ITcon

www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

THE DEVELOPMENT OF A SUSTAINABLE-CONSTRUCTION PLANNING SYSTEM

SUBMITTED: December 2011
REVISED: July 2012
PUBLISHED: July 2012 at http://www.itcon.com/2012/10
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SUMMARY: *Since construction is considered as one of the main sources of environmental pollution in the world, the level of knowledge and awareness of project participants, especially project managers, regarding the construction impacts on the environment are required to be enhanced. The aim of this paper is to develop a prototype of a Sustainable-Construction Planning System (SCPS) in order to mitigate the negative impacts of the construction industry on the environment. To achieve this aim, frequency and severity of known environmental impacts of construction process of residential buildings were investigated through interviews with a safety expert panel in Malaysia. Then, risk level associated with each environmental impact was calculated based on the relevant risk matrix. The SCPS extracts current construction activities from any computer-based schedule (Microsoft Project® in this study) and identifies sustainable strategies, and environmental impacts related to each activity as a report. The SCPS was presented to an expert panel who was asked to assess the reliability and usability of the SCPS. It can be concluded that the SCPS is efficient and helpful in mitigating construction related impacts on the environment. The practical implication of this study is to promote sustainable construction by promoting the project participants' knowledge and awareness of significant environmental impacts related to construction operations. This study could be a platform for developing automated sustainable planning systems that can be used broadly in construction projects.*

KEYWORDS: *environmental pollution, impacts assessments, sustainable strategy, prototype.*

***REFERENCE:** Javier Irizarry, Assistant Professor Dr.,Samaneh Zolfagharian, Mehdi Nourbakhsh, Rosli Mohamad Zin, Associate Professor Dr., Kamaruzaman Jusoff, Professor Dr., Rozana Zakaria, Assistant Professor Dr., (2012) The Development of a Sustainable-Construction Planning System, Journal of Information Technology in Construction (ITcon), Vol. 17, pg. 162 - 178, http://www.itcon.org/2012/10*

1. INTRODUCTION

Environmental protection is an important issue throughout the world. Compared with other industries, construction is a main source of environmental pollution (Ofori et al., 2002). Building construction and operations have a massive direct and indirect effect on the environment (Cho et al., 2010, Levin, 1997). Pollution sources resulting from construction processes include harmful gases, noise, dust, solid and liquid wastes (Tah and Abanda, 2011). This issue has motivated construction participants to intentionally monitor and control the impacts of their activities by adopting environmental management systems (Shen et al., 2010).

Construction practitioners should be aware of sustainable construction practices in order to be able to adequately reduce the negative impacts of their actions on the environment. Awareness and knowledge are the main factors to intensify the sustainable movement in the construction industry (Zainul Abidin, 2010). The Malaysian government, professional bodies and private organizations have started several programs to enhance the awareness and knowledge of construction practitioners, and also to promote sustainable practice application within construction projects (Zainul Abidin, 2010). Unfortunately, there is no pattern for construction participants to follow to mitigate environmental impacts resulting from construction activities. Management needs a reliable database to provide comprehensive information on environmental impacts of construction projects and sustainable strategies. Such a system will enable managers to be aware of the environmental impacts of current construction activities in order to devote adequate resources to mitigation of such environmental impacts on the construction site.

The objective of this study is to propose a Sustainable-Construction Planning System (SCPS) by integrating construction schedules in Microsoft Project® (MS Project®) with sustainable construction databases including environmental impacts databases, environmental risk assessment databases and sustainable construction strategy databases. The SCPS automatically provides the essential information which is required to perform sustainable construction, for achieving superior quality in both performance and economic terms of a project. Due to the wide range of materials being used in the construction, the consideration of materials is out of scope of this study. In addition, MS Project® is selected to develop the SCPS because it is commonly used for project planning (Bansal and Pal, 2009).

