A FRAMEWORK TO IDENTIFY OPPORTUNITIES FOR ICT SUPPORT WHEN IMPLEMENTING SUSTAINABLE DESIGN STANDARDS

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EDITOR: T. El-Diraby

Annie Andrews, Graduate Student
Dept. of Civil Engineering, University of New Brunswick
email: annie.andrews@unb.ca

Jeff H. Rankin, Associate Professor
and M. Patrick Gillin Chair in Construction Engineering and Management
Dept. of Civil Engineering, University of New-Brunswick
email: rankin@unb.ca

Lloyd M. Waugh, Professor
Dept. of Civil Engineering, University of New-Brunswick
email: waugh@unb.ca

SUMMARY: *Sustainable construction advocates efficient use of resources during the design, construction and operation phases for high performance, energy efficient buildings to minimize environmental impacts. This is accomplished through the application of comprehensive management strategies, whose direct effect is the creation of healthy and productive working environments for building occupants. In this paper, Information and Communications Technology (ICT) is addressed and it is argued that the use and development of ICT is essential for the construction industry, particularly in the area of adoption of standards. The discussion has a focus on the Leadership in Energy and Environmental Design (LEED) rating system. A case study has been documented to determine the impact of applying the LEED rating system beginning at project initiation. This was followed by a series of analyses of the case to identify opportunities for ICT support. The primary aim of the research described in this paper is to present the proposed framework which can be used to analyse the potential of applying ICT for the implementation of new standards in the construction industry.*

KEYWORDS: *Sustainable construction, LEED, information and communication technologies, integrated design.*

1. INTRODUCTION

Sustainable construction refers to those construction practices that enable the elimination of negative impacts on the environment and its occupants. Buildings are major consumers of natural resources and are therefore a natural focus when emphasizing the need to practice and make mandatory sustainable construction (Horman et al., 2005). For example, in United States, the acceptance of sustainable building concepts was originally dominated by government agencies such as the General Services Administration, the army and NASA (2003) and is now rapidly being driven by both the public sector (e.g., educational systems) and private sectors (e.g., multi-family housing, commercial office centers). On a general note, advantages of sustainable construction for buildings include healthier interior spaces, better natural lighting and greater flexibility in space layouts, all of which have a positive impact on occupant performance and satisfaction.

It has been established that a design based on sustainable construction is successful because of the integrated design approach (Riley et al., 2004). This approach is implemented from project initialization through to the end of construction, commissioning and operation. The integrated design is undertaken in order to assess the impact that a design decision in one part of the building has on all other parts, in an attempt to optimize decisions over the entire life cycle of the whole facility (Horman et al., 2004). This differs from conventional practices, as there is greater investment of design resources such as time, research for information and brainstorming.

The LEED (Leadership for Energy and Environmental Design) rating system is a framework that facilitates a streamlined implementation of sustainable construction principles which is available in both paper and electronic formats (USGBC, 2003a). The view presented in this paper is that effective implementation of the LEED process presents unique opportunities for the application of Information and Communication Technologies (ICT) in the construction industry. The concepts developed should be of interest to researchers and leading edge practitioners in the area of sustainable construction.

The scope of this paper includes a brief outline of the general research being conducted in the field of sustainable construction. A case study is then presented, which serves as the input to describe a framework that can be used to identify opportunities for ICT support for projects implementing sustainable design standards. The framework consists of three components. They are: a) an issue analysis b) a process analysis, and c) tool analysis of the project. The purpose of the framework is to analyse the potential of applying ICT for the implementation of new standards in the construction industry.

2. BACKGROUND

In support of the concept of sustainable construction adopted for this paper, this section discusses related research on the general topic of sustainability, integrated approaches, and adoption of ICT technology. The final subsection, entitled "points of departure," summarizes the relevance of these concepts to the subsequent sections.

2.1 Studies on sustainability

The construction industry suffers from poor project performance and dissatisfied parties as identified by Latham (1994) and Egan (1998). Sustainable construction optimizes the use of resources while minimizing any untoward impact on the environment. The essence of optimal usage is closely linked to the philosophy of lean design which is being applied to construction processes, aimed at minimizing waste and also reducing the gap between design and construction (Jorgensen et al. 2004). For example, Riley et al. (2005) have been conducting research examining the role of design-build mechanical contractors in order to produce high performance, sustainable buildings. This has been attributed to the inadequacy of construction processes. The following subsections focus on specific themes within sustainability research.

2.1.1 Drivers of sustainable design

According to the USGBC, buildings in the United States account for 36 percent of total energy use, 65 percent of electricity consumption, 30 percent of greenhouse gas emissions, 30 percent of raw materials use, 30 percent of waste output (136 million tons annually) and 12 percent of potable water consumption (USGBC, 2003b).

The three main types of benefits associated with sustainable construction are environmental, economic, and health and community benefits. Environmental benefits include improved air and water quality, reduced energy and water consumption, and reduced waste disposal. Economic benefits include reduced operating costs, reduced maintenance costs, and increased revenue (sale price or rent). Health and community benefits include enhanced occupant comfort and health, reduced absenteeism and turnover rate, and reduced liabilities. (USGBC, 2003b, USGBC, 2004)

Green building policies are now being adopted and implemented by governmental agencies from the national to the local level, as well as by nonprofit organizations and major multi-national corporations simply because it makes economic sense and has a multitude of peripheral benefits that diverse entities find attractive (CentreViews, 2004). Major corporations, including Wal-Mart and Toyota, are building according to sustainable design principles to save on energy and water costs. Sustainable building design can be used to reflect or enhance corporate culture in the eyes of staff and customers; it may boost a company's image and support its environmental or "good citizen" policies (Horman et al 2005). This ties in well with the public relations benefits of certification. Often owners occupying buildings appreciate this fact more so than speculative developers. Getting certified may have promotional value, but the potential marketing and public relations benefits are difficult to measure.

