Quantifying eco-architecture

R. E. Smith
Integrated Technology in Architecture Center, School of Architecture, University of Utah, USA

Abstract

Qualitative methods of evaluation predominate in designing for green building. Although accessible for architects, this paper makes a case for data driven quantification to aid in fostering change in finding a balance between the triple bottom line of sustainability: environment, society and economics. The paper proposes three functionalities that should be considered by the design team, including architects and engineers, in order to develop a unique quantification method and select appropriate tools, including subject, scale and scope. Challenges are discussed and suggestions are proposed for the future of method and tool development for sustainable design processes.
Keywords: quantification, green building, life-cycle assessment, simulation.

1 Introduction

A key factor in quantifying sustainability in design and building includes not only environmental issues, but economic, social and cultural considerations as well [1, 2]. The U.S., and other free market capitalistic societies, as the EPA and Bruntland (1987) suggest, must assess sustainability from the perspective of both natural and human capital [3]. The need for quantifiable data related to sustainable design of buildings is therefore necessary in order to make effective decisions regarding the future of resource use. Data is also necessary to convince decision makers of the need for regulatory changes. Quantification is a key component in order to foster real change in public attitudes and actions with regard to sustainability. In addition, as sustainable practices, including green building, continue to progress in different sectors of the world economy, it will be necessary that an effective balance is found between social, economic and environmental concerns.

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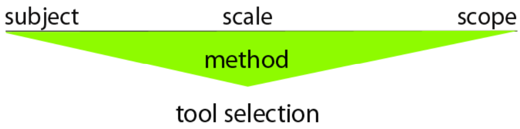

Figure 1: Three functions in developing a method for quantification of sustainability include subject, scale and scope. These together constitute the methodological framework for a project. A tool is then developed or selected based on the methodological approach.

Designers interested in performing a sustainability assessment are often at a loss as to how to begin. Design teams are confronted with a myriad of methods and tools, each carrying potential opportunities and challenges. Each quantification study is unique and requires a strategic critical development of an analysis method. This paper will outline items to consider in developing a method for sustainability quantification during design, the subsequent selection of appropriate quantification tools, and relate the challenges associated therein. The paper will then conclude with suggestions on how design professionals may conceptualize the next generation of quantification tools.

2 Method development

Sustainability quantification includes three general functionalities: Subject, Scale, and Scope (Fig. 1). Identifying these parameters ensures an appropriate development of method and selection of tools to perform a quantification evaluation during design.

2.1 Subject

In looking at the methods for evaluation of sustainability, one must consider the subject under investigation. Designers should target the subject specifically so that no wasted time is spent gathering innocuous data not pertinent to the project at hand. In order to do this, a mission statement and goals need to be outlined so that all who are participating understand from the beginning the intentions of the study. For example, a study to influence legislation for green building regulations may or may not be similar in method as a study to evaluate the environmental performance of a new construction for the owner of the facility. Once the purpose has been defined, all who are involved set the goals and objectives of the project. Often this results in a number of varied subjects that need to be investigated for a given project.

These subjects can be evaluated separately or independently, depending on the parity of the data and whether the data will be assessed comparatively or aggregated. For example, a company considering moving their business because of a lack of space and the desire to invest in a new building are deciding between demolition and build new or remodel an existing building on the site and add on. In order to evaluate the natural and human capital the design team needs to consider not only a comparison of material but also resource data. At first glance new construction consumes much more resources than reusing an existing building. However, upon quantifying the comparison, designers need to take into consideration operational energy and water use, air quality, etc. These additional subjects might point in favour of new construction as the preferred option, depending on the situation.

Green design quantification includes the following subjects of consideration:

- Site: brownfield/greenfield development, erosion control, permeability, soils, proximity to transportation and life sustaining resources, vegetation, habitat disruption, etc.
- Water: underground waterways, water recycling, landscape watering, wastewater treatment, water catchments, water runoff, water use
- Energy: construction energy, operational energy, passive and active systems, renewables
- Materials: embodied energy, local materials, sustainable harvesting and extraction, recycle, reuse
- Air Quality: exterior and interior air quality, toxins, low VOC materials, passive and active ventilation systems

These subjects can be isolated or evaluated holistically. Designers also need to determine what kind of social and economic subjects will be evaluated against these environmental considerations. The green building criteria listed above are all subjects that give purpose to the study. Once the subjects under assessment are established the design team needs to consider the scale of the inquiry.

