	1	turbidity
1.4 HABITAT						
1 Grasping the potential of the natural environment	1	1	1	5	1	%
2 Conservation or regeneration of natural resources	1	1	1	5	1	%
3 Creating ecosystem networks	1	1	1	5	1	%
4 Providing a suitable habitat for flora and fauna	1	1	1	5	1	%
1.5 OTHER ENVIRONMENT						
1 Ensuring good air quality, acoustic and vibration	4	1	1	1	1	%
2 Improving the wind environment	1	1	1	4	1	m/s
3 Securing sunlight	1	1	1	4	5	hr/day
QUD2 SERVICE FUNCTIONS						
2.1 SUPPLY & TREATMENT SYSTEMS						
1 Reliability of supply and treatment systems	1	3	1	1	1	#
2 Flexibility to meet changing demand and technical innovation in supply and treatment systems	1	1	1	2	2	#
2.2 INFORMATION SYSTEMS						
1 Reliability of information systems	1	1	1	4	4	#
2 Flexibility to meet changing demand and technical innovation in information systems	1	1	1	3	1	#
3 Usability	1	1	1	3	1	#
2.3 TRANSPORTATION SYSTEMS						
1 Sufficient capacity of transportation systems	1	1	1	5	5	#
2 Securing safety in pedestrian areas etc.	1	1	1	4	1	#

CASBEE-UDe (2007) (Cont'd)	Atmosphere	Hydrosphere	Lithosphere	Ecology	Energy	units
2.4 Disaster and Crime Prevention						
1 Understanding the risk from natural hazards	1	1	1	4	1	#
2 Securing open space as wide area shelter	1	1	5	5	1	#
3 Providing proper evacuation routes	1	1	1	3	1	250m
4 Crime prevention performance	1	1	1	3	1	#
2.5 Daily Life						
1 Distance to daily-use stores and facilities	1	1	1	5	5	300m
2 Distance to medical and welfare facilities	1	1	1	5	5	600m
3 Distance to educational and cultural facilities	1	1	1	4	1	300m
2.6 Universal Design	1	1	1	5	1	%
QUD3 THE LOCAL COMMUNITY						
3.1 Local Resources						
1 Use of local industries, personnel and skills	1	1	1	5	5	8000m
2 Conservation of historical and natural assets	4	4	4	4	1	%
3.2 Social Infrastructure	1	1	1	4	1	%
3.3 Nurturing a Good Community						
1 Formation of local centers and fostering of vitality	1	1	1	5	5	#
2 Creation of public involvement opportunities	1	1	1	2	1	#
3.4 Urban Context and Scenery						
1 Formation of urban context and scenery	1	1	1	2	1	#
2 Harmony with surroundings	1	1	1	5	1	%
LRUD1 MICROCLIMATES & LANDSCAPE						
1.1 Thermal Impact						
1 Planning of building forms to avoid blocking wind	2	1	1	1	2	%
2 Consideration for paving materials	1	1	4	4	4	10%
3 Consideration for building cladding materials	1	1	4	4	4	20%

CASBEE-UDe (2007) (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
4 Consideration for reduction of waste heat	1	1	1	1	5	100W/m^2
1.2 Impact on Geological Features						
1 Prevention of soil contamination	1	1	5	5	1	#
2 Reduction of ground water subsidence	1	1	5	5	1	30%
3 Air Pollution						
1.4 Noise, Vibration and Odor	3	1	1	3	1	%
1.5 Wind Hazard and Sunlight Obstruction	4	1	1	4	1	%
1.6 Light Pollution	5	1	1	5	1	lumens
LRUD2 SOCIAL INFRASTRUCTURE						
2.1 Mains Water Supply						
1 Encouragement for the use of stored rainwater	1	5	1	1	1	%
2 Water recirculation and use through water system	1	4	1	1	1	%
2.2 Rainwater Discharge Load						
1 Mitigation of surface water runoff	1	5	1	1	1	m^3/ha
2 Mitigation of rainwater outflow	1	5	1	1	1	300m^3/ha
2.3 Sewage and Graywater						
1 Load reduction by high-level treatment of sewage	1	5	1	1	1	%
2 Load leveling by water discharge balancing tanks	1	4	1	1	1	%
2.4 Waste Treatment Load						
1 Load reduction by centralized-storage	1	1	5	1	1	%
2 Facilities to reduce volume and weight of waste	1	1	5	1	1	%
3 Classification, treatment and disposal of waste	1	1	5	1	1	%
2.5 Traffic Load						
1 Reduction of total traffic volume thru modal shift	1	1	1	5	5	#
2 Efficient traffic assignment on local road network	1	1	1	4	4	#
2.6 Effective Energy Use						

CASBEE-UDe (2007) (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
1 Area network of unused and renewable energy	1	1	1	1	5	10%
2 Load leveling of electrical power and heat	1	1	1	1	4	20%
3 Area network of high-efficient energy system	1	1	1	1	5	5%
LRUD3 THE LOCAL ENVIRONMENT						
3.1 Global Warming						
1 Construction and materials, etc.	1	1	1	4	4	%
2 Energy	1	1	1	5	5	%
3 Transportation	1	1	1	1	5	%
3.2 Environmentally Responsible Construction						
1 Acquisition of ISO14001 certification	1	1	1	3	3	#
2 Reduction of by-products of construction	1	1	1	5	5	%
3 Energy saving activity during construction	1	1	1	4	4	%
4 Reduction of construction-related impact	1	1	1	4	1	%
5 Selecting materials for global environment	1	1	1	5	1	#
6 Selecting materials for less impact on health	1	1	1	4	1	#
3.3 Regional Transportation Planning						
1 Coordinating with master plans for transportation	1	1	1	4	4	#
2 Measures for transportation demand management	1	1	1	4	4	#
3.4 Monitoring and Management						
1 Reduce energy usage inside the designated area	1	1	1	1	5	%
2 Conserve the surrounding environment of the area	1	1	1	5	1	%

Table C.3 Restorative significance of environmental indicators in ILBI (2010)

ILBI (2010)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
SITE - RESTORING A HEALTHY COEXISTENCE WITH NATURE						
01 Limits to Growth	1	4	4	4	1	100m
02 Urban Agriculture	1	1	5	5	1	%
03 Habitat Exchange	1	1	5	5	1	%
04 Car Free Living	1	1	1	4	1	%
WATER - CREATING WATER INDEPENDENT SITES, BUILDINGS & COMMUNITIES						
05 Net Zero Water	1	5	1	1	1	100%
06 Ecological Water Flow	1	5	1	1	1	100%
ENERGY - RELYING ON CURRENT SOLAR INCOME						
07 Net Zero Energy	1	1	1	1	5	100%
HEALTH - MAXIMIZING PHYSICAL & PSYCHOLOGICAL HEALTH AND WELL BEING						
08 Civilized Environment	4	1	1	1	1	%
09 Healthy Air	5	1	1	1	1	%
10 Biophilia	1	1	1	5	1	#
MATERIALS - ENDORSING PRODUCTS & PROCESSES THAT ARE SAFE FOR ALL SPECIES THROUGH TIME						
11 Red List	5	5	5	1	1	#
12 Embodied Carbon Footprint	1	1	1	1	5	tCO_2e
13 Responsible Industry	1	1	1	5	1	500km

ILBI (2010) (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
14 Appropriate Sourcing	1	1	1	4	1	%
15 Conservation + Reuse	1	1	4	4	4	%
EQUITY - SUPPORTING A JUST, EQUITABLE WORLD						
16 Human Scale + Humane Places	1	1	1	5	1	%
17 Democracy + Social Justice	1	1	1	5	1	%
18 Rights to Nature	4	4	4	4	4	#
BEAUTY - CELEBRATING DESIGN THAT CREATES TRANSFORMATIVE CHANGE						
19 Beauty + Spirit	1	1	1	5	1	%
20 Inspiration + Education	1	1	1	5	1	#

Table C.4 Restorative significance of environmental indicators in LEED (2014)

LEED-ND (2014)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
SSL - SMART LOCATION & LINKAGE						
Prereq 1 Smart Location	1	1	2	4	2	300ft
Prereq 2 Imperiled Species and Ecological Communities	1	1	1	5	1	#
Prereq 3 Wetland and Water Body Conservation	1	5	1	5	1	100ft
Prereq 4 Agricultural Land Conservation	1	1	5	1	1	DU/ac
Prereq 5 Floodplain Avoidance	1	3	1	3	1	#
Credit 1 Preferred Locations	1	1	4	4	1	#/mi^2
Credit 2 Brownfields Remediation	1	1	5	5	1	#

LEED-ND (2014) (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
Credit 3 Access to Quality Transit	1	1	1	4	1	%VMT
Credit 4 Bicycle Facilities	1	1	1	4	4	10%
Credit 5 Housing and Jobs Proximity	1	1	1	3	1	1/2 mi
Credit 6 Steep Slope Protection	1	1	4	1	1	%
Credit 7 Site Design for Habitat or Wetland and Water Body Conservation	1	5	5	5	1	%
Credit 8 Restoration of Habitat or Wetlands and Water Bodies	1	5	5	5	1	%
Credit 9 Long-Term Conservation Management of Habitat or Wetlands and Water Bodies	1	5	5	5	1	%
NPD - NEIGHBORHOOD PATTERN & DESIGN						
Prereq 1 Walkable Streets	1	1	1	4	4	90%
Prereq 2 Compact Development	1	1	5	5	1	7DU/ac
Prereq 3 Connected and Open Community	1	1	1	4	4	#/mi
Credit 1 Walkable Streets	1	1	1	3	1	#
Credit 2 Compact Development	1	1	1	5	1	63DU/ac
Credit 3 Mixed-Use Neighborhoods	1	1	1	5	5	%
Credit 4 Housing Types and Affordability	1	1	1	5	1	%
Credit 5 Reduced Parking Footprint	2	1	1	4	4	%
Credit 6 Connected and Open Community	1	1	1	2	1	#/mi
Credit 7 Transit Facilities	1	1	1	4	4	#
Credit 8 Transportation Demand Management	2	1	1	1	3	%
Credit 9 Access to Civic & Public Space	1	1	3	3	1	1/4 mi
Credit 10 Access to Recreation Facilities	1	1	3	3	1	1/2 mi
Credit 11 Visitability and Universal Design	1	1	1	3	1	%
Credit 12 Community Outreach and Involvement	1	1	1	2	1	#