Several studies linked Building Information Modelling (BIM) with the design of sustainable buildings. Azhar& Brown (2009) investigated the possibility of utilizing BIM-based sustainability analyses and Leadership in Energy and Environmental Design (LEED®) certification process to ensure an optimized sustainable building design. It was indicated that BIM can simplify the process of construction design and automate complex activities. In addition, Azhar et al. (2011) examined the use of BIM in sustainable design and LEED® rating systems to demonstrate methods in which designers and planners may use BIM for various sustainability analyses in the pursuit of the LEED® certification. Although, BIM creates similar results to the manual calculation, some discrepancies were recorded. It might be because of the incompleteness of the building information model of a project and limitation of modelling some finishes in the model. Thus, it was recommended to check results manually. O'Keeffe et al. (2009) presented a 5D BIM model to review the LEED® certification in a virtual environment. By such a system, architecture, engineering, and construction can have access to the LEED® information in a BIM model, in order to mitigate the cost of sustainable design and provide better sustainable designs for achieving more efficient built environments. Geyer (2012) developed

Parametric Systems Modelling (PSM) as a technique for parametric geometric CAD/BIM modelling in which the German Sustainable Building Council (DGNB) serves as a reference. PSM models the interdependencies between disciplinary approaches to evaluate sustainability, so designers can almost automatically develop well-performing configurations of the whole design. Wu & Issa (2010) investigated the viability of Virtual Design and Construction (VDC)/ BIM to leverage LEED® projects. The results of integrating VDC/BIM tools with the LEED® credit requirements were more reliable because all the quantities are automatically provided which will prevent team members from making mistakes.

Some BIM technologies are available for making sustainable design practices easier, more efficient, and less costly, which are developed by Autodesk (2005). For instance, Revit Conceptual Energy Analysis® allows users to convert conceptual design models into rich analytical energy models and compare design alternatives. Another BIM technology is Revit Solar Studies® which helps users to estimate the impact of natural light and shadows on designs at the initial stages of design. Moreover, Autodesk Green Building Studio® evaluates carbon emissions, assess energy consumption and determine possible renewable energy use. Another application is Autodesk® Simulation CFD which allows architects and engineers to find whether design changes on their models results in achievement of environmental objectives and energy certifications or not (Autodesk, 2005).

Other research approaches considered implementing and adopting decision support systems for sustainable construction. A web-based decision support system- namely DeconRCM- was developed for the optimal management of construction and demolition waste. The purpose of developing DeconRCM was to increases knowledge and awareness of users towards sustainable construction and demolition waste management (Banias et al., 2011). Likewise, the application of the semantic web techniques was explored to represent sustainable building technologies, and recommend proper measures to make decisions in various circumstances (Tah and Abanda, 2011). Ruiz and Fernández (2009), designed a spatial decision support system using the Geographical Information System (GIS) to measure the environmental performance in construction. The system helped planners in their decision-making process, and also provides a tool for inspection and management of the sustainability of buildings. The major advantage of using Spatial Decision Support System lies in permitting planners to edit, store, transform, analyze and visualize environmental information for making decisions in different situations.

Other research resulted in the development of a tool to manage the environmental performance of construction activities. Shelbourn et al. (2006) developed Sustainability Management Activity Zone (SMAZ) and prototype web portal to provide sustainability knowledge on construction projects. The particular aspects of SMAZ were to present sustainability criteria and process during the design stage, construction projects, and the selection of subcontractors and materials. Shen, et al. (2005) developed a scoring method to measure contractor's environmental performance. The system assisted contractors to find poor environmental performance in order to adopt proper measures. Besides, the system linked environmental performance achieved by a contractor to the different construction practitioners.