2.1.2 Beyond life cycle costs

Castillo and Chung (2004) assert that the lifecycle cost of a building includes initial design and construction costs and ongoing expenses such as maintenance, energy, and repair costs. However, quantifying the benefits of sustainable construction from a cost perspective must go beyond these typical life cycle costs and include usage costs, capturing all stakeholder costs. Fig. 1 is a basic representation of the relative value of these costs based on various studies such as that of Yates (2001). The usage costs, a significant portion of which are employee costs, are in the order of 200 times higher in relation to first costs (design and construction), whereas operating costs are in the order of five times higher than these first costs. From the perspective of the user or tenant of a building this is the central concept from a financial perspective.

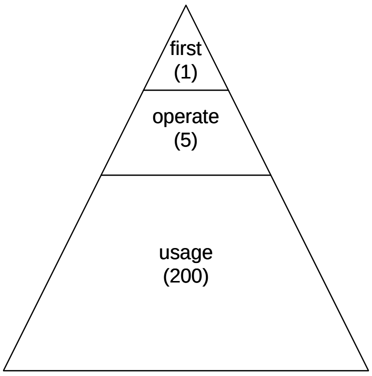

FIG. 1: Representation of all stakeholder costs.

2.1.3 A barrier to sustainability

There is one main barrier associated with sustainable construction. Buildings created following sustainable construction principles typically have a 2 to 7 percent higher initial cost than ordinary buildings. As the payback period for these higher costs varies from project to project, a life cycle cost analysis should be completed to account for reduced operating costs and increased productivity. However, this analysis is rarely done (Castillo and Chung, 2004). Although the benefits of sustainable construction appear to considerably outweigh this initial cost disadvantage, there are several impediments to implementation that are slowing the adoption rate. These impediments include: a) changing the way the industry builds; b) implementing sustainability and still meeting the owner's needs and cost requirements; c) removing the resistance of the construction industry to change; d) eliciting action, support, and involvement by all participants in the supply chain, and e) reducing the lack of relevant skills and knowledge. Until life cycle analysis becomes standard practice, integrated design will continue to be considered one reason why adhering to sustainable practices can cost more than conventional construction.

2.2 Integrated approaches

Laborde and Sanvido (1994) are of the opinion that some of the impediments to innovation are the first costs, delayed returns and rigid government rules and policies. The current trend in construction practices demands new technologies and innovation and hence construction companies who do not keep up with the advancing technology will fall behind. Therefore it is risky not to be innovative. Process and product innovation are discussed as well as several existing models of innovation. On this basis, a new process of implementing innovation is proposed and applied to small and large contractors. The new model is a four step process consisting of: identification, evaluation, implementation and feedback.

There are diverse forms of knowledge and reasoning involved in all phases of the lifecycle of a project. It has been established that knowledge generated in one phase will be useful in proceeding phases and vice-versa. Downstream data is that which is generated during the earlier phases to be used in later phases and upstream data that is generated during the later phases to be used in earlier phases. Downstream knowledge refers to lessons that can be used for better decision making in later phases. Upstream knowledge refers to lessons that can be used for better decision making in earlier phases. (Fischer et al., 1998)

The purpose of capturing past lessons is to be able to address changes proactively or avoid changes altogether thereby reducing the gap between the end result and the intended result. Research in the area of change-management offers justification for this. The major cost due to change is the cost of rework, which typically amounts to 10-15 percent of a contract value, and change leads to time overruns, cost overruns and quality deviations, which reinforces the fact that mistakes should not be repeated (Brurati et al., 1992, Love and Li, 2000).

Project information can be understood as tacit and explicit knowledge as indicated by the original works of Polanyi (1967). Tacit knowledge is highly personalized and hard to formalize, making it difficult to share with others while explicit knowledge is transmittable and can be found in rules, policies, procedures, specifications and documents. Another line of thought is that knowledge is context specific and therefore the context should also be captured. (Senaratne et al., 2004)

Tatum (2005) makes reference to nine shared activities that overlap during the different phases of project development. Historically, this was seen in large complex industrial projects, but its relevance is more pronounced in today's construction scenario. Emphasis is placed on providing technical support to all types of constructed facilities and on implementing integrated planning that will anticipate and avoid field problems. Reference is also made to the benefits of using computer tools early in the project. Formulating an orderly sequence for the process is however left to the reader.

Reed and Gordon (2000) presents the most comprehensive detailing of the process to date, tying community, natural and economic systems together as the key to sustainable design. They present a workable and cost justifiable model for initiating and implementing integrated design which has an enormous positive impact on the environment and the design and procurement processes.This was undertaken as a response to the reality of specialisation, isolated decision making, conventional practices and the speed of building process which conspire to prevent achievable optimisations of the systems engaged when buildings are produced. Riley et al. (2004) reinforces the research of Reed and Gordon by presenting a process model for high performance buildings called the building design process model. Riley et al. describe a "cross functional design process map" both for a traditional and an integrated project delivery with the aim of improving the processes entailed within the design and construction phase.

2.3 Adoption of ICT technology

Technological change is a critical factor that determines growth in the construction industry yet rates of adoption are notoriously low. This may partially arise because the industry is labor intensive compared with manufacturing industries in which production is almost fully automated. Many attribute this difference to the lack of investment in research and development. On the other hand, Jorgensen et al. (2004) make reference to economist Ball's argument claiming that the construction industry is not backward, but is merely different compared to other industries, as it is faced with a constant challenge, that being the separation of design and construction cultures. Integration efforts are influenced by political, economic, social and cultural concerns, but are more significant when supported at the government level. It is important to be aware of not only the technical and contractual organization of the project, but the entire context of the business, its market, stakeholders and the society at large. (Jorgensen et al. 2004)

Teicholz et al. (1994) propose the use of a shared object oriented project model as the basis for integration and networking technology as the communication links between project participants and individual applications. They have suggested technology transfer from mechanical design and have outlined a framework that suits a facility development process. Concurrent design has been suggested here by them as the apt solution to poor coordination of paper based design efforts. Several computer integrated construction (CIC) technologies are discussed which include relational databases, artificial intelligence applications, dynamic simulation and robotics. They go on to describe a process flow diagram and piping and instrumentation diagrams for an entire plant and identify areas where CIC technologies can be applied.

Kagioglou et al. (2000) proposed an IT enabled document system called the "legacy archive" that will record and review project information at every phase of the project since knowledge is identified as the key resource. Information technology has made its way into the scene of sustainability, in the form of assessment tools.