LEED-ND (2014) (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
Credit 13 Local Food Production	5	5	5	5	5	ft^2/DU
Credit 14 Tree-Lined and Shaded Streetscapes	4	4	4	4	4	%
Credit 15 Neighborhood Schools	1	1	1	3	1	#
GIB - GREEN INFRASTRUCTURE & BUILDINGS						
Prereq 1 Certified Green Building	5	5	5	5	5	#
Prereq 2 Minimum Building Energy Efficiency	1	1	1	1	4	%
Prereq 3 Indoor Water Use Reduction	1	4	1	1	1	%
Prereq 4 Construction Activity Pollution Prevention	1	1	1	4	1	%
Credit 1 Certified Green Buildings	5	5	5	5	5	#
Credit 2 Optimize Building Energy Performance	1	1	1	1	4	%
Credit 3 Indoor Water Use Reduction	1	4	1	1	1	%
Credit 4 Outdoor Water Use Reduction	1	4	1	1	1	%
Credit 5 Building Reuse	1	1	1	5	5	%
Credit 6 Historic Preservation and Adaptive Use	1	1	1	5	5	%
Credit 7 Minimized Site Disturbance	1	1	1	5	1	%
Credit 8 Rainwater Management	1	4	1	1	1	%
Credit 9 Heat Island Reduction	3	1	1	1	1	SRI
Credit 10 Solar Orientation	1	1	1	3	4	%
Credit 11 Renewable Energy Production	1	1	1	1	5	%
Credit 12 District Heating and Cooling	1	1	1	1	4	%/yr
Credit 13 Infrastructure Energy Efficiency	1	1	1	1	5	%
Credit 14 Wastewater Management	1	5	1	1	1	%
Credit 15 Recycled and Reused Infrastructure	1	1	1	4	1	%
Credit 16 Solid Waste Management	1	1	1	4	1	%
Credit 17 Light Pollution Reduction	1	1	4	2	1	%

LEED-ND (2014) (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
IDP - INNOVATION AND DESIGN PROCESS						
Credit 1 Innovation and Exemplary Performance	3	3	3	3	3	#
Credit 2 LEED® Accredited Professional	1	1	1	1	1	#
RPC - REGIONAL PRIORITY CREDIT						
Credit 1 Regional Priority	4	4	4	4	4	

Table C.5 Restorative significance of environmental indicators in SSI (2014)

SSI (2014)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
1 SITE CONTEXT						
Prereq 1 Limit development on farmland	1	1	5	1	1	%
Prereq 2 Protect floodplain functions	1	4	1	4	1	%
Prereq 3 Conserve aquatic ecosystems	1	5	1	5	1	%
Prereq 4 Conserve habitats for threatened and endangered species	1	1	4	5	1	%
Credit 5 Redevelop degraded sites	1	1	5	1	1	%
Credit 6 Locate projects within existing dev. areas	1	1	5	4	4	75%
Credit 7 Connect to multi-modal transit networks	3	1	4	1	5	%
2 PRE-DESIGN ASSESSMENT + PLANNING						
Prereq 1 Use an integrative design process	2	4	5	4	4	%
Prereq 2 Conduct a pre-design site assessment	1	1	1	2	1	%
Prereq 3 Designate and communicate Vegetation and Soil Protection Zones	1	1	3	3	1	%
Credit 4 Engage users and stakeholders	1	1	1	3	1	%

SSI (2014) (Cont’d)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
3 SITE DESIGN - WATER						
Prereq 1 Manage precipitation on site	1	4	1	1	1	%
Prereq 2 Reduce water use for landscape irrigation	1	5	1	1	1	%
Credit 3 Manage precipitation beyond baseline	1	4	1	1	1	%
Credit 4 Reduce outdoor water use	1	5	1	1	1	%
Credit 5 Design functional stormwater features	1	4	1	1	1	%
Credit 6 Restore aquatic ecosystems	1	5	1	1	1	%
4 SITE DESIGN - SOIL + VEGETATION						
Prereq 1 Create a soil management plan	1	1	1	3	1	#
Prereq 2 Control and manage invasive plants	1	1	1	4	1	%
Prereq 3 Use appropriate plants	1	1	4	4	1	%
Prereq 4 Conserve healthy soils and vegetation	1	1	4	1	1	%
Prereq 5 Conserve special status vegetation	1	1	1	4	1	%
Credit 6 Conserve and use native plants	1	1	1	5	1	%
Credit 7 Conserve and restore native plants	1	1	1	3	1	%
Credit 8 Optimize biomass	1	1	1	4	1	%
Credit 9 Reduce urban heat island effects	1	1	1	5	1	%
Credit 10 Vegetation to minimize energy use	1	1	1	4	1	%
Credit 11 Reduce the risk of catastrophic wildfire	1	1	1	4	1	%
5 SITE DESIGN - MATERIALS SELECTION						
Prereq 1 Eliminate wood use from threatened trees	1	1	1	5	1	%
Credit 2 Maintain on-site structures and paving	1	1	4	4	1	%
Credit 3 Design for adaptability and disassembly	1	1	1	1	2	%
Credit 4 Reuse salvaged materials and plants	1	1	4	4	4	%
Credit 5 Use recycled content materials	1	1	5	5	5	%
Credit 6 Use regional materials	1	1	1	4	4	%

SSI (2014) (Cont'd)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
Credit 7 Support responsible extraction of materials	1	1	1	4	4	%
Credit 8 Support transparency and safer chemistry	2	1	1	1	1	%
Credit 9 Support sustainability in materials manufacturing	1	1	1	3	1	90%
Credit 10 Support sustainability in plant production	1	1	1	1	4	%
6 SITE DESIGN - HUMAN HEALTH + WELL-BEING						
Credit 1 Protect and maintain cultural historic places	1	1	3	3	1	%
Credit 2 Provide optimum site accessibility, safety, and wayfinding	1	1	1	3	1	%FTE
Credit 3 Promote equitable site use	1	1	1	3	1	#
Credit 4 Support mental restoration	1	1	1	3	1	%
Credit 5 Support physical activity	1	1	1	4	4	#
Credit 6 Support social connection	1	1	1	4	1	m^2
Credit 7 Provide on-site food production	1	1	1	4	1	%
Credit 8 Reduce light pollution	1	1	1	4	4	%
Credit 9 Encourage fuel efficient and multi-modal transportation	1	1	1	1	5	%
Credit 10 Minimize exposure to environmental tobacco smoke	3	1	1	1	1	%
Credit 11 Support local economy	1	1	1	3	1	%
7 CONSTRUCTION						
Prereq 1 Communicate and verify sustainable construction practices	1	1	1	3	1	%
Prereq 2 Control and retain construction pollutants	3	3	3	3	1	%
Prereq 3 Restore soils disturbed during construction	1	1	1	3	1	%
Credit 4 Restore soils disturbed by development	1	1	4	1	1	%

SSI (2014) (Cont’d)	**Atmosphere**	**Hydrosphere**	**Lithosphere**	**Ecology**	**Energy**	**units**
Credit 5 Divert construction and demolition materials from disposal	1	1	5	1	1	%
Credit 6 Divert reusable vegetation, rocks, and soil from disposal	1	1	5	1	1	%
Credit 7 Protect air quality during construction	4	1	1	1	1	%
8 OPERATIONS + MAINTENANCE						
Prereq 1 Plan for sustainable site maintenance	1	1	4	1	4	%
Prereq 2 Provide for storage and collection of recyclables	1	1	4	1	4	%
Credit 3 Recycle organic matter	1	1	1	4	1	%
Credit 4 Minimize pesticide and fertilizer use	2	1	4	1	3	%
Credit 5 Reduce outdoor energy consumption	1	1	1	1	5	%
Credit 6 Use renewable sources for landscape electricity needs	1	1	1	1	5	%
Credit 7 Protect air quality during landscape maintenance	4	1	1	1	1	%
9 EDUCATION + PERFORMANCE MONITORING						
Credit 1 Promote sustainability awareness and education	1	1	1	3	1	#
Credit 2 Develop and communicate a case study	1	1	1	3	1	#
Credit 3 Plan to monitor and report site performance	1	1	1	3	3	%
10 INNOVATION OR EXEMPLARY PERFORMANCE						
Credit 1 Innovation or exemplary performance	3	3	3	3	3	#

Appendix D - Indicators of Environmental Restoration

The assembled indicators of environmental restoration include the following.

Table D.1 Synthesis of restoratively significant indicators: Atmosphere

Restoratively significant indicators	**Atmosphere**	**units**
Ene 01 Reduction of CO2 Emissions		$kgCO_2/m^2$
Ene 04 Low and Zero Carbon Technologies		% reduced
Pol 01 Impact of Refrigerants		$kgCO_2/m^2$
Pol 02 NO_x Emissions		% reduced
1.1.1 Mitigation of heat island effect with the passage of air		> 65% open space
1.3.3 Atmospheric purification measures		> 20% planted
09 Healthy Air - Number of days per year on which attention levels defined by law are exceeded		days/yr
Global Climate equivalent (GCeq) = total greenhouse gases (CO_2, CH_4, N_2O and CFCs)		tons
Air pollution Concentration of SO_x, NO_x, PM10 (mg/cu.m)		mg/m^3
Industrial pollution - Industrial SO_2 discharged per GDP (T/ RMB)		lt/capita
Air Quality - NO_2, CO_2, greenhouse gas concentrations		tons/yr
Transport - Access to services without using a car		min/month/person
AIR QUALITY NO_2 - Daily average NO_2 concentration registered by the monitoring stations		ppm
AIR QUALITY: PM10 - Highest daily average NO_2 concentration		ppm
Air Quality		ppm
Ecological - Oxygen contribution by vegetation		ton/yr
Air Quality		NAAQS days/yr
NO_2 - Urban population weighted NO_2 concentration		mcg/m^3
SO_2 - Urban population weighted SO_2 concentration		