The growth of construction and its environmental impacts emphasize the importance of the need for sustainable construction processes and actual ways to manage sustainability measures for sustainable construction. It is very important to predict what the environmental impact of construction is and how it can be prevented before starting an activity. For such anticipations, an interaction between sustainable construction planning and scheduling can be helpful. The above approaches have focused on developing sustainable design and scoring methods for environmental performance assessment. Thus, there is a lack of a sustainable construction model that can be fully integrated with a construction schedule. Such a model would be able to determine the environmental risk level of construction activities and report the current environmental impacts of the construction process as well as the applicable sustainable strategies that can mitigate such impacts. This paper contributes to the body of knowledge by developing an algorithm to automate evaluation of activity-level environmental issues and becomes part of an automated computer-based sustainable planning tool for residential buildings. This contribution will help construction parties and construction managers, especially less experienced managers, to access a comprehensive overview of the probable environmental impacts of construction activities and essential sustainable strategies to mitigate environmental impacts. The proposed system generates results very quickly which can aid in saving time and resources. It enables construction parties to focus on the environmental impacts of construction activities and the required sustainability measures individually.

2. CONSTRUCTION PROCESS AND ENVIRONMENTAL IMPACTS

Malaysia aims to achieve the status of a developed country by the year 2020 and the construction industry is considered as a main catalyst to obtain this aim (Zainul Abidin, 2010). However, the construction industry has negative influences on the environment in Malaysia, such as soil erosion and sedimentation, destruction of vegetation, flash floods, dust pollution, and the use of building materials harmful to human health (CIDB Malaysia, 2007). The green movement in Malaysia is mostly in its initial stage and more efforts should be made regarding recognizing the green agenda of the construction industry (Zainul Abidin, 2010).

Construction management is not just related to optimization of time, cost, quality, and safety, but it is also related to sustainable construction (Shelbourn et al., 2006). The economic elements such as increased profitability and competitiveness, the social dimension such as the delivery of buildings which meet the agreement of its customers and also stakeholders, and the environmental elements like protection of natural resources and ecosystems as well as reduction of environmental impacts are the elements of a sustainable construction sector (CIDB Malaysia, 2007). Sustainable construction consists of creating constructed items using best-practices and clean and resource-efficient techniques during a project's life-cycle (Ofori G, 2000). Construction activities will always cause undesirable environmental impacts but the application of sustainable construction principles can reduce the environmental impacts (Ofori G, 2000). Construction activities are considered as one of the main obstacles to achieving sustainable development (Wetherill et al., 2007), because they have caused resource waste, environmental pollution, and safety problems in developing countries (U.S. Green Building Council (USGBC), 2001).

Prediction of the correlated environmental impacts of construction before the construction stage, will lead to improved environmental performance of construction projects and sites. The determination of major environmental impacts will assist to consider a range of on-site measures to mitigate them (Irizarry and Gill, 2009). The environmental impacts across construction processes consist of ecosystems impact, natural resources impact, and public impact (Dave et al., 2010).

3. ENVIRONMENTAL RISK ASSESSMENT

Determining the risk rate of the environmental impacts of construction activities depends on the probability of occurrence and, the severity of the environmental impacts. Frequency is defined as a likelihood of construction activities' potential being realized and initiating a series of impacts that could result in damage to the environment. The severity of the consequences is defined as the extent of damage that could result from an impact on the environment. Risk can be assessed and presented, using matrices, by estimating probabilities and consequences in a qualitative manner or with quantitative values (Ayyub, 2003). The significant rating of a risk (expected loss) is shown in Eq.(1) (Modarres, 2006):

$$\text{Risk} = \text{Frequency} \times \text{Severity} \qquad \text{Eq. (1)}$$

4. METHODOLOGY

The main steps, which were undertaken to achieve the aim of this study, are summarized in Figure 1. The methodology consists of data collection, risk level of environmental impacts, and development and evaluation of the SCPP. The details of the development process are described in the following sections.