2.4 Points of departure

In summary, there is growing momentum in both the public and private sectors for more sustainable approaches to buildings. This momentum arises from the need to reduce raw materials, water, and energy use, as well as waste and greenhouse gas output. However, even more important than mitigating these negative impacts is the potential of amplifying the positive impacts of occupant satisfaction and performance. An essential principle of sustainable construction is the use of a more integrated team who consider all aspects of the building from cradle to grave.

The key barriers to an integrated approach are slightly higher first costs and a lack of ICT tools to support such activities. Although fundamental technologies exist, applications are not readily available, a track record of which tools to use is not evident, and processes for identifying them are not established. The authors have taken up process innovation as the first step to minimizing problems and enhance its use with the introduction of Information and Communication Technology. This extends from the studies on innovation by Laborde and Sanvido (1994).

Although Reed and Gordon (2000) and Riley et al. (2004) refer to the use of computer tools and information technology for improvement in the process, no specific examples are offered through out their discussion. The research conducted at the University of New Brunswick is an extension of the process model development in which the design and construction processes for LEED projects are modeled to identify opportunities for Information and Communication Technology (ICT) support.

Concurrent design has not been adopted as a solution for poor co-ordination by paper based design efforts as proposed by Teicholz and Fischer (1994) since concurrent design is conceptually similar to fast tracking a project which raise concerns in LEED projects. The LEED rating system is point based, limiting simultaneous construction and design development as it affects the estimation of points.

Laborde and Sanvido (1994) state that adhering to conventional practices and not being innovative will lead firms to business failure. In the context of sustainable construction, industry practitioners seem to be driven towards adopting LEED standards out of a competitive necessity. Large corporations have been setting examples to enforce this widespread change. However, this widespread adoption of a relatively new standard can be supported with appropriate ICT and can facilitate increased rates of adoption.

The ability to learn from the past is essential in order to improve the adoption process as suggested under knowledge reusability. Moreover, an integrated team approach, encouraged by LEED introduces a vast amount of tacit knowledge that is often more important than general project information which is explicit and needs to be captured. These aspects increase the need for the inclusion of ICT tools in the design and construction of LEED projects. The research discussed in this paper aims to refine the design and construction process for LEED, processes which will be aided by ICT tools so as to take advantage of benefits of integrated design at the inception of a project.

3. CASE STUDY

The new district office building of the New Brunswick Department of Natural Resources (NBDNR), planned for the city of Bathurst, was designed to meet LEED requirements. The project was initially registered with the US Green Building Council (USGBC) in order to access and utilize the LEED tools (e.g., reference guide, templates and calculator, and credit interpretation rulings) and was then transferred from the USGBC registered projects to the Canada Green Building Council (CaGBC). Upon completion of construction, the project will be submitted to CaGBC for certification as a LEED silver or bronze building. The data collection phase of the case study began as the project entered the detailed design stage and ended as the project neared completion of the detailed design, although information was collected for all stages of the project. The facility entered operation in the end of June 2005.

3.1 Project brief

The NBDNR building was designed as a one-storey building with an area of 585 square metres, providing occupancy for 22 employees consisting of forest rangers, wardens and support staff. The functions of NBDNR are sustainable forestry management, protection of fish and wildlife population and also fire protection for both crown and private lands. The new building is detached from the existing headquarters building and is composed of an office wing oriented perpendicular to the Bathurst-St. Quentin Road and a support wing oriented to the West of the new office wing. Fig. 2 shows the proposed site and building with its access roads and site entry is an aerial view that was provided by the New Brunswick Department of Supply and Services (NBDSS) who were the designers for the project.

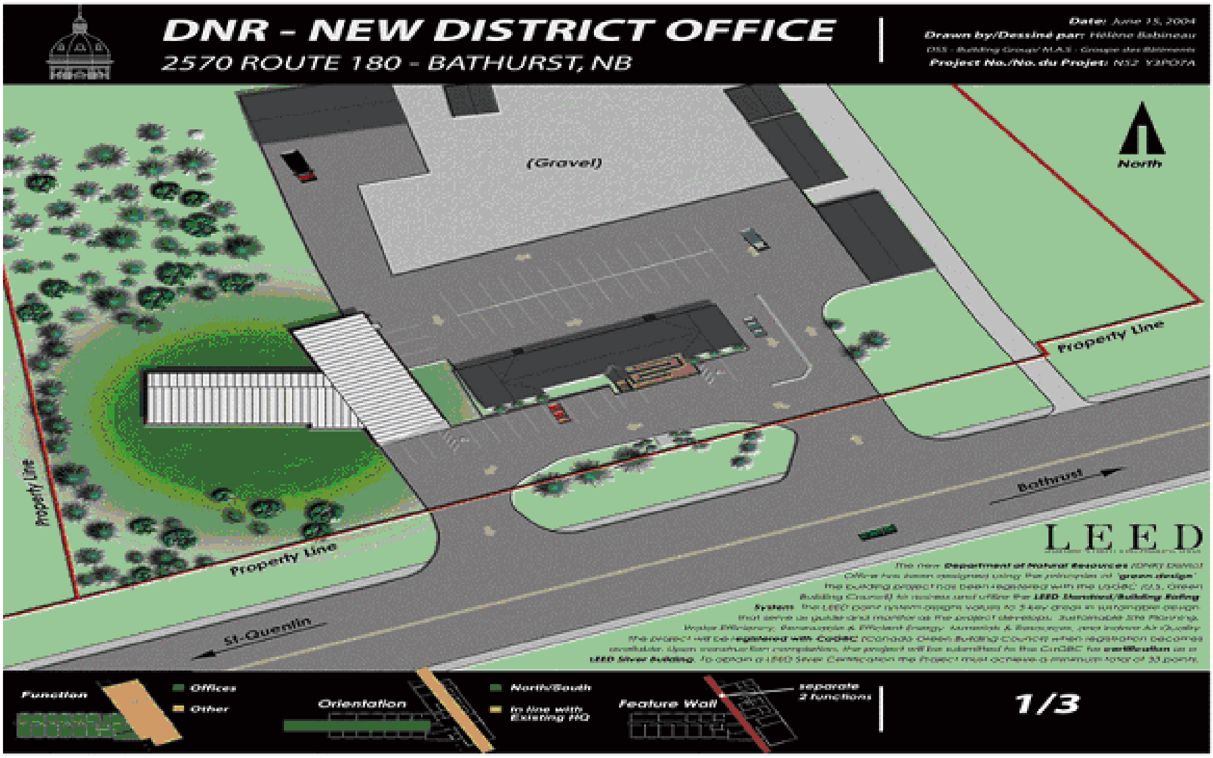

FIG. 2: Site plan of the proposed NBDNR district office at Bathurst.