Restoratively significant indicators (Cont’d)	**Atmosphere**	**units**
TSP - Urban population weighted TSP concentration		mcg TSP/m^3
NOXKM - Anthropogenic NO_x emissions per populated land area		tons/km^2
SO_2KM - Anthropogenic SO_2 emissions per populated land area		tons/km^2
VOCKM - Anthropogenic VOC emissions per populated land area		tons/km^2
GR2050 - Percentage change in projected population 2004-2050		% change
NH_3 Emissions - Kg (EPA- National Emissions)		kg
Greenhouse gases emissions		
Sulphur Dioxide emission		tons
CO_2 emissions in 2006		tons
CFC Emission		
Biochemical Oxygen Demand (BOD) Emission		tons
ACIDIFICATION		% change
Air Pollution (Effects on Human Health) - Particulate matter		mcg/m^3
Indoor air pollution		% change
Air Pollution (Ecosystem Effects) - SO_2 per capita		SO2/capita
SO_2 per GDP		SO2/GDP
Climate Change - CO_2 per capita		kg CO2/capita
Indicator 37 - Sulphur Dioxide Emissions		tons/km^2/yr

Table D.2 Synthesis of restoratively significant indicators: Hydrosphere

Restoratively significant indicators	**Hydrosphere**	**units**
Wat 01 Water Consumption		% reduced
1.3.1 Conservation of water bodies		> 50% conserved
1.3.2 Conservation of aquifers		% restored
1.3.3 Consideration of water quality		turbidity
2.1.1 Encouragement for the use of stored rainwater		max 60%
2.2.1 Mitigation of surface water runoff using permeable paving and percolation trenches		
2.2.2 Mitigation of rainwater outflow using retaining pond and flood control basins		> $300m^3/ha$
2.2.2 Mitigation of rainwater outflow using retaining pond and flood control basins		> $300m^3/ha$
2.3.1 Load reduction using high-level treatment of sewage and graywater		% reduced
2.3.2 Load leveling using water discharge balancing tanks etc.		% discharged
05 Net Zero Water		100% onsite captured
06 Ecological Water Flow		100% onsite managed
Prereq 3 Wetland and Water Body Conservation		50ft or > 100ft to water
Credit 9 Long-Term Conservation Management of Habitat or Wetlands and Water Bodies		
Credit 14 Wastewater Management		25 > % reused > 50
Water equivalent (Weq) expressed in m3 per inhabitant per year		inhabitant/yr
Waste water treatment rate		% treated

Restoratively significant indicators (Cont'd)	**Hydrosphere**	**units**
WATER CONSUMPTION - Quantity of drinking water distributed to households and services		m^3/person/month
Hydrologic Balance		m^3/yr
Water Consumption		gal/day
WQ_DO - Dissolved oxygen concentration		mg/lt
WQ_EC - Electrical conductivity		mSI/cm
WQ_PH - Phosphorus concentration		mg/lt
WQ_SS - Suspended solids		mg/lt
WATAVL - Freshwater availability per capita		$1000m^3$/capita
GRDAVL - Internal groundwater availability per capita		$1000m^3$/capita
BODWAT - Industrial organic water pollutant (BOD) emissions per available freshwater		tons/km^3
FERTHA - Fertilizer consumption per hectare of arable land		100g/hectare
PESTHA - Pesticide consumption per hectare of arable land		kg/hectare
Riparian Buffers - Percent vegetated (MTRI developed)		% vegetated
Industrial Waste Discharge into Water Sources		tons
Unaccounted Water		km^3
Protected Marine Area		% protected
Water (Ecosystem Effects) - Change in water quality		%
Marine protected areas		% protected
Indicator 36 - Renewable Water		% used

Table D.3 Synthesis of restoratively significant indicators: Lithosphere

Restoratively significant indicators	Lithosphere	units
Tra 02 Proximity to Amenities		< 500m
Wst 01 Construction Waste Management		$m^3/100m^2$
Wst 02 Recycled Aggregates		% recycled
Wst 03 Operational Waste		% diverted
LE 01 Site Selection		75% redeveloped
01 Limits to Growth		100 > m > 30
02 Urban Agriculture		80 > % area > 0
1.2.2 Conservation of topsoil		> 30% shaded
1.2.3 Consideration of soil contamination		total / maximum
2.5.1 Distance to daily-use stores and facilities		> 300m
2.5.2 Distance to medical and welfare facilities		> 600m
1.2.1 Prevention of soil contamination		total / max > 60%
1.2.2 Reduction of ground water subsidence		< 30% usage
2.4.1 Reduction of collection load using centralized-storage facilities		% stored
2.4.2 Installation of facilities to reduce the volume and weight of waste and employ composting		% reduced
2.4.3 Classification, treatment and disposal of waste		> 5 types
15 Conservation + Reuse		100 > % > 80
Prereq 1 Smart Location		infill / transit
Prereq 4 Agricultural Land Conservation		DU/ac FAR
Credit 2 Brownfields Redevelopment		
Prereq 2 Compact Development		7DU/ac or 0.50 FAR
Credit 13 Local Food Production		60 > ft^2/DU > 200

Restoratively significant indicators	**Lithosphere**	**units**
Household Waste All reused, recycled and composted materials		% recycled
Recycling - Percentage of household collected waste reused, recycled or composted		% recycled
BIKE PATHS Length of bicycle paths in the urban area		mi
PRODUCTION OF SOLID WASTE - Production of urban waste		tons/yr
Erosion		% change
Soil Erosion		turbidity
Impervious Surfaces		% land cover
Solid Waste Generated and Recycled		
Local Farm Production		acres
ANTH10 Percentage of total land area (including inland waters) having very low anthropogenic impact		% low impact land
ANTH40 Percentage of total land area (including inland waters) having very high anthropogenic impact		1 > score > 0
ACEXC Acidification exceedance from anthropogenic sulfur deposition		% land area
IRRSAL Salinized area due to irrigation as percentage of total arable land Reducing Environmental Stresses		7 > score > 1
PRAREA Percentage of total land area under protected status		% protected
Soil Erosion - Tons of sediment (EPA STEPL model)		tons
ANTH40 Percentage of total land area (including inland waters) having very high anthropogenic impact		1 > score > 0
Tillage Practice - Percent conservation (CTIC Purdue)		% conserved
Industrial Waste Buried in Landfills		tons
Indicator 30 - Intensive Farming		tons/km^2
Indicator 38 - Waste Production		tons/km^2/yr
Indicator 39 - Waste Treatment		% treated

Table D.4 Synthesis of restoratively significant indicators: Ecology

Restoratively significant indicators	Ecology	units
LE 02 Protection of Ecological Site Features		% protected
LE 03 Mitigating Ecological Impact		# x m^2
LE 04 Enhancing Site Ecology		# x m^2
1.1.2 Mitigation of heat island effect with shading		> 30% shaded
1.1.3 Mitigation of heat island effect with green space and open water etc.		10 > % > 15
1.4.1 Grasping the potential of the natural environment		
1.4.2 Conservation or regeneration of natural resources		> 30% green space
1.4.3 Creating ecosystem networks		total / maximum
1.4.4 Providing a suitable habitat for flora and fauna		> 150% floor area
2.3.2 Securing safety in pedestrian areas etc.		
2.6 Universal Design		
2.1.2 Conservation and use of historical, cultural and natural assets		total / max > 60%
3.3.1 Formation of local centers and fostering of vitality and communication		total / max > 60%
3.4.2 Harmony with surroundings		total / max > 60%
3.2.2 Reduction of by-products of construction		100% recycled
3.2.5 Selection of materials with consideration for the global environment		total / max > 60%
3.4.2 Monitoring and management system to conserve the surrounding environment of the designated area		total / max > 60%
03 Habitat Exchange		100% set aside
10 Biophilia		6 items / 2000 m^2
11 Red List		
13 Responsible Industry		

Restoratively significant indicators (Cont'd)	Ecology	units
14 Appropriate Sourcing		2000 > km > 500
18 Rights to Nature		
Prereq 2 Imperiled Species and Ecological Communities Conservation		conservation plan
Credit 7 Site Design for Habitat or Wetland and Water Body Conservation		% conserved
Credit 8 Restoration of Habitat or Wetlands and Water Bodies		% restored
Credit 2 Compact Development		63DU/ac - 3.0 FAR
Credit 3 Mixed-Use Neighborhood Centers		4 > uses > 19
Credit 4 Mixed-Income Diverse Communities		5 > % > 15
Credit 6 Historic Resource Preservation and Adaptive Use		historic site
Credit 7 Minimized Site Disturbance in Design and Construction		100% developed
Urban density Persons per square kilometer of urban area		#/km^2
Public green space - Public green space per capita (m^2 per capita)		m^2/capita
Investment on Env Protection - Amount of environmental sanitation funds per GDP		$/GDP
Nature - Resources and Ecosystem Services		%
Biodiversity - Conservation of habitats for plants, animals		%
Ecological Footprint - Consumption habits, food, drinks, energy and transport		ha/person
Health - Life expectancy from birth		
Green Space - Number of green spaces per 10,000 inhabitants		#/10000
Local Food- Number of allotment plots per 1,000 residents		#/1000
Vegetation Covering Change		% change
Habitat Protected Areas		km^2
Species - Amphibians		# of species

Restoratively significant indicators (Cont'd)	Ecology	units
Reptiles		# of species
Birds		# of species
Mammals		# of species
Populations		#
MARINE BIOME - Ecological Health		benthic index
Open Space near Urban Villages		% open space
Population		# and % change
Pollution Prevention		lbs/day
Gardening Activity		
ECORISK Percentage of country's territory in threatened ecoregions		% threatened
PRTBRD Threatened bird species as percentage of known breeding bird species in each country		% threatened
PRTMAM Threatened mammal species as percentage of known mammal species in each country		% threatened
PRTAMPH Threatened amphibian species as percentage of known amphibian species in each country		% threatened
NBI National Biodiversity Index		1 > score > 0
FOREST Annual average forest cover change rate from 1990 to 2000		% change
EFPC Ecological Footprint per capita		hectare/capita
RECYCLE Waste recycling rates		% recycled
FORCERT Percentage of total forest area that is certified for sustainable management		% certified
Habitat Improvement Acres (MTRI developed)		acres
T&E Species Count		#
Habitat Fragmentation Index (MTRI developed)		%