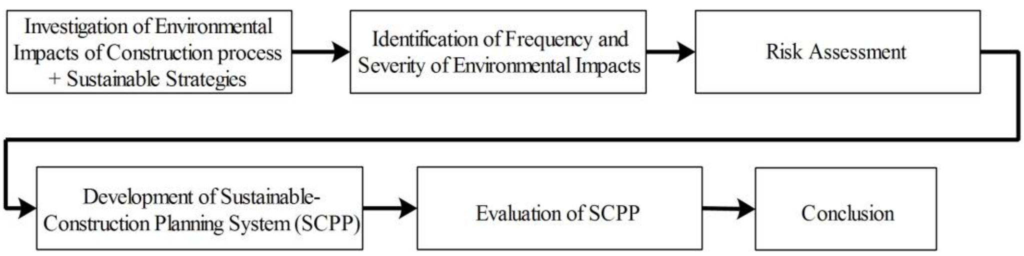

FIG. 1: Methodology of the Research.

4.1 Data collection

The data for this research was collected through literature and a structured interview with an expert panel group. A thorough literature review, including (Ofori et al., 2002, Lam et al., 2011, Enache-Pommer et al., 2010, Dave et al., 2010, Irizarry and Gill, 2009), was performed to develop greater understanding of the environmental impacts. The environmental impacts can be developed into further subcategories. A list of 26 subcategories of the environmental impacts was identified through the previous research (Ofori et al., 2002, Dave et al., 2010, Irizarry and Gill, 2009). Table 1 shows environmental performance subcategories as environmental impacts across construction processes. The interview was conducted to investigate the frequency and severity of the environmental impacts across construction of residential buildings in Malaysia. The interview included two main sections, Section A covered the background and general information of the respondents, and Section B included the environmental impacts of construction process.

TABLE 1: Environmental impacts of construction processes

Ecosystem Impacts	Reference	Public Impacts	Reference	Natural Resources Impacts	Reference
Noise pollution	1, 2, 3,5	Site hygiene condition	1	Transportation resources	1
Dust generation with construction machinery	3,4, 5	Public health effects	1	Energy consumption on site	1,2,4
Land pollution	1	Social disruption	1	Raw materials consumption	1, 3, 5
Waterborne suspend substances such as lead and arsenic	4			Resource deterioration	2,4
Air pollution	1, 2			Electricity consumption	3,4, 5
Operations with vegetation removal	3, 4, 5				
Emission of volatile organic compounds (VOC) and (CFC)	3				
Generation of Inert Waste	3,4,5				
Operation with high potential soil erosion	3,4,5				
Water pollution	1, 2				
Dust generation	3,4,5				
Waste generation	1,3, 5				
Inert Water	3				
Chemical Pollution	2				
Landscape alteration	3,4, 5				
Toxic generation	1				

Waterborne toxicities	4
Greenhouse gas emission	3,4, 5

[1] Shen et al., 2005a, [2] Tam et al., 2006, [3] Gangolells et al., 2009, [4] Li et al., 2010, [5] Gangolells et al., 2011

4.2 Risk Level of Environmental Impacts

During the interview, the respondents were requested to rate the frequency and severity of the environmental impacts (Table 2). In addition, the relationship between the environmental impacts of construction process and the common construction activities was discussed. There is a variety of construction activities, thus similar type of work across construction projects was selected for this study. The common activities of construction of residential buildings are related to one or more of the following domains: a) earth work, b) reinforcing steel placement, c) concrete placement, d) formwork installation, and e) masonry.

TABLE 2: Likert Scale (Rensis, 1932) Used to Determine the Level of Frequency and Severity- adopted from (Jeong et al., 2010)

Scale	Severity	Description	Frequency
1	Insignificant	Minimal impact	Never
2	Minor	Short-term impact	Unlikely
3	Moderate	Significant impact	Possible
4	Major	Major short-term impact	Likely
5	Catastrophic	Major long-term impact	Always

4.3 Automated Sustainable-Construction Planning System (SCPS) Prototype

An algorithm was proposed in order to develop the Sustainable-Construction Planning System (SCPS). The simplified proposed algorithm of the SCPS is shown in Fig. 2. The main programming procedure should look for the current activities of a project. If the activity is one of the common construction activities, namely a) earth work, b) reinforcing steel placement, c) concrete placement, d) formwork installation, and e) masonry, related environmental impacts of activities and sustainable strategies will be assigned. Then, the environmental impacts will be classified based on their risk levels. Finally, after finding all current activities, the activities will be compared with each other to be ranked in order of their environmental risk levels. This means that the most risky activity will be listed first, while the least risky activity will be listed last on the report. The proposed algorithm was evaluated by the same expert panel group to ensure the accuracy and efficiency of the final system.

