Using Ecosystems Services Impacts for Green Building Assessment

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ABSTRACT: Assessing the environmental impacts of buildings is inherently an interdisciplinary issue. The concept of ecological capacity can be put into an architectural context and is developed as a time- and area-dependent tool to evaluate the effectiveness of environmental building design. By basing the measure of building impacts on the ecological capacity of a site, we find a common language between architectural and ecological disciplines and we generate useful analyses for establishing sustainability parameters. This method offers the additional benefit of generating environmental design criteria that can reduce the environmental impacts of construction.
The use of Ecosystems Services Criteria is a simple and effective method for objectively assessing the ecological impacts of a building. The overall size of the impact is measurable (IBS), as well as the ecological efficiency of the building (IES). The common baseline (hectare / years) allows projects of different sizes and typologies to be objectively compared. In application, this method allows building designers to plan the ecological debit and return of their interventions, much as they may develop a financial plan. The method recognizes individual efforts towards environmental responsibility, and also shows the magnitude of our interdependence. An ecologically derived baseline is shown to measure negative impacts as well as positive impacts of buildings. As we increase the positive impacts of our buildings beyond their negative impacts, we will have a net positive change on our ecosystems structure. This is a profound change in thinking, making us into guardians of our environment, where we are continually investing in and profiting from our environmental stewardship. The implication of this information is that as the value of our ecosystem services become socially recognized, it will be well within our technical means to design buildings to create an ecological profit.

Keywords: ecosystem services, green building assessment, ecological capacity

1. INTRODUCTION

In the discussion of environmental architecture, we are conjoining two disciplines, the subject of architecture and that of ecology. At their best, green buildings are examples of applied ecology, where designers understand the constitution, organization, and structure of ecosystems, and the impacts of architecture are considered from an environmental perspective. By utilizing the concepts, methods, and language of ecology, designers can create architecture that intentionally engages the natural systems of a site.

The establishment of ecological assessment criteria becomes, in effect, the establishment of building design criteria. If we establish criteria that are based on our best scientific understanding of environmental capacity, we can begin to develop building stock that is sustainable. To do this we must quantify the link between the resulting environmental impacts and their cause in building production and use. This is not done in traditional building environmental impact assessment methods, which are based on quantifying assumed negative impacts of man-made interventions on the natural environment, typically using a code compliant reference building as a standard. These indexes lack an ecologically derived baseline or standard, under which sustainable developments can be analyzed and compared on a universal basis.

An ecologically derived baseline can be used to measure both the positive and negative impacts of buildings. It also allows vastly different project types, sizes, and locations to be compared on an equal basis. This study extends the concept of ecological capacity into an architectural context and develops carrying capacity as a time- and area-dependent tool to evaluate the effectiveness of environmental building design. The Ecosystem Services Criteria study uses an objective metric of carrying capacity as an ecologically derived baseline (hectare/years) to assess building sustainability. The Farmhouse, a low energy, biological-material-based building located in Boulder, Colo. is evaluated herein to show the application of this method. The relative ecological impacts of energy and materials for this project are described, and effective strategies for reducing environmental impacts of typical buildings are identified.

2. HUMAN CARRYING CAPACITY AS A MEASURE OF ENVIRONMENTAL IMPACT

Today, sustainable design remains a “good neighbor policy,” in that it is a choice in which our actions benefit our global neighborhood as much as they do our selves. This was poetically articulated in Garrett Hardin’s seminal thesis “The Tragedy of the Commons,” which amongst other points illustrates that the success of sustainability is rooted in an awareness of the interdependence of our community.

Since the earth has finite material resources and biological capacity, humans must live within the carrying capacity of the earth. As we exceed the carrying capacity of the earth’s ecosystems, over time they are stressed, then go into decline, and finally collapse. They are expended rather than renewed. The construction and operation of buildings contributes to these environmental loads. Those who design and purchase buildings, however, have few methods to assess the environmental impacts of their actions.

2.1 Other Sustainable Building Indices

Several assessment indexes that are specific to buildings have emerged in recent years. The Building Research Establishment Environmental Assessment Method (commonly referred to by its acronym BREEAM) was launched in the UK in 1990 to provide an environmental assessment and labelling scheme for buildings (Baldwin, 1998). BREEAM, a voluntary market-oriented assessment of a building’s environmental performance, allows licensed assessors to perform assessments to maintain a consistent level of quality and objectivity. Buildings are assessed for both construction and operation. Metrics include environmental impact, energy efficiency, and health. Assessments are scored in terms of “credits earned” for good performance on water conservation, carbon dioxide emissions, etc. In the United States, a similar assessment system is the U.S. Green Building Council’s “Leadership in Energy and Environmental Design” or “LEED” rating system. Internationally, the Green Building Tool (GBT) is an evolving assessment system sponsored by National Resources Canada that has generated substantial interest.