3.2 Data collection and documentation

The project was chosen by NBDSS to be a pilot LEED project. As it was of small scale, tackling the LEED process and gaining the experience was more important than maintaining extensive records. The record keeping was similar to a conventional project. To collect information on the time spent in the design phase for this project an issue analysis was conducted. Data was captured from: 1) minutes of meetings, 2) retrieval from memory, and 3) approximate dates and milestones. Interviews were used as the mode of eliciting information from the designers in 2) and 3).

A questionnaire was developed in order to identify major milestones that were achieved and this was used in interviews that were conducted with eight participants of the project. The information collected with the questionnaire interviews was used to identify: an accurate description of the work sequence, the meetings held, the purposes of these meetings, the work scheme and deadlines; how much of the work was successfully completed according to plan and if not, the reasons for it; what issues arose during the entire period that may or may not have led to changes in the initial work scheme; and finally, the general impact felt by the project participants and the community as a result.

The documentation process included compilation of information collected from interviews, which were chronologically arranged. Information was arranged under the sections: milestones, issues and impacts. The milestones were compiled according to the phases of the work.

3.3 Project participants

Six of those interviewed were NBDSS employees. The interaction of all eight participants was observed in order to define the functional structure of the organisation. NBDSS championed the design phase while they also took responsibility for building the project defined by the bid documents (specifications, drawings and the addenda) as the contract administrator. The general contractor was not involved in the design and tender phase and since the tender was administered through the design-bid-construct method, the contractor was not involved until the construction contract was awarded.

4. ISSUE ANALYSIS

The first step in the analyses framework is the issue analysis in which issues are identified and their impacts on the project assessed. According to the project designers, this exercise elicited significant information which would have otherwise been lost. Issues were broken down into problems and resolutions for a clearer understanding. It was observed that almost all of the issues arose during the design phase. These issues were studied by comparing it against the baseline information provided within the LEED Version 2.1 Reference Guide of the USGBC. These issues impacted the project and the areas of impact were drawn from the knowledge areas of the Guide to the Project Management Body of Knowledge (PMI STANDARD, 2000). Table 1 lists issues that arose in the design phase. Details of issues A and B are explained below as an example of findings and of the process followed.

TABLE 1: List of issues.

Issue – A	Siting the building	Issue – F	Clerestory fenestration (height of the feature wall)
Issue – B	Choice of glazing	Issue – G	Feature wall
Issue – C	Choice of HVAC systems	Issue – H	Rain water harvesting/storm water
Issue – D	Insulation levels	Issue – I	Installation of wind turbine
Issue – E	Height of the ceiling		

4.1 Issue A: siting the building

Table 2 captures the details of Issue A. The unanimous resolution to this problem was Option 3. Issue A was one in which the aspect of site familiarity and understanding played an equal role as that of design implications. Therefore, this issue was addressed not only by the designers, but also the user representatives. This resulted in the generation of more than one option for the resolution process.

TABLE 2: Options for issue A.

Option 1	**Option 2**	**Option 3**
Tear down the old DNR building and the adjoining 4-bay garage and put up a new building in the space made available.	Site and attach the new building to the parking lot side (North) of the existing DNR HQ office.	Have a new free standing, slab on grade building located close to the HQ building. NBDNR advised that traffic patterns could be modified so the new building could be located adjacent to the existing HQ.
Expected Result: a) New site area is not disturbed. b) Increase in cost due to demolition. c) Loss of the 4-bay garage. d) Additional cost to build a new garage.	Expected Result: a) The first floor of the new building would have to be 1.22m (4 ft) off grade to match the existing floor level of the HQ building. b) Increase in cost due to entry level steps and barrier free access.	Expected Result: a) No increase in cost from the initial estimate. b) No demolition and minimal site disturbance. c) The position of the new building would give the site a better visual impact. d) Public access from highway face of building. e) Barrier free access. f) Existing west driveway paving could be used to accommodate ten public parking spaces for the office.

4.2 Issue B: choice of glazing

Typically, the choice of glazing for a wood frame building with batt insulation would be double-glazing. However, to optimize energy performance it was decided to evaluate energy efficient window assemblies. Window assemblies with triple glazing, tinted glass, opaque media, gas-filled and coated glass were evaluated. As part of the resolution process, energy simulations, daylighting analysis and cost comparisons were conducted. This resulted in the selection of double glazed, gas filled low ‘e’ window assemblies. Also larger window area for every unit was decided upon, to let in more daylight.

Issue B had technical implications at the outset and hence needed to be tackled at the technical level. User representatives were not involved during the problem analysis or resolution process of this particular issue. The nature of Issue B is quite different from Issue A, hence a different process and participants is appropriate (the form of problem solving follows its function).

4.3 Scoring of impacts

Fig. 3 contains a set of rows and columns capturing five dimensions in each cell. Every cell has been assigned: 1) a rank, which is row specific, 2) an impact effect indicator, 3) an impact type, both of which are cell specific, 4) a phase, and 5) a problem or resolution that comes under an issue, both of which are column specific. The figure legend provides details of the five dimensions. The ranks are in descending order of importance, the highest being 1 and the lowest being 4. The impact types are scope (indicated by horizontal and vertical line mesh shading), cost (indicated by diagonal line shading), quality (indicated by the diagonal mesh shading) and time (indicated by vertical line shading). The impact effect indicators are '+' which denotes an increase in the designated impact type, '-' which denotes a decrease, '?' denotes an unknown, and '0' which denotes a neutral impact.