2.2 Scale

Sustainability covers a range of scales from the macro city, region or world scale to the micro individual building scale. After selecting the subjects under consideration, design teams must break the study into a smaller subject scale. Although not presented herein as such, scale can be performed before the subject selection as well. For example, a building may need evaluation of operational energy, however many factors contribute to the operational energy quantification including: passive and active systems, enclosure definition, fenestration makeup, etc. One might choose to isolate the study and evaluate different enclosure definitions and their impact on the energy quantification study.

These smaller scale studies often are included into a larger aggregate at either the entire energy quantification, entire building, or even folded into a larger planning model. There exist many methods for quantification at the planning scale including cities, regions and even nations, as well as many methods for individual building or component assessment. However, there is a noticeable lack of method available for the in-between (Fig. 2). Macro level studies require less specific data, usually taken from census or publicly available information. Building level assessment data is taken from data sets with known values for materials. An assessment of neighbourhoods for example requires teams to often develop data themselves purposed for the study in question. This points to larger problems of communication between the macro level study and micro level study that will be discussed later.

MACRO	IN-BETWEEN	MICRO
World Continent Country Grouping Nation Region Metro Area City	Neighborhood Voting district Street Development Urban Design Corporation (dispersed) Campus / Cluster	Building Building Component Infrastructure Isolated system

Figure 2: Macro and micro level studies are well supported with data available parsed for their respective scales. So-called “in-between” studies such as a neighbourhood scale required medium level data not readily available requiring evaluators to develop data or use a combination of both macro and micro level data.

2.3 Scope

In addition to subject and scale, design teams need to critically select a scope mechanism. Scope in this context refers to the type of operation that will be performed on the subject and scale of project. The following are a list of scoping operations and their respective descriptions:

2.3.1 Life cycle assessment

Referred to as whole building assessment, LCA is an International Organization for Standardization 14000 environmental standard. An advantage of using the LCA procedures is that LCA can potentially cover a wide variety of impacts not accounted for in other types of studies such as more detailed data concerning the life cycle energy of specific materials, called embodied energy. To calculate embodied energy of material a comprehensive Materials Flow Analysis (MFA) procedure is performed [4]. This evaluates the cradle-to-cradle life cycle of a specific material or system [5]. MFA is encompassed within LCA. Other benefits of utilizing LCA not commonly used in Green Building Assessments should be noted such as human toxicity and acidification.

ISO sections 14040 and 14044 identify 4 phases in order to perform an LCA: 1- goal and scope; 2- life cycle inventory; 3- life cycle impact assessment; and 4- interpretation. The goal and scope of assessing buildings is quantifying the total energy consumption over the life cycle of a facility [6]. The inventory in order to accomplish this goal includes both construction energy, including the embodied energy of materials, the energy of construction, maintenance energy and demolition/recycle energy; and operational energy including HVAC, power and gas to operate the facility. In addition to quantifying the total energy or total environmental impact during a life cycle, LCA also includes an economic and cultural cost benefit evaluation. Although not many tools have been developed, one called Life Cycle Cost Analysis (LCCA) [7] uses the same method but adapts it toward economic analysis.

2.3.2 Performance assessment

This approach uses simulation to evaluate how a city or building will perform with regard to a specific subject if designed in a particular way. For example, a building in design is modelled as a parameterized simulation and tested for thermal gain so that orientation adjustments are made, alternative energies suggested, and different materials determined in the envelope system. The data produced in simulation is can be used within an LCA. Simulations are becoming more and more accurate as verification assessments are performed. Performance assessments can include cost/benefit analysis regarding green building initiatives and operational cost to illustrate return on investment for sustainable building systems. To date, most developed software tools fall under the category of performance assessment in order to quantify sustainable building practices.

2.3.3 Verification assessment

Verification relies upon post occupancy data being gathered concerning the subject in question. If one is evaluating water efficiency, monitors may be installed or data can be gathered from the local water company to evaluate peak and low water usage throughout an annual cycle. Post occupancy studies are the data that feed performance assessment models. An example of how this is occurring can be seen in the related field of seismic vulnerability assessment methods in the U.S. In order to develop accurate designs in buildings for structural performance, engineers continue to gather data from devastations as a result of seismic events across the globe. Scenario events are documented and compared with damage sustained by different types of building construction, structure, and configuration. This data feeds the algorithms in performance models. As with green building, isolated full-scale mock ups may be tested, however no earthquake or performance simulation digital or actual can account for the many variables present in actual practice.