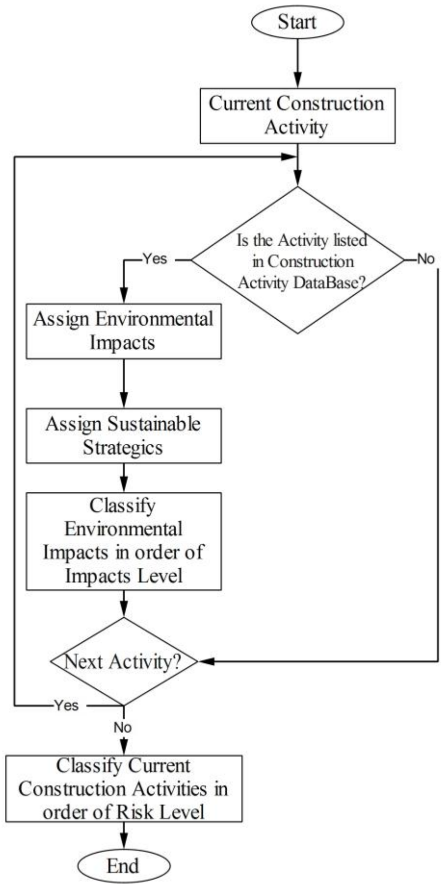

FIG. 2:The Algorithm of the SCPS.

The algorithm was then implemented in a computer program using Visual Basic for Application® (VBA) so as to design and develop the SCPS. Microsoft Excel® is used as a database and MS Project® as a source of schedule data. The primary reason for choosing MS Project® lies on its broad use for project planning (Bansal and Pal, 2009, Dave et al., 2010). Since VBA is embedded in MS Project® and has the benefit of good potential for system programming and database management, it is adopted for developing the SCPS as the programming application. SCPS can be easily installed on a Microsoft Windows-based system and run in MS Project®. There are several objects and functions from MS Project® Object Library which were used to develop SCPS. For instance, the Task object was used to retrieve all tasks in the Active-Project object model. The Date function was used to check the activities' date whether they are occurring in the current date or not. In addition, the link between the MS Project® and Microsoft Excel® as a database was made by Microsoft Excel® Object Library. The database was opened using connection string; and information related to current activities was retrieved from Worksheet and Range objects.

The developed SCPS consists of three main phases: input, procedure, and output. The input used to apply the SCPS contains four databases: Environmental Risk Assessment, Construction Activities, Environmental Impacts, and Sustainability Strategies (Fig. 3). Environmental Risk database includes the risk rate of construction activity related impacts on the environment, including their frequency and severity. Using the environmental impacts assessment database, the project management team can be aware of the most dangerous environmental impacts during each construction activity. The Construction Activity database is based on the common construction activities. Sustainable Strategy database contains the essential sustainable strategies which were extracted from relevant references (Ofori et al., 2002, Woolley et al., 1997, The Hong Kong Building Environmental Assessment Method (HKBEAM), 1999, Department of Design and Construction of New York (DDCNY), 1999, Hong Kong Productivity Council (HKPC), 2001, Leggett). These strategies identify the environmental impacts of construction projects and also proper protective measures, e.g., “Providing access for waste collection vehicles.