These scoring systems each use code-compliant built environments as baselines to evaluate the environmental performance of the buildings being assessed. This skews the evaluation and has no correlation to environmental impacts. No indicators of environmental health are measured. For example, using LEED it is possible to construct a “250,000-square-foot building rated “Gold” and a small 25,000-square-foot building rated “Silver.” Even though the large building will have a better environmental rating, it will also have a larger environmental impact. In addition, many of the evaluation criteria in these systems are either subjective or difficult to quantify (e.g., “Site Selection”), or they have tenuous relationships to environmental impacts (such as “Views”).

Another category of assessment methods is referred to as “nature-based. These assessments include Malcolm Wells’s “Wilderness – Based Checklist,” the “Net Positive Change” analysis, and the “Tadoseec” checklist. These methods all share the concept that natural systems provide services we desire, and we should also rate our built environments in terms of their ability to provide those services. In addition, each of these checklists provides the ability to rate an intervention positively as well as negatively, setting the stage for regenerative design rather than only reducing impact.

2.2 The Concept of Ecosystems Services

“In amnesiac revelry it is also easy to overlook the services that ecosystems provide humanity. They enrich the soil and create the very air we breathe. Without these amenities, the remaining tenure of the human race would be nasty and brief.” (Wilson, 1992) [1]

Ecosystems goods and services are the benefits that we derive from the earth’s natural systems (e.g., clean air, water, etc.). Ecosystems services are critical to the functioning of the earth life-support systems since they contribute to human welfare both directly and indirectly (Table.1). All human endeavours depend on ecosystems services.

Table 1: Some Ecosystem Goods, Services, and Functions (after Costanza, 1997) [2]

Gas regulation	Water regulation	Refugia
Climate regulation	Water supply	Nutrient cycling
Disturbance regulation	Erosion control and soil retention	Waste treatment
Pollination	Food Production	Raw Materials
Biological control	Genetic resources	Soil formation

Ecosystem services are interconnected and interdependent, yet it is possible to identify individual critical impacts caused by building construction and operation. Buildings utilize the raw materials generated through ecosystem services and depend on the waste assimilation and climate regulation provided by ecosystem services. As evidenced by global warming, we are now exceeding the capacities of the earth’s ecosystems to assimilate the carbon dioxide we generate. In the United States, buildings consume 68 percent of the electricity produced annually, 75 percent of which is generated through the combustion of fossil fuels. The significance of this impact requires its measure; quantifying this metric ensures that the majority of the environmental effects are accounted for. The energy consumed in the construction and operation of the buildings and the subsequent generation of carbon dioxide and its sequestration are the primary ecosystem services addressed in this study. In other contexts, additional ecosystem services— may be critical, such as water supply in dry climates. The ecosystem service metric of water supply is also addressed herein.

It is possible to measure the ecological carrying capacity of a given site and quantify the various ecosystem services of a specific site. Similarly, we can measure our consumption of natural resources (in this case, those used specifically for the production and operation of buildings) and calculate degrees of environmental impact based on ecosystem consumption. By comparing these two metrics, ecological resources and building impacts, we can meaningfully assess the environmental impacts of buildings. This method is based on the "Ecological Footprint" carrying capacity baseline as defined by Rees and Wakernagel (Rees, 1996) [3].

3. EVALUATION METHOD AND METRICS

3.1 Time and Area define the metrics

Using ecosystem services as a baseline, a dual-criteria frame can be used to determine sustainability. First, the quantities of ecosystem services consumed in the production, products, and operation of a given building are reviewed. These quantities can be calculated with the following equation: (ecosystem productivity) x (area) / (time). Second, it is important to consider the amount of land assigned to the project. The less land consumed per unit constructed is a strong measure of ecological efficiency. Two metrics are thereby generated: the Index of Building Sustainability (IBS) and the Index of Efficiency in Sustainability (IES). These two metrics can be applied to assess both construction and operational impacts.