2.3.4 Qualitative assessment

Instead of using data that quantifies energy, carbon, or some other unit of measure that puts environmental impact in terms of hard numbers, qualitative methods use a unique relative point system to measure the potential green quality of a city or building. These systems appear user friendly: environmental scientists, engineers, and specialists within design teams do not have to be the calculators, but the system can be manoeuvred by laypersons. This is deceiving however as it relies upon the interpretation of the user to make sustainable judgments and translate them into representative points. In addition, many green building characteristics are given the same amount of value, but may or may not be equal in environmental impact. There is inherent bias in each system, but the qualitative methods are not flexible in their ability to accept much adaptation in the evaluation.

The scoping operation will vary according to the subject and scale. The scope also varies depending on the condition of existing remodel, adaptive reuse or new construction. For example, if operational energy as a subject and building enclosure as the scale have been selected, one might select a performance assessment that evaluates how the facility will perform once it is constructed. As discussed in the qualitative assessment, metrics vary depending on the method. However, this is true for all the other scoping methods. Environmental impact metrics can be manifest in as many ways as there are methods of evaluation. For example, the industry preference to calculate life cycle energy consumption including construction, operational, and demolition/recycle is MJ/Kg, BTU/Kg or carbon emitted into the atmosphere as a result of energy production measured in CO2. These basic units are also often converted to a number of other metrics.

3 Tool selection

Tools refer to software, spreadsheets, algorithms, and mechanisms for capturing data and evaluating it. Each tool is based on a method or a purpose. Using the right tool is critical to getting an accurate and mathematically complete answer. Tools have multiple functionalities and can serve diverse studies. There are many tools, and rather than being decided by subject, most often they are determined by scale and scope, with many subjects being covered by one tool. To provide a comprehensive list of tools and their functionalities would be difficult. Instead, below are a listing of resources, agencies and organization that continually provide sustainability quantification tools, where design professionals may find resources available.

The U.S. Department of Energy oversees many organizations and teams with funding centres at universities and private companies to develop software tools for purchase or free download for the public [8]. Organizations that fall under the DOE include the Federal Energy Management Program (FEMP), and the National Renewable Energies Laboratory (NREL). Teaming groups include the Pacific Northwest National Laboratory, Carnegie Mellon, Lawrence Berkeley Laboratory and other universities. Software developed by the DOE are varied in their purpose and can be applied to unique situations due to their multifaceted applications. In addition to developing new tools, The Energy Efficiency and Renewable Energy section of the DOE website has catalogued over 341 building software applications for evaluating sustainability in buildings, with many developed outside of DOE oversight [9]. The website includes a directory database with descriptions so design teams may use tools as needed or access links to additional software. The website is updated continually. The website database is catalogued to allow users to query based on subject or scope. Links are offered to the U.S. Green Building Council, which has produced the LEED products (Leadership in Energy and Environmental Design), and the National Institute of Standards of Technology, which developed the BEES program (Building for Environment and Economic Sustainability). The software tools primarily focus on performance measures assessment.

Precedent green building studies are important to both the legacy of information and to design and building practice. Rather than reinvent the process, using relevant or similar existing studies and their findings to develop a custom and more specific method for a given situation is desirable. Design teams on the precedent projects will have more information concerning the day-to-day challenges that are not found in the formal reports or papers. A phone call or email can go a long way to determine how to approach a related assessment study. A report produced by Todd and Fowler provides an up to date listing of studies that establish precedent methods [10]. Many of the precedents discussed by Todd and Fowler have provided background and a purpose to instigate new tool development.

William Rees and co-author Mathis Wackernagel wrote *Our Ecological Footprint: Reducing Human Impact on the Earth* [11]. Since this seminal book Ecological Footprint (EF) analysis has gained in popularity as an environmental impact assessment tool because of the accessibility of its technique and simplicity of interpretation. EF is an accounting method that illustrates the environmental impacts of human consumption and the earth's bio-capacity to accommodate. EF studies are generally at the macro scale including evaluations of nations, regions, states, cities, but can also be used for individual lifestyle evaluations [12]. The EF is calculated in global hectares (gha), an area that is converted to actual area on earth. Ideally, EF accounts for all aspects of consumption of resources for lifestyles per capita. The EF is therefore, a feedback tool to tell us how sustainable we are living within our resources on the planet [13].