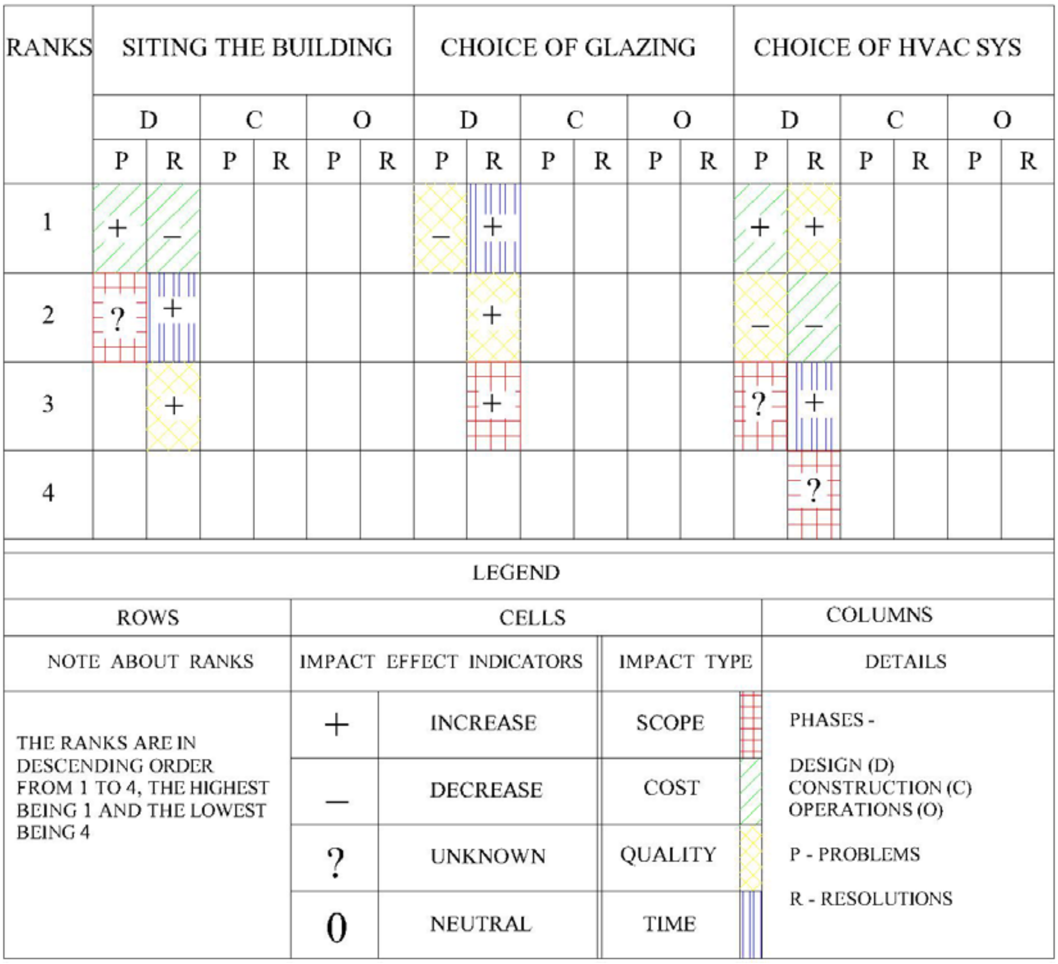

FIG.3: Scoring of impacts

For example, Issue A 'Siting the building' as described above has a problem (P) and a resolution (R). The problem has its first rank (greatest) impact on cost (diagonal line shading). A '+' sign indicates that the problem, if not addressed, would result in an increase in cost. The problem has a second rank impact on scope (horizontal and vertical mesh shading), although the total scope effect on the facility cannot be gauged ('?'). The selected resolution is implemented in the design phase and primarily resulted in a decreased (-) cost (diagonal shading), which secondarily required an increased (+) amount of time (vertical line shading) and thirdly increased (+) quality (diagonal mesh shading).

4.4 Preliminary results

The graphical method employed for the issue analysis was useful in capturing the details of each individual impact as well as an overall perspective of the project (Andrews et al., 2005). The preliminary results drawn from the issue analysis conducted on the case study were:

a) NBDSS came to the consensus that there was an extra 25 percent invested in design time. They attributed this high premium to the lack of familiarity with the LEED process and the extensive literature search that they had to conduct to optimise their design solutions, as well as the demand for intensive teamwork. This led to the conclusion that there was a need to streamline the design and construction process of LEED projects.

b) The designers also felt that a lot of time and effort went into obtaining relevant information regarding the materials and resources category of the LEED rating system. This seemed much harder to tackle due to the lack of a materials database and a specialty contractor database. This finding validated the need for the construction industry to address the lack of databases in the suggested areas.

c) Lastly, the designers gained confidence that substantial savings will be reaped from all six LEED categories and it will begin to pay off after the operations phase commences. This conclusion validated the incorporation of LEED within the design and construction process and signified the requirement for project teams to plan early in an integrated fashion.

5. PROCESS ANALYSIS

The next step to identifying opportunities for improvement (i.e., the next step in the framework) is a detailed investigation of the processes in the case study project. For the NBDNR case study, the design and construction processes of three modes of operation were modeled to facilitate comparisons. The three models were based on a conventional project, the NBDNR project and a proposed integrated LEED project. The conventional project processes were modeled as a baseline for the NBDNR processes. The NBDNR project processes were modeled in order to learn as much as possible from the case study. These two models were used as context for the proposed integrated LEED processes. Three important observations made during the comparisons of the three models were: 1) the change in the number of steps during preliminary design (five steps for conventional, eleven for NBDNR, and eight for the proposed), 2) the preliminary design phase entailed the processes that offered the greatest number of opportunities for ICT support, and 3) the construction and commissioning phases are not markedly different from each other with respect to the steps undertaken, except that the steps differ in the content being discussed. The first two observations support the concept of implementing an integrated design approach early on in the project. The remainder of this section focuses on the preliminary design phase of the proposed integrated LEED approach.

The roles of participants are investigated to assess their contribution to the project. Table 3 defines terms for the participants, and the groups of participants, of the proposed integrated LEED approach as well as their functional responsibilities.