3.2 The Index of Building Sustainability (IBS)

The Index of Building Sustainability (IBS) is the fraction of the annual carrying capacity of the project's land that is consumed by a building. An assessment of IBS 1.0 would meet the carrying capacity of a site and IBS 0.5 would use half of the available site ecosystem services, where as IBS 1.5 would exceed the carrying capacity of the site and is therefore not sustainable (Fig.1). The IBS is a fraction and has no units; however, in application it can be considered as a unit of time. For a single impact, an IBS of .5 is equal to one half year of ecologically productive site capacity. While the size of the site may seem to be an arbitrary measure to use to determine sustainability, it typically defines the extent of the owners' control. The IBS metric is thereby an indicator of the individual's relationship to the community and shows the individual's environmental obligation or contribution.

3.3 Index of Efficiency in Sustainability (IES)

The Index of Efficiency in Sustainability (IES) is the quantity of land required to meet a sustainability index of 1. The less land required to meet sustainability index of 1, the more ecologically efficient the building is (Fig. 2). The IES is a measure of land area, and may use any area measure, such as acres or hectares as its units.

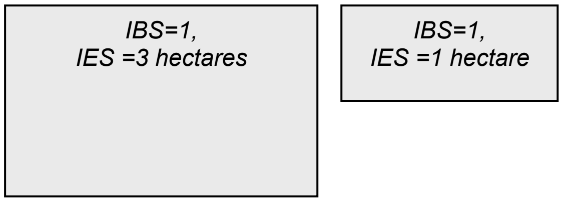

Figure 2:The Index of Efficiency in Sustainability

Building impacts can be reduced through careful design and selection of materials that increase the ecological efficiency of the product. On the supply side, it is possible to use building construction as an opportunity to rebuild ecosystems, thereby increasing the ecological productivity of the site and reducing its impacts as measured by the IBS.

4. ECOSYSTEM SERVICES EVALUATION

4.1 Water Balance

The amount of water used by a building is determined by the number and types of fixtures, the rate of consumption, and the number of individuals. The residence under examination has two individuals, who are above average in their water conservation, using on average 45 gallons (170 litres) per person per day. From a water harvesting standpoint, a 10,000 gallon (37,854 L) storage tank is assumed, and a 2500 square foot (232 sq M) roof for rainwater collection. Using 2004 Boulder Colorado weather data, it can be seen that this project is operating within the available resource, with an IBS of .69 (less than 1) (Fig. 3). Its IES equals 2350 square feet (218 sq M). If however, household water consumption is closer to 52gallons (197 L) per person per day, this exceeds the available ecosystem capacity; the IBS measures 2.08, and the IES jumps

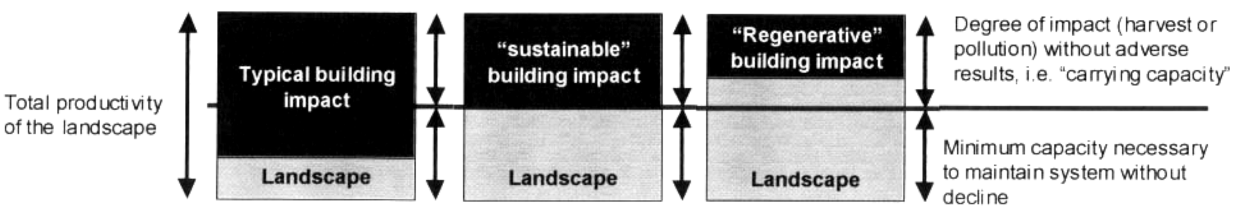

Figure 1: IBS: Indices of Building Sustainability of 1.5, 1.0, and 0.5 respectively

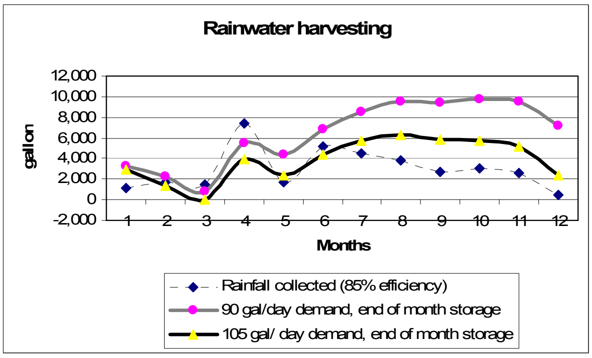

Figure 3: Balancing rainwater resource and demand

4.2 Carbon Dioxide Balance

Use of ecosystem services to evaluate the carbon dioxide balance of buildings is similar but slightly expanded. It requires three previously identified metrics for assessment: (1) construction impacts, (2) operational impacts, and (3) site capacity.