Other methods for macro level sustainability quantification exist including the Living Planet Index, Environmental Sustainability Index, and a number of key indicator studies, most of which are based off of the tools described above. They illustrate what elements of everyday living contribute to a more or less environmentally impact. These all rely on a similar goal of the EF studies to render to users how lifestyle impacts environment. Few studies focus on economic or social impacts however, as this has been less important in these models. Tools related to sustainable balance between environment, society and economics have had much more headway at the individual building scale.

Todd and Fowler state,

> "One of the most persistent questions about sustainability design is its cost – does it cost more to build and operate a green building and if so, how much more? How long does it take to recoup these costs in operating savings? Which investments in green design pay back more quickly?" [14]

Todd and Fowler provide a listing of recent studies that provide a precedent for design teams searching for cost models regarding sustainability [14]. These models rely on the cost/benefit of green building in order to justify initial increase in cost compared with traditional construction. In addition to precedents, LEED has developed a cost study that works in tandem with LEED evaluation tools. This measures the first cost (construction capital) impacts of LEED requirements on the design and construction process. The Federal Energy Management Program, under the U.S. DOE, has developed a sustainable cost and performance metric. Carnegie Mellon has produced in collaboration with the U.S. DOE an e-building Investment Decision Support, or e-BIDS for short, which compares cost to energy saving efforts such as day lighting, temperature control, etc. The National Institute of Standards of technology has produced a life cycle cost analysis to ride on top of general LCA analyses. The method developed by Sieglinde Fuller provides more discriminating evidence of the need for verification of cost with traditional LCA analyses for initial and operational investment [15]. These studies focus on the building proper, but do not make a connection to evaluation at the planning scale. Ironically, it is macro level studies that have a much greater impact on changing attitudes with respect to environmental stewardship. Ideally, these costing studies would fold into a larger methodological study that then can feed a planning or policy model.

Although many new precedents, methods and now tools are becoming available, resources focused on social and cultural aspects are not readily available. Social and community tool evaluation is not only the least available, but also the most difficult to develop a method around and quantify. By nature these are qualitative functions. Future environmental studies will need to develop connections to social, behavioural and health sciences in order to devise effective ways of translating these studies to have a much greater social impact. Studies completed to date that have been successful in linking environment to social issues have relied on verification methods. Utilizing post occupancy evaluation through interviews, surveys and other data collection devices common to the social sciences will provide the necessary background to illustrate how green building decisions are impacting human capital: health, culture, and well being.

4 Challenges

The challenges of developing sustainability quantification methods are far reaching. The problems point to the relative immaturity of the field. One of the major difficulties with measuring sustainability is the investigator themselves. Already discussed before, beginning a study without a clear understanding of one's purpose, what one would like to measure, how and at what scale is a recipe for disaster. This is exacerbated because of the lack of training among design professionals in research. For example, in architecture, design is often an intuitive process. Expecting an architect to be able to perform a quantification study in many ways is against the grain of training and practice.

Another challenge to developing and performing a green building assessment is the issue of interoperability of methods and tools. Currently there exist no common systems for sustainability rating. With varying levels of scale, specificity of data and metrics, each method and tool uses its own logic to determine sustainability of a facility proposed or existing. There first needs to be a common agreed upon metric for methodological comparison that thereby software might also be developed to talk to one another. For example, in a recent study performed by the author, the planning level data produced outputs in an EF model that were in hectacres (a metric developed specifically for EF), while the building specific data that fed the EF was in MJ/kg of energy. A conversion process was necessary. The data is also not as detailed in the macro study as in the micro. As opposed to large-scale studies, whose purpose is to provide convincing evidence to state and regional elected officials that might result in smart-growth initiatives or metropolitan environmental policies, micro studies are usually targeted at local decision makers of the built environment including the professional design community of planners, urban designers, and architects to influence neighbourhood design and form. Finding common ground so that diverse scaled studies may be able to support one another and different subjects and scopes can be mutually supportive is necessary for impact.

Although quantification is valuable, it also points to the problem of computation in general - the reliance upon data - whether correct or incorrect. In the event of bad data, the problems are obvious. However, often data driven design also does not give space for the designer to look at a problem qualitatively and intuitively in order to manipulate spatial environments and natural materials to emerge as climatically, socially and culturally responsive solutions. In addition, data in tools are only as good as the algorithms that drive them. These methods are built upon smaller scale studies and verification needs for simulation. Therefore, current buildings are being designed using quantification performance software that is based upon best practices known. As additional data is discovered through verification, the algorithms may change. Aforementioned, in seismic design building assessment models, the algorithms continue to be updated after each scenario event as additional knowledge is gained concerning more effective design.