Restoratively significant indicators (Cont'd)	**Ecology**	**units**
Recycling Rate		% recycled
Rate of Deforestation		% change
Electricity Generated from Renewable Sources		% generated
Ecological Footprint Per Capita		hectare/capita
Threatened Species		% recycled
Participation in Selected International Environmental Agreements		#
Stringency of Environmental Regulations		#
Reforestation Rate		% change
Number of Environmental Non-Government Organization		#
Terrestrial Protected Area		% land area
Enforcement of Environmental Regulation		
CHANGE OF CLIMATE		% change
Biodiversity & Habitat - Critical habitat protection		% protected
Biome protection		% protected
Forests - Forest growing stock		% change
Change in forest cover		% change
Forest loss		% change
Indicator 19 - Migrations		#
Indicator 21 - Introductions		#/1000km^2
Indicator 22 - Endangered Species		#/1000km^2
Indicator 23 - Extinctions		#/1000km^2
Indicator 24 - Vegetation Cover		% protected
Indicator 25 - Loss of Cover		% lost
Indicator 27 - Degradation		% degraded
Indicator 28 - Terrestrial Reserves		% protected
Indicator 29 - Marine Reserves		% protected

Restoratively significant indicators (Cont'd)	Ecology	units
Indicator 45 - Population		#/km^2
Indicator 46 - Population Growth		% change
RESOURCE CONSERVATION		% preserved
Regional effect on species numbers		#/yr
Local effect on species numbers		#/yr
Effect on target species		#/yr

Table D.5 Synthesis of restoratively significant indicators: Energy

Restoratively significant indicators	Energy	units
Ene 06 Energy Efficient Transportation Systems		% reduced
Tra 01 Public Transport Accessibility		< 1000m
Mat 04 Insulation		% reduced
2.3.1 Sufficient capacity of transportation systems		total / max > 60%
2.1.1 Use of local industries, personnel and skills		> 8000m
1.1.4 Consideration for reduction of waste heat		< 100 W/m^2
2.5.1 Reduction of the total traffic volume through modal shift		
2.6.1 Area network of unused and renewable energy		> 10% annual
2.6.2 Load leveling of electrical power and heat through network		< 20% peak load
2.6.3 Area network of high-efficient energy system		> 5% reduced
3.1.2 Energy		total / max > 60%
3.1.3 Transportation		total / max > 60%
3.4.1 Monitoring and management system to reduce energy usage inside the designated area		total / max > 60%
07 Net Zero Energy		renewable onsite

Restoratively significant indicators (Cont'd)	**Energy**	**units**
12 Embodied Carbon Footprint		tCO_2e
Credit 11 On-Site Renewable Energy Sources		5 > % onsite > 20
Credit 13 Infrastructure Energy Efficiency		15% under estimate
Prereq 1 Certified Green Building		LEED
Credit 5 Existing Building Reuse		50% reuse
Enforced Umeq (EUMeq) = total number of passenger kilometres – passenger kilometres by foot and bicycle – passenger kilometres by public transport, per inhabitant and for basic needs each year		pass-km/inhabitant/yr
Disposal equivalent (Deq) expressed in tonnes per inhabitant and per year		tons/inhabitant/yr
Energy equivalent (Eeq) expressed in TOE (tonnes of oil equivalent) per inhabitant per year		tons/inhabitant/yr
Power Total electricity consumption (kWh per GDP)		kWh/GDP
HOUSEHOLDS ELECTRICITY CONSUMPTION - Electricity used in households		kWh/yr
Electricity intensity		kWh/mi^2
Vehicle Miles Traveled and Fuel Consumption		miles/capita
Renewable and Nonrenewable Energy Use		BTU
COALKM Coal consumption per populated land area		kJ/km^2
ENEFF Energy efficiency		TJ/$1000000
RENPC Hydropower and renewable energy production as a percentage of total energy consumption		% produced
Consumption of Oil		barrels/yr
CO_2 per kWh		$grCO_2/kWh$
Renewable electricity		% generated

Appendix E - Indicators of The RUD model

The proposed indicators of the RUD model include the following.

Table E.1 Atmosphere indicators of the RUD model

ATMOSPHERE	**units**
EMISSIONS	
AEM-CDE Anthropogenic CO_2 emissions per populated land area	tons/ha/yr
AEM-CME Anthropogenic CO emissions per populated land area	tons/ha/yr
AEM-MTE Anthropogenic CH_4 emissions per populated land area	tons/ha/yr
AEM-NDE Anthropogenic NO_2 emissions per populated land area	tons/ha/yr
AEM-SDE Anthropogenic SO_2 emissions per populated land area	tons/ha/yr
POLLUTANTS	
APL-CFC Anthropogenic CFC emissions per populated land area	tons/ha/yr
APL-HCF Anthropogenic HCFC emissions per populated land area	tons/ha/yr
APL-NOX Anthropogenic NO_X emissions per populated land area	tons/ha/yr
APL-NHX Anthropogenic NH_3 emissions per populated land area	tons/ha/yr
APL-VOC Anthropogenic VOC emissions per populated land area	tons/ha/yr
AIR QUALITY	
AAQ-TSP Anthropogenic TSP per populated land area	tons/ha/yr
AAQ-OCV Oxygen contribution by vegetation	tons/yr
AAQ-BOD Biochemical Oxygen Demand Emission	tons
AAQ-HIE Mitigation of heat island effect with the passage of air	> 65% open space
AAQ-APM Atmospheric purification measures	> 20% planted
OZONE DEPLETION	
AOD-AQD Number of days attention levels are exceeded	NAAQS days/yr
AOD-REF Impact of Refrigerants	$kg/m^2/yr$
AOD-CDO CO_2 per capita	tons/yr
AOD-SDO SO_2 per capita	tons/yr
AOD-GCE Global Climate Equivalent (GCeq) = total greenhouse gases (CO2, CH4, N2O and CFCs)	tons/ha/yr

Table E.2 Hydrosphere indicators of the RUD model

HYDROSPHERE	**units**
STORMWATER	
HSW-HAB Conservation of habitat, wetland and water bodies	> 50% conserved
HSW-AQU Conservation of aquifers	% restored
HSW-SRW Stored rainwater	max 60%
HSW-PPT Mitigation of surface water runoff using permeable paving and percolation trenches	% mitigated
HSW-PCB Mitigation of rainwater outflow using retaining pond and flood control basins	> 300m^3/ha
DOMESTIC WATER	
HDW-FWA Freshwater availability per capita	1000m^3/capita /yr
HDW-DWU Domestic water distributed for use and services	m^3/person/mo
HDW-NZW Net Zero Water	100% onsite
HDW-EWF Ecological Water Flow	100% onsite
HDW-UAW Unaccounted Water	1000m^3/yr
WATER QUALITY	
HWQ-WPO Water Pollution	ppm
HWQ-DOC Dissolved oxygen concentration	mg/lt
HWQ-ELC Electrical conductivity	mSI/cm
HWQ-PHC Phosphorus concentration	mg/lt
HWQ-SSO Suspended solids	mg/lt
WASTEWATER	
HWW-HLT Load reduction using high-level treatment of sewage and graywater	
HWW-WDB Load leveling using water discharge balancing tanks	
HWW-WWT Wastewater treatment rate (%)	25 > % > 50
HWW-OWP Industrial organic water pollutant (BOD) emissions per available freshwater	tons/km^3
HWW-WDS Waste discharge into water sources	tons

Table E.3 Lithosphere indicators of the RUD model

LITHOSPHERE	**units**
LAND USE	
LLU-MUE Managed and limited urban expansion	100 > m > 30
LLU-MUN Mixed-use neighborhood	4 > uses > 19
LLU-MIC Mixed-income communities	15 > % > 5
LLU-SML Smart location (bikeable / predeveloped / congruity / transit adjacency)	< 800m
LLU-CDV Compact contiguous development	7DU/ac - 0.5 FAR
LLU-WLK Walkability to daily-uses, facilities, amenities	< 400m
LAND COVER	
LLC-GLO Protection of green land and open space	> 50% protected
LLC-VCC Vegetation cover change	% change
LLC-PSR Pervious/impervious surface ratio	0.05 > r > 0.50
LLC-LAI Land with low anthropogenic impact	< 10% impacted
LLC-HAI Land with high anthropogenic impact	10 > % > 40
LLC-FRT Forestation Rate (reforestation - deforestation)	% change
SOIL QUALITY	
LSQ-TSE Conservation of topsoil (prevention of soil erosion)	> 30% shaded
LSQ-BFR Brownfield redevelopments	
LSQ-PSC Prevention of soil contamination	max 60%
LSQ-SAP Salinized area as percentage of total arable land	7 > score > 1
LSQ-ACI Acidification from anthropogenic sulfur deposition	% land area
URBAN AGRICULTURE	
LAG-CNL Conservation of nonurban agricultural land	DU/ac FAR
LAG-UAA Urban agricultural area	80 > % > 0
LAG-UFP Urban food production	60 > ft^2/DU > 200
LAG-FPC Fertilizer and pesticide consumption on arable land	kg/hectare
LAG-NAL Number of allotment plots per 1,000 residents	#/1000
WASTES	

LITHOSPHERE (Cont'd)	**units**
LWS-PUW Production of urban waste	tons/ha/yr
LWS-RRC All reused, recycled and composted materials	% recycled
LWS-CTD Classification, treatment and disposal of waste	> 5 types
LWS-CSF Reduction of collection load using centralized-storage facilities	% reduced
LWS-WWC Reduction of weight of waste and employing composting	% reduced

Table E.4 Ecology indicators of the RUD model

ECOLOGY	**units**
HABITAT RESILIENCE	
EHR-PRO Protection of open space, ecosystem, habitat, wetland, water bodies	km^2
EHR-REG Regeneration of open space, ecosystem, habitat, wetland, water bodies	km^2
EHR-RSE Restoration of site ecology, flora and fauna	km^2
EHR-HFB Habitat fragmentation and buffers	%
EHR-MSD Minimization of site disturbance in design and construction	100%
BIODIVERSITY	
EBD-TLS Protection of endangered and threatened land species	$\#/1000km^2$
EBD-TMS Protection of endangered and threatened marine species	$\#/1000km^2$
EBD-TSE Tracking species extinctions	$\#/1000km^2$
EBD-POF Productivity overfishing	7 > score > 1
EBD-IEA Participation in international environmental agreements	#
HUMAN POPULATION	
EHP-UPD Urban population density	$\#/km^2$
EHP-PGM Population growth management	% change
EHP-LEB Life expectancy from birth	%