Construction impacts are divisible into the material and energy components, which consist of subcategories. We have used standard Construction Specifications Institute (CSI) divisions for tracking materials impacts.

Site capacity consists of the initial capacity, any effects (typically deficits) incurred through construction, and the addition of any capacity as provided through the generation of supplementary (232 sq meter)ecosystem services on site. Ecosystem services must be contextually defined relative to impacts (i.e., building construction and operation impacts consist primarily of material and energy consumption and production of associated waste (largely carbon dioxide). Therefore, ecosystem capacity to absorb waste is an appropriate metric. This metric provides several key elements. Using "Global Average Productivity," we can assess our impacts against an "earth share average" of consumption. The assessment depicts the impacts relative to total global capacity, and is most useful for an "apples-to-apples" comparison of significantly different projects. Using site-specific values of ecosystem productivity we can generate a regionalized assessment. Regional-specific data shows the potential for restoration of local ecosystem productivity with the accompanying decrease in negative environmental impact. This is inherently more accurate and relevant because geographic context alters the value of ecosystem services. Once these quantities are established, an ecological "proforma" can be created, which shows return on investment, ecological profit, ecological deficit (or "mortgage") created during construction, and the time required to break-even, etc. Many types of economic analysis can be analogously ascertained using this instrument.

To demonstrate, a low-impact home/office in Boulder is evaluated using ecosystem service impacts criteria. The Farmhouse (5,700 square feet) is larger than a typical residential building (530 M2), and it performs as a residence as well as an office. Residential space occupies 2,476 square feet of the building, while the remaining 3,229 square feet are used as open office workspace, a shop, and a model-building area.

To normalize the results, the following metrics are compared on an absolute basis and a per unit area basis. Global average ecosystem productivity was used to measure carrying capacity. The quantity of land required to absorb the waste of the materials and energy was taken from Rees/Wakernagel, and assumed to be100 gigajoules per hectare per year. Most material impacts are translated into the energy embodied in the materials with additional land areas required for the production of the renewable materials used (Stein, 1981). "Typical" reference building impacts are from Milne/Reardon (Milne, 2003). These results are preliminary and will be refined as the data set is developed.

4.22 Evaluation of Construction Impacts

Impacts for the construction impacts are calculated as follows:

Material (quantity) x (embodied energy) / (ecosystem productivity in GJ/ha/yr) = ecosystem services consumed (acres/yr).

Table 2: Summary of CO2 impacts

Building	Construction Impacts		Operational impacts	
	IBS	IES (acres)	IBS	IES (acres)
Farmhouse	152	45.6	5.3	1.6
Typical	80	24.7	5.5	1.65

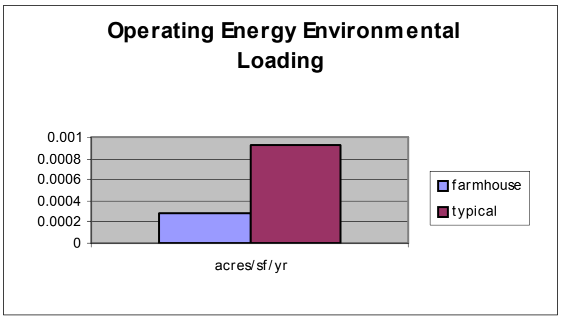

Figure 4: Operational impacts

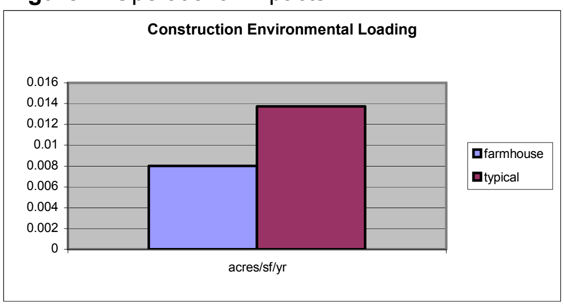

Figure 5: Construction impacts

When compared on a per-square-foot basis, the Farmhouse has 40 percent less energy embodied in its construction than a "typical" building.

Total construction impacts amount to approximately 1,800 gigajoules for the Farmhouse, and 1,000 gigajoules for a typical residence. This translates to 45.6 acres and 24.7 acres, respectively (these are their IES numbers). This means that the ecological impact (deficit) from construction of the Farmhouse can be recovered by the ecological productivity of 45.6 acres of land for one year's time. As a time/area measure, it is equivalent to 91.2 acres for half a year, 1 acre for 45 years, or 152 years (its IBS number) on its 0.3 acre site.