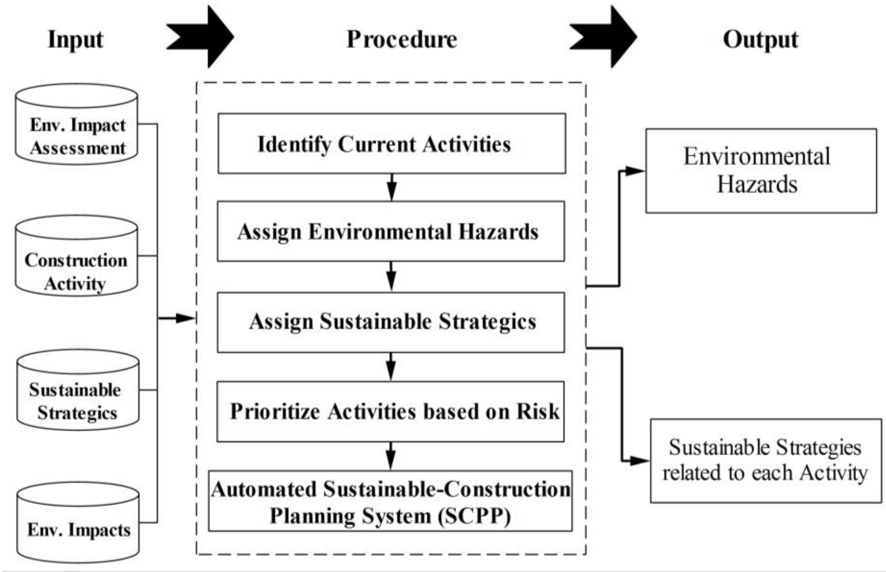

FIG.3: Schematic Model of SCPS.

4.4 Prototype Evaluation

Five site managers, who had more than 10 years of experience in environmental and sustainable construction and about five years of experience in MS Project® use, participated in a semi-structured interview to evaluate the SCPS. In the first stage of the evaluation, a meeting was held to describe the SCPS and provide required instructions. More details of the evaluation will be discussed in subsequent sections.

5. RESULTS AND DISCUSSION

5.1 Respondents’ Profile

The target respondents consisted of 15 construction professionals who were familiar with Green Building Index and/or sustainable design/construction. They were interviewed to rank the frequency and severity of common environmental impacts of construction projects in Malaysia. About 73 percent of the interviewees had more than 15 years of experience, and approximately 13 percent had less than five years of experience. The annual revenue of about 26 percent of the companies was more than USD 3,140,000 which is approximately 10 million Ringgit Malaysia (RM 10 million), about 54 percent of companies earned between USD 314,000 (one million RM) and USD 3,140,000 (RM 10 million), and around 20 percent of interviewees’ companies obtained less than USD 314,000 (one million RM)-Table 3.

TABLE 3: Respondents’ Profile

Resp[a]	YE[b]	R[c] (RM)	Resp[a]	YE[b]	R[c] (RM)	Resp[a]	YE[b]	R[c] (RM)
1	YE >15	1M≤ R<10M	6	YE >15	R≥10M	11	YE >15	R≥10M
2	YE >15	1M≤ R<10M	7	5<YE≤15	1M≤ R<10M	12	YE >15	1M≤ R<10M
3	YE >15	1M≤ R<10M	8	YE >15	1M≤ R<10M	13	YE >15	1M≤ R<10M
4	YE≤ 5	R <1M	9	YE≤ 5	R <1M	14	YE >15	R≥10M
5	YE >15	1M≤ R<10M	10	5< YE≤15	R <1M	15	YE >15	R≥10M

[a] Respondents
[b] Years of Experience
[c] Company’s Revenue

5.2 Environmental Risk Assessment

Table 4 shows the frequency and severity of the environmental impacts across construction process of residential buildings as well as their associated risk in order of priority. The risk level of environmental impacts was calculated with Equation 1, and sorted in descending order. Higher scores indicate higher impacts on the environment compared to others.