TABLE 3: Participants in the proposed integrated LEED approach

Participants		Descriptions
a.	Owner	The participant who is making the financial investment is referred to as the owner. The terms owner and client will be used interchangeably.
b.	Designer	The participant who is instrumental in bringing life to the project by virtue of administrative, creative and technical input is referred to as the designer. This is often the architect who leads the design phase.
c.	Technical specialists	Technical specialists are those participants who offer consultation services to the project e.g. electrical design consultant, mechanical design consultant, structural design consultant and the like. In the proposed design process, contractor is also being referred to as a technical specialist for financial transactions and schedule implications
d.	Users	The end users of the facility.
e.	Regulatory bodies	The concerned body that is in charge of the verification of building drawings and the issuance of permit.
f.	Contractor	The technical specialist who executes the project design and temporarily invests the finance for construction, on behalf of the owner.
g.	Integrated team (a+b+c+d)	The integrated team comprises of the owner, designer, technical specialists and the users.
h.	Project team (a+b+c)	The integrated team without the users is referred to as project team.

A project is assumed to have five phases namely: feasibility, preliminary design, detailed design, construction and commissioning. Each of these is composed of several steps or processes which can be further decomposed into sub-processes. Processes and sub-processes are undertaken by the participants with or without the help of ICT tools. Although a full analysis of all processes for appropriate ICT was conducted, for illustration purposes, the only project phase that is extended in this paper is the preliminary design phase.

The proposed integrated LEED approach for preliminary design is presented as an activity diagram in Fig. 4. An activity diagram is a Unified Modelling Language (UML) diagram that captures dynamic behaviour (activity oriented) and essentially shows the actual flow of events during a particular process. The activity diagram is composed of action states (which are round-cornered rectangles representing the processes) and control flows (which are arrows representing the sequence of these processes). The diagram also includes yes or no decisions (diamond shapes), forks (when a process divides into two or more processes) and joins (when two or more processes merge into a single process). (Filey et al., 2002)

The project designers were of the opinion that this modeling process was useful in bringing out the shortcomings in their approach to a sustainable type project. This revealed opportunities for improvement that would significantly improve the process in subsequent project undertakings.

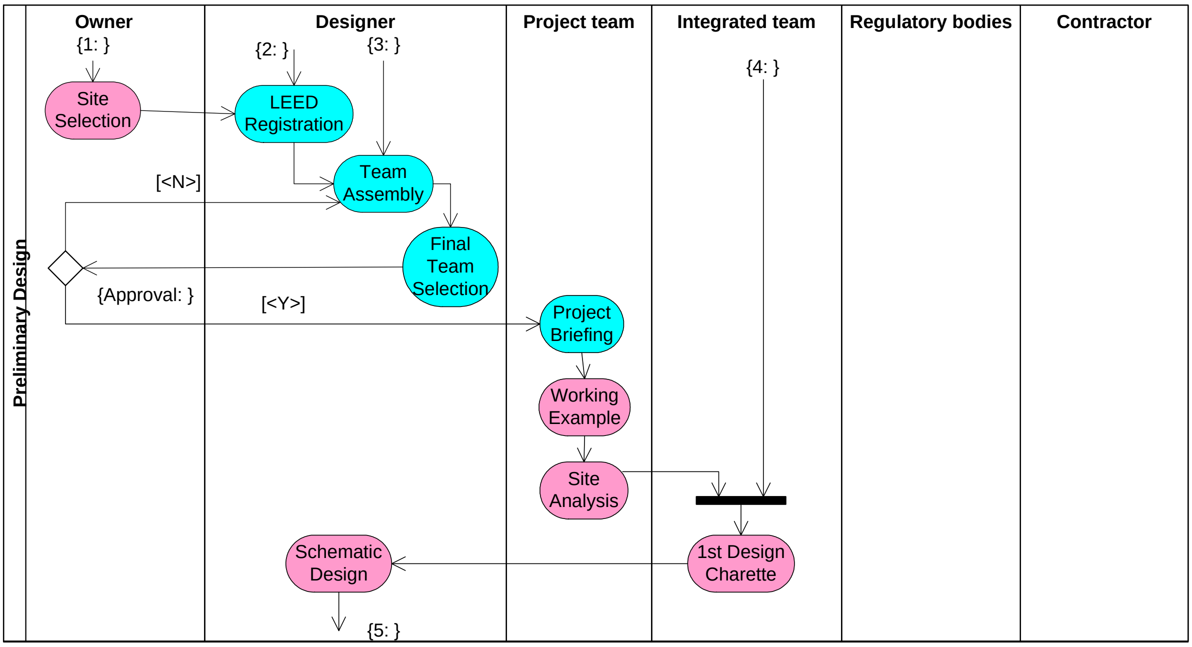

FIG. 4: Activity diagram of preliminary design phase.

5.1 Administrative processes

The processes described in this section are from the preliminary design phase and are those grouped as administrative. These are processes that are not highly technical in nature and do not normally involve the integrated team. Each of these administrative processes is represented as light blue colored action states in Fig. 4.

5.1.1 LEED registration

The first step towards obtaining LEED certification is registration. Projects must be registered with the USGBC in order to establish contact between the project and the USGBC. This also allows them to receive continual updates on the status of the LEED application and also updates on the LEED building rating system. Once registered, the project is referred to as a LEED registered project.

5.1.2 Team assembly

LEED advocates an integrated design concept that requires that an integrated team be formed at the initial stages of a project. Typically a project team will include an architect, an electrical engineer, a mechanical engineer, a structural engineer and a civil engineer. As the project complexity increases, it requires the input from other disciplines as well. Neuferts Standards or Time Saver Standards are typical references for the technical requirements of any building type. This information will help to finalize the different disciplines required on the project team. Recent studies have shown that it is not only advantageous, but also critical that the contractor be involved in the upstream phase of the project (Riley et al., 2003). For financial and schedule questions the contractor is also a technical specialist. Although a list of general contractors can be obtained from local industry associations, it is essential that a current listing of general contractors and technical specialists classified by discipline and location be maintained. In addition to the above information, a request for qualifications (RFQ) may be requested in order to help the decision making process. This is the first round of assembling a team.