Construction impacts are an order of magnitude larger than annual operating impacts, and will typically exceed site capacity many times. However, construction impacts only occur once, and in this way resemble an environmental mortgage, which can potentially be repaid over time with efficient building operation and a productive landscape.

4.23 Evaluation of Operational Impacts

Operating impacts were calculated using a similar procedure—using utility bills to determine energy consumption. When compared on a per-square-foot basis, the Farmhouse is 70 percent more efficient to operate than a "typical" building (Figures 5, 6, 7, 8, and 9). This is a significant reduction in environmental impact when compared to a "typical" conventional residence. From this analysis, the Farmhouse on 0.3 acres of land is shown with an annual operating Index of Building Sustainability (IBS) of 5.3 and an Index of Efficiency in Sustainability (IES) of 1.6. This means the Farmhouse would require approximately 1.6 acres of land (of global average productivity) annually to accommodate its ecological impacts. Because it is located on 0.3 acres, it exceeds its capacity by 5.3. While these numbers still exceed our goals, they show the significant savings achieved by the Farmhouse, and point the way to designing and assessing higher-performance buildings.

5. LIFE CYCLE SPACE: THE RELATIONSHIP OF ECOLOGICAL DEFICIT, EMBODIED ENERGY AND OPERATIONAL ENERGY

5.1 Relative Impacts

The operational energy of a building over its lifetime is typically much greater than the energy embodied in its construction. Reducing environmental impacts of buildings requires increasing the ecological efficiency in both construction and operation. According to Milne/Reardon,[4] (Fig 6), a typical residential building's construction energy is equal to 15 years of operating energy. In the Farmhouse, the construction impacts are lower per unit and the operating energy required is even lower, meaning it will take approximately 28 years of operating costs to equal the construction impacts. As operating costs go down, construction impacts increase in relative importance.

5.2 Durability

Another implication of this is the more energy put into construction, the more durable the building should be in order to realize the value related to environmental cost Ephemeral buildings, such as tents and igloos, which have extremely low embodied energy, do not incur significant environmental liability due to their short life spans. From this it is evident that buildings with long lives cannot be simply equated with responsible sustainable design. They still must be evaluated to assess their ecological cost, despite the significantly longer return on investment.

5.3 Towards a restorative architecture

Current design knowledge and technology allow designers to produce high-performance buildings that have minimal or negative operating energy requirements. "Net zero energy" buildings and "net energy producing" buildings are becoming more common; clearly, the reduced operating impacts of these buildings allow them to operate at levels more commensurate with the carrying capacity of the site. Construction impacts, however, are likely to be greater in magnitude than the site capacity. In other words, construction "borrows" capacity from our global ecological store, the earth's accumulated ecological capital.

Architecture is not designed to be restorative and even minimal or zero operational energy buildings have construction impacts. Ecosystems primarily use autotrophic systems to capture solar income and transform it to biomass. They build increasingly complex systems, containing stores of energy, sinks, and regulated flows. If ecological capacity is increased as part of a construction project (thereby making the operating impacts less than preconstruction site capacity), a net increase in ecosystem services could occur. Increasing available moisture, moderating temperatures, augmenting soil chemistry, or changing biotic material are all methods that may increase the ecological productivity of a site.

A second method is to include autotrophic qualities in the built environment. If a building produces more energy than it requires for its

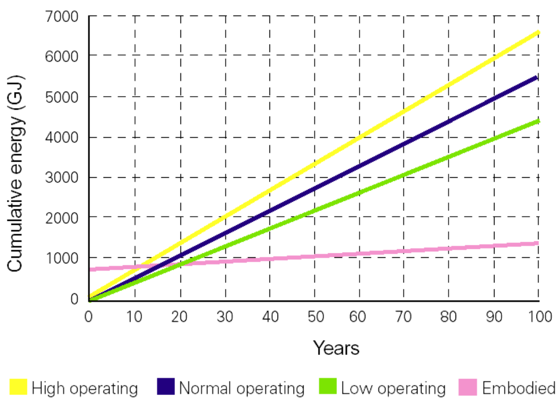

Figure 6: Over time typical residential building operating energy impacts are greater than embodied energy

operation, it can augment the capacity of other interventions in the network. By displacing the need for additional ecosystem services, the services are "virtually" provided, and can be considered restorative. Photovoltaic systems can be considered autotrophic, as their embodied energy accounts for approximately 5–10 years of their energy productivity, after which they begin to generate more energy than was required for their manufacture (Knapp, 2000). Employing the autotrophic qualities of biological and mechanical systems, we can approach a restorative architecture that repays ecological debts as a result of construction, and eventually contribute to a sustainable environment.