ECOLOGY (Cont'd)	**units**
EHP-DRT Death rate	%
EHP-EFP Ecological footprint	hectare/capita
BIOPHILIA	
EHP-PGS Area of public green space per capita	m^2/capita
EBP-DGE Number of dissimilar green elements	6 items/2000 m^2
EBP-GAC Gardening Activity	m^2/capita
EBP-CEN Creating ecosystem networks	total / maximum
EBP-RLE Regional and local effect on species numbers	#/yr
RESOURCE MANAGEMENT	
ERM-ARP Adaptive reuse and historic resource preservation	% preserved
ERM-RRR Reliance on regional resources	8000 > km > 2000
ERM-RLR Reliance on local resources	2000 > km > 500
ERM-OCD Consumption of oil and coal derivatives	tons/km^2 /yr
ERM-RNR Regeneration of natural resources	> 30% open space

Table E.5 Energy indicators of the RUD model

ENERGY	**units**
RENEWABILITY	
ERN-SWH Solar, wind, hydro and geothermal energy production	% generated
ERN-OSR Onsite renewable energy	20 > % onsite > 5
ERN-RTN Renewable energy to nonrenewable ratio	%
ERN-CPW CO_2 per kWh	kgCO_2/kWh
ERN-EEQ Energy equivalent (Eeq) expressed in TOE (tonnes of oil equivalent) per inhabitant per year	tons/inhabitant/yr
EFFICIENCY	
EEF-EBR Existing building reuse	> 50% reuse
EEF-CGB Percentage of certified green buildings	> 50% certified
EEF-HEE Reduction by network of high-efficiency energy system	> 30% reduced
EEF-RWH Reduction of waste heat	> 100W/m^2

ENERGY (Cont'd)	**units**
EEF-NZE Net zero energy	%
CONSUMPTION REDUCTION	
ECR-TEC Total electricity consumption	kWh/km^2 /yr
ECR-TER Total electricity consumption reduction	30 > % > 5
ECR-TGC Total gas consumption	ton/km^2 /yr
ECR-TGR Total gas consumption reduction	30 > % > 5
ECR-LLN Load leveling of electrical power and heat through area network	> 20% peak load
TRANSPORTATION	
ETP-PTA Public transport adjacency	< 1000m
ETP-EUM Urban mobility indicator - EUMeq	km/inhabitant/yr
ETP-LBP Length of bicycle paths	km
ETP-PTS Number of public transport stops	#/km^2
ETP-MTS Number of mass transit stops	#/km^2

Appendix F - Existing Parcels

The following tables include the existing land use codes, parcel ID numbers and sizes.

Table F.1 Existing parcel sizes in the city blocks A1 through A9 of the case study area

Block No.	Parcel FID	Land Use Code	Shape Area (m^2)	Total Area (m^2)
A1				11,021
	22	1,222	11,021	
A2				8,146
	23	1,130	8,146	
A3				9,584
	20	1,222	3,489	
	21	1,540	6,095	
A4				9,483
	149	1,540	9,483	
A5				9,802
	121	1,232	9,802	
A6				9,089
	74	1,232	2,411	
	75	1,250	2,161	
	311	1,540	4,518	
A7				9,441
	118	4,220	9,441	
A8				9,436
	77	1,232	4,398	
	159	1,350	5,037	
A9				9,759
	293	1,232	5,045	
	294	1,130	4,714	

Table F.2 Existing parcel sizes in the city blocks B1 through B9 of the case study area

Block No.	Parcel FID	Land Use Code	Shape Area (m^2)	Total Area (m^2)
B1				12,300
	24	1,222	12,300	
B2				10,847
	258	1,232	5,307	
	259	1,540	5,541	
B3				10,507
	260	1,250	4,183	
	261	1,232	3,348	
	262	1,130	2,977	
B4				10,753
	148	1,222	10,753	
B5				11,239
	263	1,250	2,575	
	264	1,250	8,664	
B6				10,354
	160	1,240	5,050	
	161	1,232	5,304	
B7				10,781
	113	1,130	10,781	
B8				10,834
	162	4,300	4,448	
	163	1,232	3,075	
	164	1,130	3,311	
B9				11,319
	313	4,210	5,650	
	314	1,232	5,670	

Table F.3 Existing parcel sizes in the city blocks C1 through C9 of the case study area

Block No.	Parcel FID	Land Use Code	Shape Area (m^2)	Total Area (m^2)
C1				19,527
	25	1,130	7,541	
	234	1,232	5,423	
	235	1,250	6,563	
C2				11,067
	57	1,232	5,350	
	58	1,222	5,716	
C3				10,889
	59	1,250	2,888	
	257	1,232	8,001	
C4				10,815
	265	1,232	3,606	
	266	1,540	2,492	
	267	1,222	4,718	
C5				11,124
	112	4,210	11,124	
C6				10,693
	185	1,540	6,043	
	193	1,250	4,651	
C7				10,615
	72	1,232	4,788	
	73	4,300	2,261	
	194	1,560	3,565	
C8				10,812
	196	1,130	5,265	
	295	1,232	5,547	
C9				11,253
	178	1,130	11,253	

Table F.4 Existing parcel sizes in the city blocks D1 through D9 of the case study area

Block No.	Parcel FID	Land Use Code	Shape Area (m^2)	Total Area (m^2)
D1				19,487
	128	1,540	8,379	
	129	1,222	6,968	
	130	1,250	4,140	
D2				11,561
	55	1,232	1,378	
	56	1,540	10,183	
D3				11,539
	49	1,330	3,061	
	50	1,222	3,337	
	51	1,232	5,141	
D4				11,718
	268	1,540	6,020	
	269	1,222	1,636	
	270	1,232	1,975	
	271	1,222	2,087	
D5				11,539
	52	1,330	11,539	
D6				11,657
	301	1,231	4,049	
	302	4,210	3,018	
	303	1,232	2,650	
	304	1,560	1,940	
D7				10,955
	11	1,231	4,697	
	305	1,232	6,258	
D8				11,395
	78	1,232	5,628	
	165	1,130	5,767	
D9				11,764
	306	1,232	7,059	
	307	1,130	4,705	

Table F.5 Existing parcel sizes in the city blocks E1 through E9 of the case study area

Block No.	Parcel FID	Land Use Code	Shape Area (m^2)	Total Area (m^2)
E1				17,999
	131	1,222	2,358	
	132	4,210	3,353	
	133	4,220	3,083	
	158	4,300	9,205	
E2				10,877
	288	1,232	10,877	
E3				10,711
	47	1,540	3,258	
	48	1,232	7,453	
E4				10,827
	275	1,232	5,296	
	276	1,222	5,531	
E5				10,407
	272	1,232	5,234	
	273	1,250	3,733	
	274	1,540	1,441	
E6				11,008
	181	1,231	4,687	
	285	1,540	6,321	
E7				10,249
	122	1,540	3,125	
	286	1,232	7,124	
E8				10,731
	296	1,130	1,897	
	297	1,232	8,834	
E9				11,376
	6	1,370	7,332	
	145	1,231	4,044	

Table F.6 Existing parcel sizes in the city blocks F1 through F9 of the case study area

Block No.	Parcel FID	Land Use Code	Shape Area (m^2)	Total Area (m^2)
F1				18,304
	0	1,222	4,790	
	1	1,540	10,817	
	2	1,222	2,697	
F2				11,404
	289	1,540	11,404	
F3				11,197
	45	1,540	5,063	
	46	1,232	6,134	
F4				11,422
	277	1,232	5,780	
	278	1,540	2,363	
	279	1,370	3,279	
F5				10,765
	125	1,232	10,765	
F6				11,413
	191	1,250	3,445	
	192	1,232	7,968	
F7				10,844
	124	1,222	10,844	
F8				10,834
	37	1,540	1,756	
	38	1,232	4,568	
	298	1,540	4,510	
F9				11,315
	200	1,250	5,012	
	201	1,232	6,303	

Table F.7 Existing parcel sizes in the city blocks G1 through G9 of the case study area

Block No.	Parcel FID	Land Use Code	Shape Area (m^2)	Total Area (m^2)
G1				30,937
	123	1,212	30,937	
G2				10,419
	43	1,540	2,853	
	44	1,232	7,565	
G3				10,374
	127	1,232	10,374	
G4				10,533
	280	1,540	1,581	
	281	1,232	1,803	
	282	1,231	3,162	
	283	1,232	3,986	
G5				9,904
	242	1,232	4,209	
	243	1,540	5,695	
G6				10,670
	187	1,231	2,406	
	188	1,540	2,159	
	189	1,232	1,899	
	190	1,420	4,206	
G7				10,510
	184	1,231	5,333	
	186	1,420	5,177	
G8				10,301
	202	1,232	7,038	
	203	1,540	3,263	
G9				11,096
	150	1,232	11,096	

Table F.8 Existing parcel sizes in the city blocks H1 through H9 of the case study area

Block No.	Parcel FID	Land Use Code	Shape Area (m^2)	Total Area (m^2)
H1				36,658
	8	1,250	6,034	
	26	1,540	9,082	
	29	1,212	17,938	
	54	3,100	3,605	
H2				11,142
	291	1,130	11,142	
H3				11,127
	15	1,350	5,288	
	16	1,222	1,722	
	17	1,540	4,117	
H4				11,199
	290	1,130	11,199	
H5				10,510
	244	1,232	2,931	
	245	1,540	5,596	
	246	1,420	1,983	
H6				11,318
	70	1,540	4,274	
	71	1,420	7,044	
H7				11,355
	66	1,540	3,918	
	67	1,222	3,648	
	68	1,232	1,615	
	69	1,222	2,173	
H8				10,702
	204	1,540	2,193	
	205	1,540	3,547	
	206	1,232	4,962	
H9				11,465
	198	1,232	7,583	
	308	1,540	3,882	

Table F.9 Existing parcel sizes in the city blocks J1 through J9 of the case study area

Block No.	Parcel FID	Land Use Code	Shape Area (m^2)	Total Area (m^2)
J1				19,550
	114	1,240	14,435	
	247	1,540	5,115	
J2				10,418
	12	1,540	3,492	
	13	1,222	5,060	
	14	1,430	1,866	
J3				14,707
	9	1,540	7,780	
	10	1,222	6,927	
J4				19,388
	248	1,231	5,106	
	251	1,130	8,834	
	252	1,110	5,448	
J5				25,272
	135	1,231	7,821	
	136	1,560	5,465	
	137	1,222	4,372	
	284	1,430	7,615	
J6				28,520
	34	1,512	15,208	
	62	1,232	2,910	
	166	1,231	2,500	
	256	1,130	7,901	
J7				32,469
	63	4,210	3,262	
	64	1,540	2,546	
	65	1,130	11,480	
	238	1,130	2,371	
	240	1,232	6,686	
	241	1,232	4,347	
J8				10,212
	207	1,232	5,386	
	208	1,540	4,826	
J9				10,864
	253	1,130	10,864	

Table F.10 Existing parcel sizes in the city blocks K1 through K9 of the case study area

Block No.	Parcel FID	Land Use Code	Shape Area (m^2)	Total Area (m^2)
K1				11,522
	134	1,130	6,820	
	254	4,300	4,702	
K2				10,260
	255	1,540	10,260	
K3				11,077
	209	3,100	7,002	
	210	4,300	4,075	
K4				10,612
	199	1,420	7,769	
	250	1,232	2,843	
K5				10,754
	299	1,130	10,754	
K6				10,789
	197	1,420	10,789	
K7				10,882
	249	4,300	10,882	
K8				10,751
	233	1,222	7,854	
	341	1,130	2,897	
K9				11,149
	287	1,232	8,933	
	309	1,540	2,216	

Appendix G - Existing Buildings

The following tables include the summary of existing building uses and areas.