5.1.3 Final team selection

There are two stages in the final team selection process. In the first stage a copy of the project design brief and a letter soliciting their participation is sent to the technical specialists selected in the first round. A time period for notification is specified within which interested parties should respond to the client and consultant. The second stage is when interested parties are then sent a request for proposals (RFP). A time period must be specified within which the RFP should be submitted and this will form the basis for selection. The selected technical specialists will later be informed of an official meeting with the rest of the team. It is important to select a project champion who should ideally be a LEED accredited professional (LAP).

5.1.4 Project briefing

The project team should be briefed about the project, client requirements and the LEED rating system that will be used. Ongoing updating with the USGBC or CaGBC, whichever is applicable, is essential to keep abreast of the latest LEED developments. These briefings are ideally undertaken by the LAP who may be part of the team or act as an external consultant to the project team.

5.2 Design processes

The remaining processes in the preliminary design phase are design processes. These are processes that contribute directly to the development of the design through the completion of design steps (e.g., site selection) or collection of relevant information (e.g., working example) and are highlighted in Fig. 4 as light pink colored action states.

5.2.1 Site selection

Identification and selection of the site is a time consuming process. Sites considered for building construction are broadly divided into two categories, state owned and privately owned, and these are further classified according to zone and use regulations. This step is essential if the client has not yet determined a site. The LEED rating system encourages the use of previously used land, which matches the concept of minimizing the impact on the environment. However, previously used land could come with soil conditions that may or may not require site remediation procedures. This trade-off has to be justified within the project budget. The selection of the site will be based on, but is not limited to, the following factors: area of land available, cost of the land, adjoining land, neighborhood, building and zoning regulations, and existing structures on the site if any.

5.2.2 Working example

An appropriate facility resembling the proposed project in terms of functionality and character is now selected for as a working example. This is helpful as it aids the project team to visually comprehend all the required spaces in three dimensions. It also makes it easier to relate to the design brief and the information gathered on LEED.

5.2.3 Site analysis

A thorough site analysis (just as in any design phase on a conventional project) should be undertaken in order to maximize the opportunities for good design. This is a very important step in the process of design development as it offers several avenues to make the design cost-effective from the LEED certification perspective. Some of the main items to be assessed are: terrain and topography of the site, sun and wind factors, soil conditions, slope of the site, water table, drainage, utilities, foundation type of adjoining structures if any, vegetation, access from roads, highways etc., as well as compliance to standards as stipulated by the LEED Reference Guide.

5.2.4 First design charette

A charette is an intense effort to solve any design problem within a limited time. From a creative standpoint, a charette can be divided into three portions; listen, envision or brainstorm, and draw fast. A charette works best in a collaborative atmosphere and is ideal for LEED design. All the project stakeholders (integrated team as defined in Table 3) are required to attend the first design charette. At this stage a project briefing has previously been completed, the functional program, which is a refined version of the requirements analysis, is discussed and the site analysis is completed as a preceding process. There is sufficient information gathered at this point for a comprehensive discussion. The preliminary design proposals that are contained within the RFP's are made available for review by all project participants much ahead of the first design charette and an open discussion is arranged.

The preliminary design for every discipline involved is presented by the designer in charge and the platform is open to ideas. Intensive brainstorming takes place which will result in ideas that need to be documented. Some key objectives for this charette are: refining the design requirements, project schedule, work breakdown structure, and budget allocation; clarifying the scope of work under each discipline; ensuring compliance with codes and standards; determining achievable LEED points and method of achieving them.

5.2.5 Schematic design

The designer will now prepare a schematic design based on the information to date. Conceptual information will support sketch-level detail for plans, elevations and sections of the building and the site layout. The site layout will be comprehensive, detailing road layout, parking facilities (if any), support structures, building footprint and as well as other details that were included in the site analysis stage.

6. TOOL ANALYSIS

The final step in the analyses framework is the tool analysis. This step is not as relevant to the project designers as it does not add significantly to the case study process implementation but rather it highlights gaps in the use of or availability of ICT tools for those who are interested in improving the processes for subsequent projects. Three design processes (site analysis, first design charette, schematic design) out of the nine distinct processes in the preliminary design phase have been selected for discussion in this section. The choice of the three selected processes was based on the fact that these processes had been implemented in the case study, due to which there was an opportunity to compare the current level of application to the potential level of ICT application. The previous section provided a description of all nine processes, divided into administrative and design processes, while this section provides an analytical description of the selected three design processes.

Table 5 shows the three selected design *processes* within the preliminary design *phase*. Four aspects of each process are captured here: *participants, inputs, constraints, and outputs.* These aspects have been taken from the $IDEF_0$ (NIST, 1993) representation technique and adjusted to suit the purpose of this research. Inputs to a given process are generally a product of preceding processes. When acted upon by a process, a change of state occurs and the resulting transformation is an output and therefore a potential input to a subsequent process. Input can repeat itself in more than one process and are not constrained in any way. The term participants refers to human resources only (see Table 3). The term constraints refers to controls over scope, time, cost and other attributes of a project.

TABLE 5: Selected Processes from the Preliminary Design Phase

Selected Processes	Participants	Inputs	Constraints	Outputs	Context	Current Tools
Site Analysis	Project team	Design brief LEED rating system	Site slope, terrain and topography Sun and wind factors Soil conditions Building rules and regulations	Site Analysis report	Sharing	Site drawings Videos Photographs
					Analysis	3-D scale models
					Interactive	Round-table discussions
					Documentation	Word processors Spreadsheets
First Design Charette	Integrated team	Design brief LEED rating system Site Analysis report	Project scope Project budget Project goals	First charette minutes	Sharing	Drawings Notes
					Analysis	
					Interactive	Round-table discussion Meetings
					Documentation	Word processors Spreadsheets
Schematic Design	Designer	Site Analysis report First charette minutes	Project scope Project budget Project goals	Schematic floor plans	Sharing	Drawings Notes
					Analysis	Sketches (manual/computerized) 3D models
					Interactive	
					Documentation	CAD software Word processors Spreadsheets

6.1 Identifying contexts and support tools

Also, for each process four contexts are identified as: sharing, analysis, interactive, and documentation. Therefore, the opportunities for ICT support to improve processes were context-specific. The aids that are required to support any process are referred to here as tools, which come under the larger $IDEF_0$ category of resources.