Designing to meet sustainability goals can now be seen in a context that balances environmental impacts with the time required for ecosystem services to be generated, and the space required for them to operate. We can generate an ecological proforma with this data. The Farmhouse data (Fig.7) show somewhat typical environmental impact trends over time: if operating impacts are not within the site carrying capacity, there will continue to be a decline in available ecosystem services, with no possibility of recouping the initial construction impacts. The slopes of the lines show the trends as well as the path towards decreasing impacts.

However, this analysis also points the direction towards a sustainable or restorative architecture. By:

1) Reducing operating impacts to be within site capacity (IBS=9); and

2) Increase the energy productivity of the building and the land productivity is increased by 50 percent in year 5.

an upward trend is produced in the ecological balance with a net ecological profit occurring after about 20 years. After this, the construction investment of global ecological capital is paid off with increased ecoservices available henceforth. From this exercise, effective means for designing to meet sustainability is likely to include: a) Increasing the building efficiency (reduced size and reduced construction and operating impacts); and b) Increasing the ecological productivity (augmenting site size, and increasing the building and site productivity).

6. CONCLUSION

This method provides an objective measure to assess environmental impacts of various interventions. As shown, the specific ecosystem service analyzed can and should vary based on the nature of the issues, and in this way the method is inherently regional and relevant. Continuing to develop the ecological economic instruments implied in this method may provide systemic fiscal motives to design buildings to create an ecological profit.

7. REFERENCES

[1] Wilson, E.O., The Diversity of Life (New York: W.W. Norton and Company, 1992.), p. 347.

[2] Costanza, R., d'Arge, R., de Groot, R., Faber, S., Grasso, M., Hannon, B., Limburg, K. Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Beit, M., "The value of the world's ecosystem services and natural capital," (Nature, Vol. 387), pp. 253–260.

[3] Wackernagle, M., and Rees,W., Our Ecological Footprint (Gabriola Island, Canada, New Society Publishers, 1996).

[4] Milne, G., Reardon, C., 2003. "Embodied Energy," CSIRO Maunfacturing and Infrastructure technology environment. Online brochure: http://www.cmit.csiro.au/brochures/tech/embodied/index.cfm.

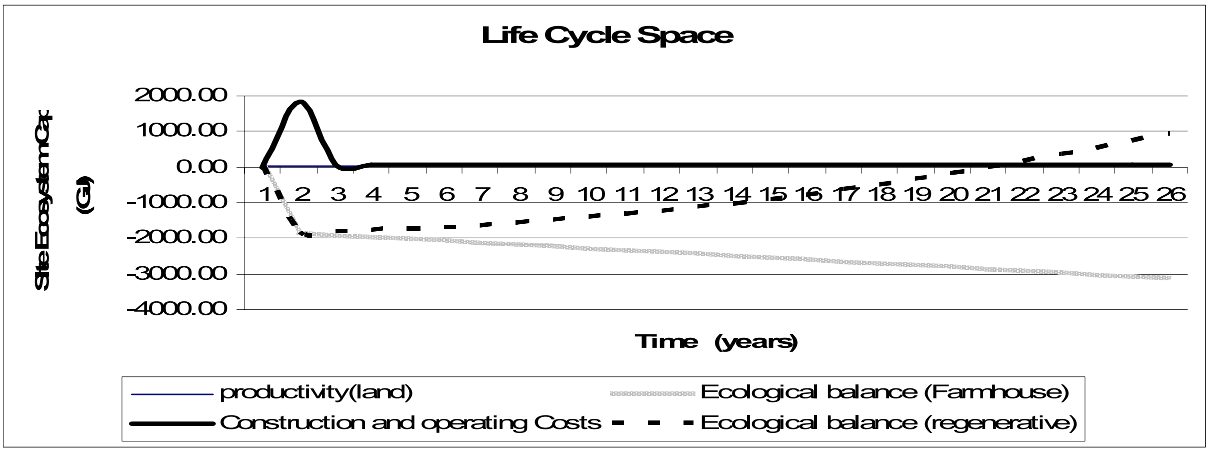

Figure 7: The Ecological proforma for the Farmhouse, and a hypothetical regenerative project: reduced operating costs to within site capacity, increased building energy productivity, and increase land productivity by 50% in year 5 results in a net ecological profit over time.