This is especially true in qualitative measuring methods such as LEED. Armpriest and Haglund report that although the Seattle City Hall was designed to a LEED standard in 2004 it is a poor energy performer [16]. The Seattle Post-Intelligencer wrote, "Seattle's new City hall is an energy hog" on July 5, 2005 [17]. Based on data from the local utility, operating costs due to energy for the new City hall ranged from 15% - 50% higher than for the building it replaced. Granted, the new building has a higher person to space ratio, however the new building is smaller than its predecessor and other design such as extensive glazing and double height spaces have made anticipating the performance difficult. Once commissioning continues through its beginning years, much of the inefficiencies in the environmental controls will hopefully be mitigated. However, in 2005, the utility company report showed that in the summer months, the building performs very well, but suffers in the cold winter and spring. This building is a victim of the sustainability hype that surrounds many cases of new "green" architecture, towns and products in general. Without quantification, relying on qualitative measures for sustainability assessment during and after design may lead to more conscientious owners and designers but not necessarily lead to better buildings. Perhaps the best outcome of this building is the lessons to be learned that can drive revision and development of future LEED and other qualitative methods.

Qualitative systems also have difficulties with inherently heavy-laden bureaucracies. In order to gain credits or evaluate for green building quality, rating systems rely upon a top down imposed system of order. This inherently places bias regarding the special interests of the organization administering the evaluation system. For example, in LEED a point system is used, giving equal weight to parameters that may or may not have as much environment impact with regard to the building at hand. A vernacular building that uses passive methods to heat and cool are not given credit in the point system. The previous example of the Seattle City Hall illustrates that a building may gain a LEED rating but not be truly sustainable from either an environmental, social or economic perspective. In this case, because it is difficult to measure the success of the building socially, it is failing from the perspective of both environment and economics. Larry Scarpa of Pugh + Scarpa, an architecture firm in Los Angeles, stated in a recent lecture on green building, “an energy hog - community loved building is more sustainable than a green - community loathed building” [18].

5 Conclusions

The American Institute of Architects recently published a white paper titled; “Quantifying Sustainability” where three major green building tools used for evaluation was reviewed [19]. Each of these methods is a building rating system, using a qualitative mechanism for scoping. Ironically, the study was commissioned because of a lack of outcome and performance based building evaluations that were occurring leaving sustainability and building still a mystery. The AIA’s goal is to promote these recommendations as the way to reduce carbon emissions as a result of the design and construction industry.

The AIA’s focus on qualitative methods is telling concerning the state of the design profession regarding sustainability assessment. The reality is that although we do need more precise and hard data methods of evaluation for green design in general, these methods also need to be accessible so that users and continual critique and updating of the methods can be done on a regular basis. For a whole building assessment, LCA is the most thorough and in depth, using many other scope mechanisms described above as part of its methods. However, data does not always exist or is available to do such an evaluation. Rather than focusing on data, a focus on people and process seem to hold the most promise to achieving the goals of a balance of environment, society and economics in order that the green building quantification process will be well established as data becomes better in the future.

The National Renewable Energy Laboratory (NREL) performed an in-depth case study of six high performing buildings [20]. The study has spawned numerous additional studies and metrics that have taken cues from this precedent. The research focused on understanding the culture of practice of architecture and planning that aided the process of sustainable design, construction and more specifically, high performing energy buildings. It found that the greatest contributors to realizing high performing architecture were communication among partners with owner driven goals and an integrated approach to project delivery. Integration in the process of design and construction delivery is the key to reaching green building objectives and goals whether they are high performing architecture or some other aspect of green building.

Although changes will continue to refine the tools and methods for environmental analysis, real success is not uncovered in technique, but will be found when a balance is struck in environment, society and economics for a sustainable system. This can only be realized as we work toward quantification. However, as this article suggests, the development of such methods requires an integrated collaborative. Integration, as in so many industries before construction, leads to innovation [21]. This paper has referred to the entity performing green building quantification analysis as "designers". This is to suggest that integrated teams involved in design in which sustainable decisions are made can use a process of subject, scale, and scope to determine a method and finally, the tools for evaluation for a given project. These players may be as traditional as architects and engineers, but in an integrated process also include owners, subcontractors, and commission agents/facility managers. Capitalizing on the skills of all involved in a building architectural project, sustainability quantification during the design phase will have much more depth, critical thought, and the end building design will be much more innovative.

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