Table G.1 Existing building types and areas in the city blocks of the case study area

Block No.	Office (m^2)	Retail (m^2)	Residential (m^2)	Totals Per Block (m^2)
A1	0	6,800	207,740	214,540
A2	0	0	88,080	88,080
A3	0	13,468	0	13,468
A4	0	32,160	19,026	51,186
A5	9,474	0	36,603	46,076
A6	1,013	3,266	1,040	5,320
A7	0	0	84,425	84,425
A8	1,231	0	10,393	11,624
A9	0	1,329	63,159	64,488
B1	162,330	0	0	162,330
B2	20,609	2,613	0	23,222
B3	10,196	0	82,808	93,004
B4	100,096	0	34,420	134,516
B5	0	0	55,740	55,740
B6	0	17,803	3,316	21,118
B7	0	0	59,270	59,270
B8	0	0	81,773	81,773
B9	4,208	0	63,540	67,748
C1	58,445	7,322	171,088	236,856
C2	58,445	0	0	58,445
C3	11,910	580	30,232	42,721
C4	3,745	1,806	12,960	18,511
C5	0	7,112	130,710	137,822
C6	0	0	213,556	213,556
C7	4,608	0	75,799	80,407
C8	0	0	54,323	54,323
C9	0	0	353,275	353,275
D1	200,871	0	81,810	282,681
D2	0	934	45,923	46,857
D3	10,536	0	2,072	12,608
D4	23,456	0	1,765	25,221
D5	10,005	0	0	10,005

(Cont'd) Block No.	Office (m^2)	Retail (m^2)	Residential (m^2)	Total Area (m^2)
D6	730	1,964	36,527	39,221
D7	0	2,523	4,246	6,769
D8	1,143	0	43,326	44,469
D9	0	382	36,616	36,998
E1	28,539	0	154,590	183,129
E2	11,153	0	10,492	21,645
E3	4,784	0	3,289	8,072
E4	427	1,059	18,583	20,069
E5	1,052	297	9,226	10,575
E6	0	1,588	0	1,588
E7	2,186	902	0	3,088
E8	1,152	3,939	35,020	40,112
E9	0	0	29,532	29,532
F1	0	3,993	198,013	202,007
F2	0	0	191,547	191,547
F3	2,691	0	10,062	12,753
F4	4,110	2,796	0	6,906
F5	3,952	0	3,883	7,835
F6	613	1,220	4,117	5,951
F7	0	0	26,021	26,021
F8	4,691	771	2,069	7,531
F9	0	1,201	8,215	9,416
G1	363,648	0	0	363,648
G2	5,862	0	12,693	18,555
G3	19,194	0	11,373	30,567
G4	2,684	1,957	12,341	16,983
G5	11,950	0	41,377	53,326
G6	7,312	2,135	0	9,447
G7	20,008	1,431	0	21,438
G8	0	1,788	11,623	13,410
G9	8,891	0	11,490	20,380
H1	112,335	0	32,972	145,307
H2	0	0	35,976	35,976
H3	3,190	2,387	1,000	6,577
H4	0	0	134,634	134,634
H5	0	0	129,271	129,271
H6	17,825	0	4,856	22,681
H7	5,492	0	27,314	32,806

(Cont'd) Block No.	Office (m^2)	Retail (m^2)	Residential (m^2)	Total Area (m^2)
H8	16,489	378	0	16,867
H9	14,033	644	0	14,677
J1	12,216	0	80,266	92,482
J2	0	294	22,328	22,622
J3	530	0	10,042	10,572
J4	3,066	0	41,975	45,041
J5	1,170	1,654	22,362	25,186
J6	4,366	524	30,319	35,208
J7	4,047	133	164,036	168,216
J8	0	1,600	2,886	4,486
J9	0	0	10,742	10,742
K1	0	0	81,982	81,982
K2	0	0	0	0
K3	0	0	80,129	80,129
K4	9,900	0	50,862	60,762
K5	0	0	31,878	31,878
K6	0	624	59,379	60,003
K7	0	0	9,856	9,856
K8	4,309	0	31,961	36,270
K9	0	1,904	21,280	23,184

Appendix H - Photographs of Existing Conditions

Some of the photographs used in the existing condition analyses include the following:

Figure H.1 Intersection of Wells and Superior

Figure H.2 Intersection of Ohio and Wabash

Figure H.3 Intersection of Wacker and State

Figure H.4 Buildings along the river front

Figure H.5 Intersection of Orleans and Kinzie

Figure H.6 Intersection of Huron and Orleans

Figure H.7 North view along Superior

Figure H.8 Intersection of Dearborn and Huron

Figure H.9 Intersection of Wells and Huron

Figure H.10 Intersection of LaSalle and Superior

Figure H.11 Intersection of Hubbard and LaSalle

Figure H.12 Intersection of Orleans and Ontario

Appendix I - Least Ambitious Scenario (RPROJ1)

The projected annual anthropogenic CO2 emissions and mitigations in the restorative (RPROJ1) scenario alternative through year 2040 are estimated as shown in the following table.

Table I.1 Anthropogenic CO_2 emissions and mitigations in RPROJ1

Year	Trajectory Forecast (TFORE) (tons/yr)	Emission Reductions (5-10%) (tons/yr)	Onsite Mitigations (1%) (tons/yr)	Offsite Mitigations (89-94%) (tons/yr)
2014	423,459	21,173	4,235	398,052
2015	427,104	21,893	4,271	400,940
2016	430,749	22,615	4,307	403,826
2017	434,394	23,362	4,344	406,688
2018	438,039	24,133	4,380	409,526
2019	441,683	24,929	4,417	412,338
2020	445,328	25,752	4,453	415,123
2021	446,715	26,601	4,467	415,646
2022	448,102	27,479	4,481	416,142
2023	449,489	28,386	4,495	416,608
2024	450,875	29,323	4,509	417,044
2025	452,262	30,290	4,523	417,449
2026	453,649	31,290	4,536	417,823
2027	455,036	32,323	4,550	418,163
2028	456,423	33,389	4,564	418,469
2029	457,810	34,491	4,578	418,740
2030	459,197	35,629	4,592	418,975
2031	462,500	36,805	4,625	421,069
2032	465,803	38,020	4,658	423,125
2033	469,106	39,274	4,691	425,140
2034	472,409	40,570	4,724	427,114
2035	475,712	41,909	4,757	429,045
2036	479,015	43,292	4,790	430,932
2037	482,318	44,721	4,823	432,774
2038	485,621	46,197	4,856	434,568
2039	488,924	47,721	4,889	436,313
2040	492,227	49,223	4,922	438,082

Appendix J - Intense Greenification Scenario (RPROJ2)

The projected annual anthropogenic CO_2 emissions and mitigations in the restorative (RPROJ2) scenario alternative through year 2040 are estimated as shown in the following table.

Table J.1 Anthropogenic CO_2 emissions and mitigations in RPROJ2

Year	Trajectory Forecast (TFORE) (tons/yr)	Emission Reductions (10-20%) (tons/yr)	Non-CO_2 Emitting Energy (10-20%) (tons/yr)	Onsite Mitigations (5-15%) (tons/yr)	Offsite Mitigations (45-75%) (tons/yr)
2014	423,459	42,346	42,346	21,173	317,595
2015	427,104	43,743	43,743	22,210	317,407
2016	430,749	45,187	45,187	23,299	317,076
2017	434,394	46,678	46,678	24,440	316,597
2018	438,039	48,218	48,218	25,638	315,964
2019	441,683	49,810	49,810	26,894	315,170
2020	445,328	51,453	51,453	28,212	314,209
2021	446,715	53,151	53,151	29,594	310,818
2022	448,102	54,905	54,905	31,045	307,247
2023	449,489	56,717	56,717	32,566	303,489
2024	450,875	58,589	58,589	34,161	299,536
2025	452,262	60,522	60,522	35,835	295,382
2026	453,649	62,520	62,520	37,591	291,019
2027	455,036	64,583	64,583	39,433	286,437
2028	456,423	66,714	66,714	41,366	281,629
2029	457,810	68,915	68,915	43,392	276,586
2030	459,197	71,190	71,190	45,519	271,298
2031	462,500	73,539	73,539	47,749	267,673
2032	465,803	75,966	75,966	50,089	263,782
2033	469,106	78,473	78,473	52,543	259,617
2034	472,409	81,062	81,062	55,118	255,166
2035	475,712	83,737	83,737	57,819	250,419
2036	479,015	86,501	86,501	60,652	245,362
2037	482,318	89,355	89,355	63,624	239,984
2038	485,621	92,304	92,304	66,741	234,272
2039	488,924	95,350	95,350	70,011	228,213
2040	492,227	98,445	98,445	73,834	221,502

Appendix K - Zero Offsite Scenario (RPROJ3)

The projected annual anthropogenic CO_2 emissions and mitigations in the zero offsite (RPROJ3) scenario alternative through year 2040 are estimated as shown in the following table.