Sharing: These are defined as tools that enable sharing of information at any time from any place. The minimum number of users at any time in this context is one.

Analysis: Analysis may be generically defined as the process of identifying a question or issue to be addressed, modeling the issue, investigating model results, interpreting the results, and possibly making a recommendation. Analysis tools support either a numerical data analysis approach (e.g., modeling software application) or an enhanced visualization approach (e.g., a 3-D model). The minimum number of users in this context is one.

Interaction: An interactive context is one that facilitates a collaborative setting. Facilitation may be defined as a collaborative process used to help parties discuss issues, identify and achieve goals and complete tasks in a mutually-satisfactory manner. This context enables decision making and dispute resolution and is appropriate when the minimum number of users is greater than one. An example of an interactive tool is an interactive display which could be employed during the first design charette.

Documentation: A documentation context enables capture of information or results that are derived from either an analysis or an interactive context. This context is appropriate with any number of users.

In general, two key tools that have demonstrated their potential are groupware applications and interactive displays. These are capable of addressing the sharing and interactive contexts in most processes. This elucidates the deficiency where tools exist but are not used. Another example is the analysis context in the first design charette. It may be observed that there are no tools to support the aforesaid context, let alone potential ones. This represents a gap where there are no obvious tools and presents an opportunity for further research, the results of which may prove a preference for current means (e.g., face-to-face interaction). It is conceivable that with the fullness of time several different tools will come to serve every single purpose. At this point, the results of the analysis simply emphasize the need for research and development to consider gaps.

6.2 Identifying contexts within processes

With respect to the context of the three selected design processes from the preliminary design phase, current supporting tools are identified below. The purpose here is to substantiate that there are gaps that need to be bridged and also to demonstrate that improvements can be brought about by using tools not widely used in the current context. This is clarified in the following subsections which follow the sequence of Table 5.

6.2.1 Site analysis

The purpose of site analysis is to arrive at optimised design solutions for several design requirements, the most important being the position of the building. Information about the site is shared among the team in the form of site drawings, videos and even photographs which elucidates the sharing context. This is how it is currently practiced. However, more dynamic means of interaction can be facilitated through the use of visualisation applications which will not only enliven the context but also inspire the team to come up with more meaningful results. Several site related decisions are taken based on the constraints that influence these decisions, as mentioned above. In order to achieve this purpose the problem has to be analysed. Therefore 3-D models of the site are built and also solutions could be modelled with the help of 3-D modelling software applications for better visualisation. This helps the analyst arrive at results. Once this is completed there is a context shift from analysis to documentation. In the latter context, results may be documented using a word processor or spreadsheet.

6.2.2 First design charette

The purpose of a design charette is to thrash out ideas, conduct intensive discussions and eventually arrive at conclusions which may be characterized as a continuum containing autocratic decision making, consensus, and dispute resolution. The venue for the first design charette should ideally be equipped with video cameras and the participants should be provided with lapel microphones to capture all information that was exchanged orally. The ability to capture as much information as possible in this stage is crucial as it has a compounding effect on the later stages. This elucidates the interactive context in this process. This is not a linear process that ends after one sequential cycle through sharing, interaction, and documentation; it is always iterative and rarely sequential and should not be otherwise constrained.

There are many vendors that offer interactive display solutions to facilitate team decision making process. An example is the SMART Board (SMART, 2005) which is an interactive whiteboard that can be used in a collaborative environment. The touch-sensitive display connects to the computer and digital projector to show computer images. Computer applications can be directly operated from the display; notes can be written in digital ink and saved to share later. Once the sharing, analysis, and interaction are complete, there is a context shift to a summary round of documentation. It is during this time that all the early, seminal/strategic decisions and other information is gathered and may be placed on a groupware application. This may be done by the project coordinator who would organize all the information gathered and request all participants to sign off for verification and approval.

6.2.3 Schematic design

The purpose of this process is to arrive at a consensus before finalizing the project design. Once the designer completes the schematic design, which is undertaken in an analysis context, it is presented to the team for group analysis. At this stage it is ideal to create a 3D model for enhanced visualization. Also, the development of the sketches and drawings should not be constrained to electronic or printed drawings. These sketches may be prepared manually or using CAD software and saved in the appropriate format after which they are uploaded to a groupware application for team viewing and data sharing. Design concerns that are expressed by the rest of the team may be documented using a word processor or spreadsheet; to be discussed in a subsequent meeting.

7. CONCLUSIONS AND RECOMMENDATIONS

The paper presents a three-step framework for analysing the impacts of implementing a new sustainable standard such as the LEED rating system. The framework consists of: 1) an issue analysis, 2) a process analysis, and 3) a tool analysis. The framework should be of interest to researchers and industry practitioners alike. This is reinforced by the opinions of the project designers who found the issue and process analysis quite useful, although tool analysis did not seem as significant. The implementation of the framework will give the practitioner a better sense of what is lacking in terms of ICT applications and will identify new areas of interest to researchers.

The authors feel that the issue analysis is particularly significant as it provides a straightforward assessment of impacts on a project. It is a useful tool, through which all decisions that were taken during different phases of the project can be efficiently captured and later referred to for the current project or when embarking on a new project. The process analysis is a structured approach which a practitioner can easily apply and modify depending on the nature of the project. The concept of tool analysis would be of interest to researchers heading in the direction of sustainable construction. The results of a tool analysis may or may not vary with projects, but the distinction can only be made while conducting a case study.

The implementation of sustainability requires new standards such as the LEED rating system. This leads to the development and implementation of new processes that expose opportunities for ICT support. With this implementation of the framework we speculate that the benefits of sustainable construction are locked in the initial phases of a project undertaking. The proposed streamlined process for LEED projects will enable the early incorporation of LEED requirements. The framework was developed for sustainable standards, but the authors are convinced that this approach could be applied to broader implementation of any new standard (e.g., ISO standards, national building standards).

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