Table K.1 Anthropogenic CO_2 emissions and mitigations in RPROJ3

Year	Trajectory Forecast (TFORE) (tons/yr)	Emission Reductions (20-40%) (tons/yr)	Non-CO_2 Emitting Energy (35-70%) (tons/yr)	Onsite Mitigations (10-25%) (tons/yr)	Offsite Mitigations (0%) (tons/yr)
2014	423,459	84,692	296,422	42,346	0
2015	427,104	87,487	295,493	44,124	0
2016	430,749	90,374	294,398	45,978	0
2017	434,394	93,356	293,129	47,909	0
2018	438,039	96,437	291,681	49,921	0
2019	441,683	99,619	290,046	52,018	0
2020	445,328	102,907	288,219	54,202	0
2021	446,715	106,303	283,933	56,479	0
2022	448,102	109,811	279,440	58,851	0
2023	449,489	113,434	274,732	61,323	0
2024	450,875	117,178	269,800	63,898	0
2025	452,262	121,045	264,636	66,582	0
2026	453,649	125,039	259,232	69,378	0
2027	455,036	129,165	253,578	72,292	0
2028	456,423	133,428	247,666	75,329	0
2029	457,810	137,831	241,486	78,492	0
2030	459,197	142,379	235,028	81,789	0
2031	462,500	147,078	230,197	85,224	0
2032	465,803	151,931	225,067	88,804	0
2033	469,106	156,945	219,627	92,533	0
2034	472,409	162,124	213,864	96,420	0
2035	475,712	167,474	207,768	100,469	0
2036	479,015	173,001	201,324	104,689	0
2037	482,318	178,710	194,521	109,086	0
2038	485,621	184,608	187,345	113,668	0
2039	488,924	190,700	179,782	118,442	0
2040	492,227	196,891	172,279	123,057	0

Appendix L - Global Remediation Scenario (RPROJ4)

The projected annual anthropogenic CO_2 emissions and mitigations in the restorative (RPROJ4) scenario alternative through year 2040 are estimated as shown in the following table.

Table L.1 Anthropogenic CO_2 emissions and mitigations in RPROJ4

Year	Trajectory Forecast (TFORE) (tons/yr)	Emission Reductions (15-30%) (tons/yr)	Non-CO_2 Emitting Energy (20-40%) (tons/yr)	Onsite Mitigations (10-25%) (tons/yr)	Offsite Mitigations (25-55%) (tons/yr)	Global Remediation (tons/yr)
2014	422,952	63,519	84,692	42,346	232,903	0
2015	426,593	65,615	87,487	44,124	233,878	4,000
2016	430,233	67,780	90,374	45,978	234,617	8,000
2017	433,874	70,017	93,356	47,909	235,112	12,000
2018	437,514	72,328	96,437	49,921	235,353	16,000
2019	441,154	74,714	99,619	52,018	235,332	20,000
2020	444,795	77,180	102,907	54,202	235,039	24,000
2021	446,180	79,727	106,303	56,479	232,207	28,000
2022	447,565	82,358	109,811	58,851	229,082	32,000
2023	448,950	85,076	113,434	61,323	225,656	36,000
2024	450,336	87,883	117,178	63,898	221,916	40,000
2025	451,721	90,783	121,045	66,582	217,852	44,000
2026	453,106	93,779	125,039	69,378	213,452	48,000
2027	454,491	96,874	129,165	72,292	208,704	52,000
2028	455,876	100,071	133,428	75,329	203,596	56,000
2029	457,261	103,373	137,831	78,492	198,113	60,000
2030	458,647	106,785	142,379	81,789	192,244	64,000
2031	461,946	110,308	147,078	85,224	187,889	68,000
2032	465,245	113,949	151,931	88,804	183,119	72,000
2033	468,544	117,709	156,945	92,533	177,918	76,000
2034	471,843	121,593	162,124	96,420	172,271	80,000
2035	475,142	125,606	167,474	100,469	166,162	84,000
2036	478,441	129,751	173,001	104,689	159,574	88,000
2037	481,740	134,033	178,710	109,086	152,489	92,000
2038	485,039	138,456	184,608	113,668	144,890	96,000
2039	488,338	143,025	190,700	118,442	136,758	100,000
2040	491,637	147,668	196,891	123,057	128,611	104,000

Figure L.1 Full mitigation assumptions in Global Remediation scenario (Table 4.9)

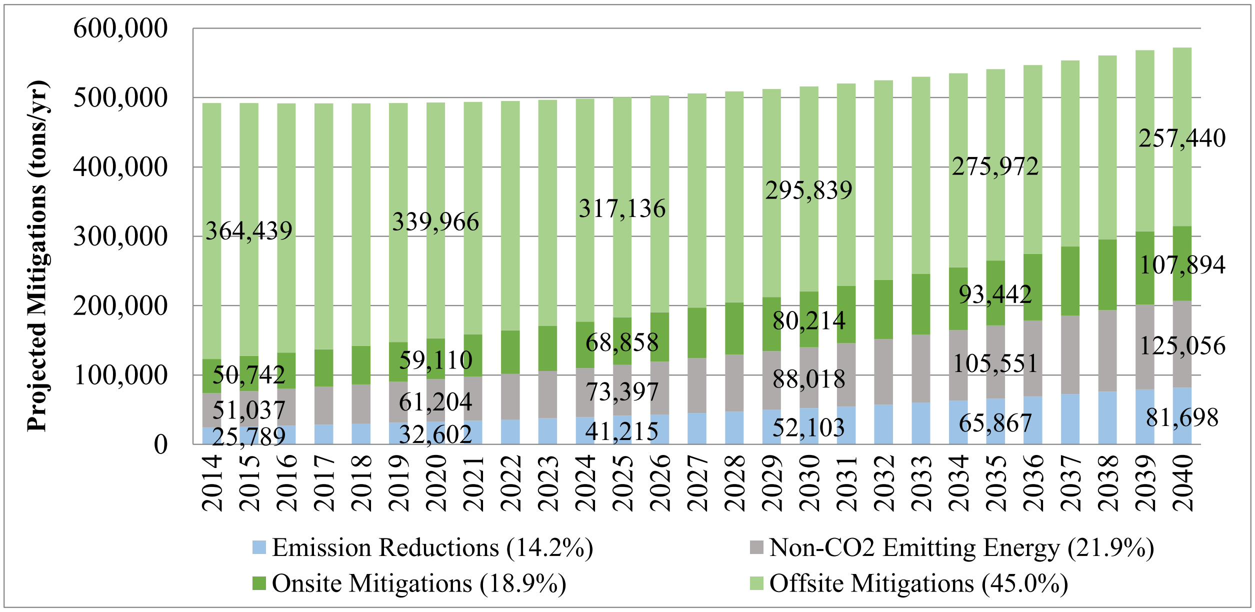
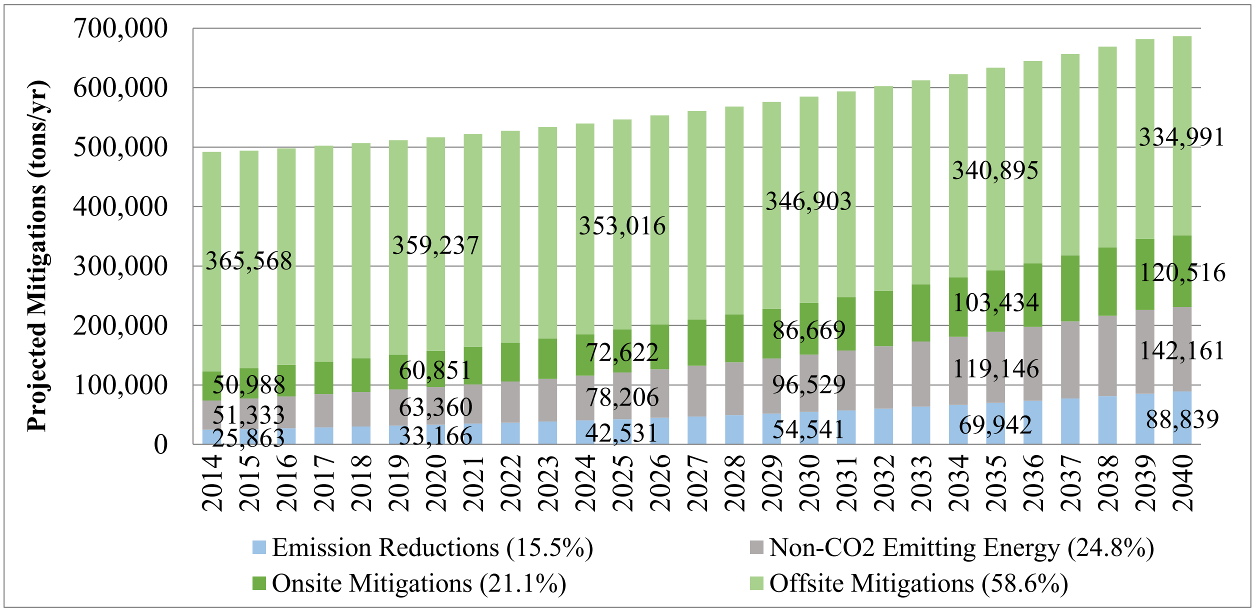


Figure L.2 Global remediation assumptions 20% beyond full mitigation (Table 4.9)



Appendix M - Final Restorative Projection (RPROJ)

The projected annual anthropogenic CO_2 emissions and mitigations in the final restorative projection (RPROJ) through year 2040 are estimated as shown in the following table.

Table M.1 Anthropogenic CO_2 emissions and mitigations in Final Restorative Projection

Year	Trajectory Forecast (TFORE) (tons/yr)	Emission Reductions (5.00%-14.95%) (tons/yr)	Non-CO_2 Emitting Energy (10.00%-23.42%) (tons/yr)	Onsite Mitigations (10.00%-20.02%) (tons/yr)	Offsite Mitigations (75.00-51.61%) (tons/yr)	Global Remediation (tons/yr)
2014	423,459	21,173	42,346	42,346	317,595	0
2015	427,104	23,188	45,151	44,508	315,151	893
2016	430,749	25,204	47,956	46,669	312,707	1,787
2017	434,394	27,219	50,761	48,831	310,263	2,680
2018	438,039	29,234	53,566	50,993	307,819	3,573
2019	441,683	31,250	56,371	53,154	305,375	4,467
2020	445,328	33,265	59,177	55,316	302,931	5,360
2021	446,715	35,280	61,982	57,478	300,487	8,511
2022	448,102	37,295	64,787	59,639	298,043	11,662
2023	449,489	39,311	67,592	61,801	295,599	14,814
2024	450,875	41,326	70,397	63,963	293,155	17,965
2025	452,262	43,341	73,202	66,124	290,711	21,116
2026	453,649	45,357	76,007	68,286	288,267	24,267
2027	455,036	47,372	78,812	70,448	285,823	27,419
2028	456,423	49,387	81,617	72,609	283,379	30,570
2029	457,810	51,403	84,423	74,771	280,935	33,721
2030	459,197	53,418	87,228	76,933	278,491	36,872
2031	462,500	55,433	90,033	79,094	276,047	38,108
2032	465,803	57,449	92,838	81,256	273,603	39,343
2033	469,106	59,464	95,643	83,418	271,159	40,578
2034	472,409	61,479	98,448	85,579	268,715	41,813
2035	475,712	63,495	101,253	87,741	266,271	43,048
2036	479,015	65,510	104,058	89,903	263,827	44,283
2037	482,318	67,525	106,863	92,064	261,383	45,518
2038	485,621	69,541	109,669	94,226	258,939	46,753
2039	488,924	71,556	112,474	96,388	256,495	47,988
2040	492,227	73,571	115,279	98,549	254,051	49,223

Appendix N - Offsite Mitigation Forest

The annual required size of offsite CO2 mitigation forest for different scenarios through year 2040 is estimated as shown in the following table.

Table N.1 Estimated size of the offsite mitigation forest

Year	Least Ambitious (RPROJ1) (ha)	Intense Greenification (RPROJ2) (ha)	Global Remediation (RPROJ4) (ha)	Final Restorative Projection (RPROJ) (ha)	km^2	mi^2
2014	540	431	316	430.93	4.309	1.664
2015	544	431	317	427.61	4.276	1.651
2016	548	430	318	424.30	4.243	1.638
2017	552	430	319	420.98	4.210	1.625
2018	556	429	319	417.66	4.177	1.613
2019	559	428	319	414.35	4.143	1.600
2020	563	426	319	411.03	4.110	1.587
2021	564	422	315	407.72	4.077	1.574
2022	565	417	311	404.40	4.044	1.561
2023	565	412	306	401.08	4.011	1.549
2024	566	406	301	397.77	3.978	1.536
2025	566	401	296	394.45	3.945	1.523
2026	567	395	290	391.14	3.911	1.510
2027	567	389	283	387.82	3.878	1.497
2028	568	382	276	384.50	3.845	1.485
2029	568	375	269	381.19	3.812	1.472
2030	568	368	261	377.87	3.779	1.459
2031	571	363	255	374.55	3.746	1.446
2032	574	358	248	371.24	3.712	1.433
2033	577	352	241	367.92	3.679	1.421
2034	580	346	234	364.61	3.646	1.408
2035	582	340	225	361.29	3.613	1.395
2036	585	333	217	357.97	3.580	1.382
2037	587	326	207	354.66	3.547	1.369
2038	590	318	197	351.34	3.513	1.357
2039	592	310	186	348.03	3.480	1.344
2040	594	301	175	344.71	3.447	1.331

Note: There is no offsite mitigation forest in RPROJ3 scenario alternative.

Appendix O - City Block Conditions

Some of the aerial views used in the existing condition analyses include the following:

Figure O.1 City blocks F7, F8, G7 & G8 – southwest aerial (©2014 Google Earth)

Figure O.2 City blocks F7, F8, G7 & G8 – southeast aerial (©2014 Google Earth)

Some of the photographs used in the existing condition analyses include the following:

Figure O.3 Intersection of Wells and Huron

Figure O.4 Street view along Huron

Figure O.5 Intersection of Huron and Franklin

Figure O.6 Intersection of Franklin and Erie

Figure O.7 Intersection of Erie and Franklin

Figure O.8 Intersection of Ontario and Franklin

Figure O.9 Intersection of Huron and Wells

Figure O.10 Intersection of Wells and Huron

Figure O.11 Intersection of LaSalle and Ontario

Figure O.12 Intersection of Ontario and LaSalle

Appendix P - Visualization Images

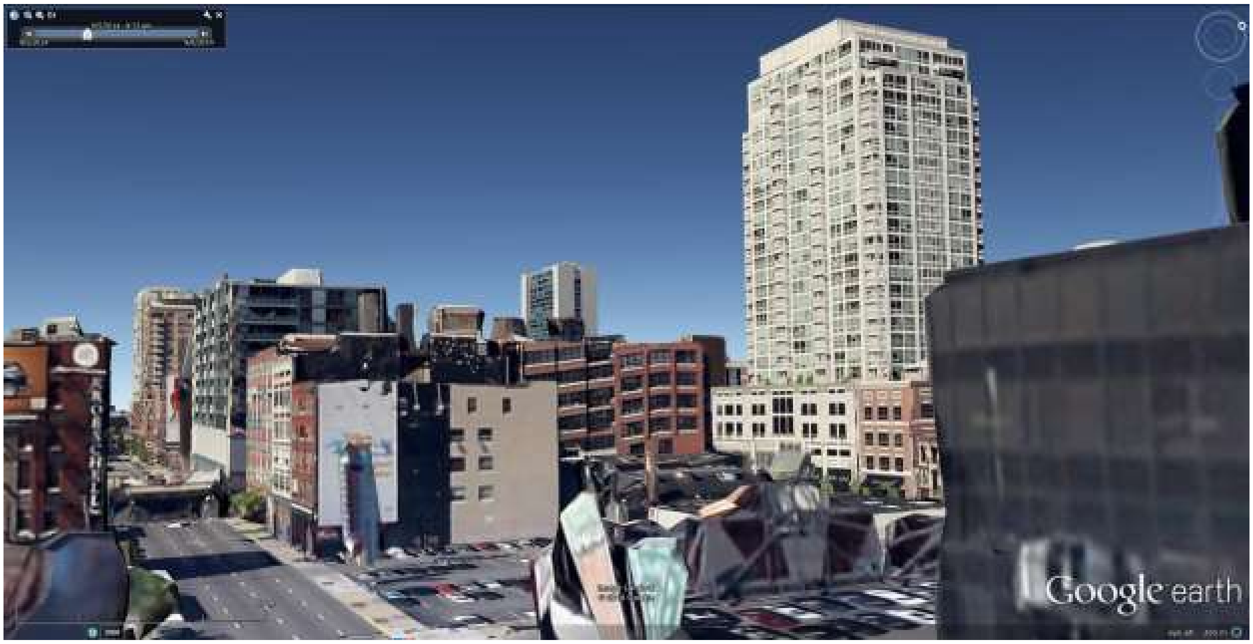
Some of the aerial views used in the 3D visualization include the following:

Figure P.1 Northeastern aerial view (©2014 Google Earth)

Figure P.2 Southwestern aerial view (©2014 Google Earth)

Figure P.3 Northwestern aerial view (©2014 Google Earth)

Figure P.4 Erie street view (©2014 Google Earth)



Appendix Q - Images from Virtual (BIM) Model

Some of the computer model renderings used in the visualization include the following:

Figure Q.1 Northwestern aerial view

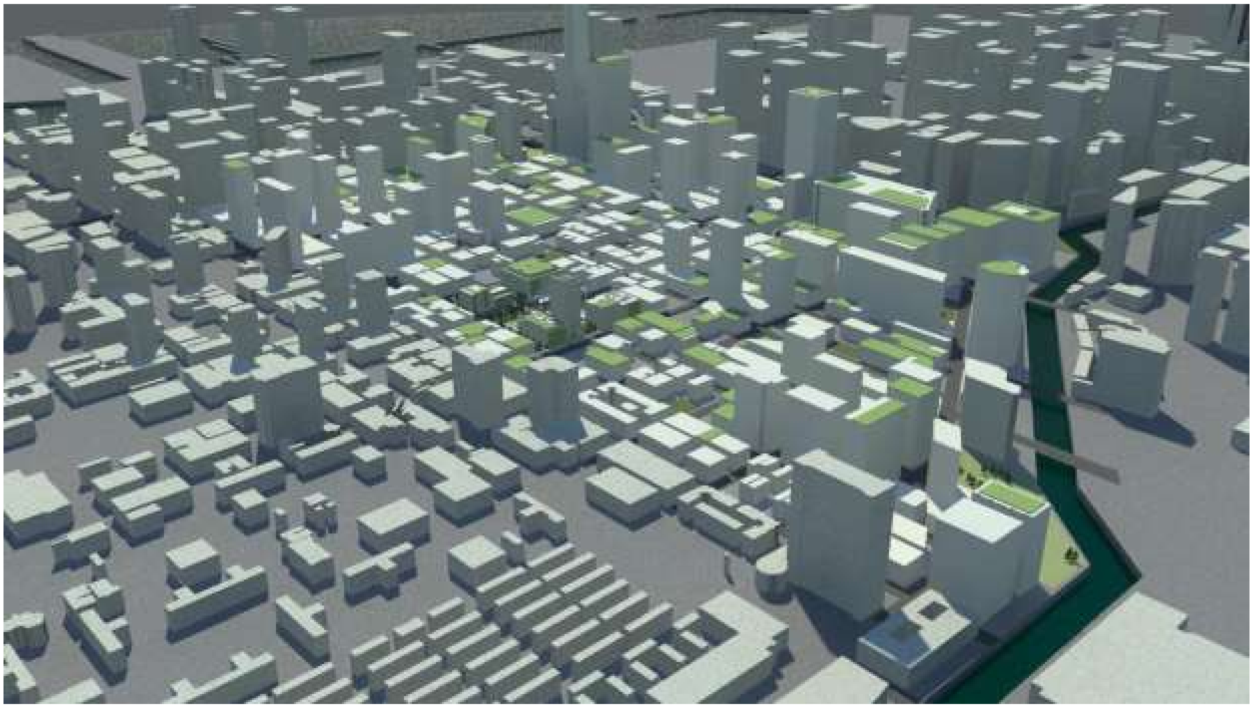


Figure Q.2 Western aerial view