TABLE 4: Evaluation of Common Environmental Impacts Assessments related to Construction Process

Environmental Impacts		FOC[a]	SD[b] (FOC)	SEV[c]	SD (SEV)	IL[d]	Priority
Natural Resources Impact	Transportation Resources	3.79	0.89	3.36	0.93	12.71	Priority 1
	Energy Consumption on Site	3.24	1.06	3.36	0.87	10.89	Priority 4
	Raw Materials Consumption	3.25	0.97	3.23	1.01	10.5	Priority 7
	Resource Deterioration	3.08	0.79	3.1	0.88	9.56	Priority 16
	Electricity Consumption	2.86	1.17	3	1.04	8.57	Priority 19
Ecosystem Impact	Noise pollution	3.67	1.05	3.23	1.09	11.85	Priority 2
	Dust Generation with Construction Machinery	3.46	1.2	3.31	1.03	11.45	Priority 3
	Land pollution	3.36	1.21	3.18	1.17	10.7	Priority 6
	Waterborne Suspended Substances such as lead and arsenic	3.11	1.27	3.27	1.1	10.18	Priority 8
	Air pollution	3.29	1.14	3.08	1.26	10.11	Priority 9
	Operations with Vegetation Removal	3.23	1.3	3.08	1.16	9.96	Priority 10
	Emission of Volatile Organic Compounds (VOC) and CFC	3.3	1.06	3	0.94	9.9	Priority 11
	Generation of Inert Waste	3.3	0.67	2.92	1.08	9.63	Priority 13
	Operation with High Potential Soil Erosion	3.2	0.92	3	0.82	9.6	Priority 14
	Water pollution	3.27	0.8	2.93	0.96	9.58	Priority 15
	Waste generation	3.27	1.1	2.83	1.11	9.26	Priority 17
	Dust Generation	2.91	0.83	3.17	1.03	9.21	Priority 18
	Inert water	3.17	1.19	2.64	1.21	8.35	Priority 20
	Chemical Pollution	2.75	1.14	3	1.04	8.25	Priority 21
	Landscape Alteration	2.79	0.89	2.69	0.95	7.5	Priority 23
	Toxic generation	3.08	1	2.36	1.36	7.29	Priority 24
	Waterborne Toxicities	2.64	1.03	2.58	1.08	6.81	Priority 25
	Green House Gas Emission	2.73	1.19	2.22	1.09	6.06	Priority 26

Environmental Impacts		FOC[a]	SD[b] (FOC)	SEV[c]	SD (SEV)	IL[d]	Priority
Public Impact	Site Hygiene Condition	3.25	1.14	3.31	1.03	10.75	Priority 5
	Public Health Effects	3.14	1.29	3.07	1.14	9.65	Priority 12
	Social Disruption	2.77	1.17	2.77	1.09	7.67	Priority 22

[a] FOC, Frequency of Occurring

[b] SD., Standard Deviation

[c] SEV, Severity of the Impacts of on the Environment or Consequences

[d] Impact Level

Table 4 reveals that 'Transportation Resources' as a subcategory of natural resource has a much greater environmental impact compared with any other subcategories (IL=12.71). This indicates that choosing appropriate and local products and materials may result in a significant reduction in the environmental impact, because the lower rate of fuel will be required to transport materials. It is followed by 'Noise Pollution' (IL=11.85) which is the second most contributory source of noise pollution in Malaysia (Haron et al., 2008).The noise generated during construction and its influence vary, depending on the nature of the activities, the type and the status of equipment being used, the nature of the surrounding environment, and considerations of environmental and health regulations (Gannoruwa and Ruwanpura, 2007).

Furthermore, it can be seen that 'Green House Gas Emission' contribute the smallest portion of total impact (IL=6.06) compared with any other subcategories and it is followed by 'Waterborne Toxicities' (IL=6.81). Even though their shares are small, it is important to decrease their environmental impact. There is a potential to decrease their impact by applying advanced technologies or changing construction equipment.

Table 5 represents the environmental risk level of the five common construction activities as a result of summation of the risk level of related environmental impacts to each activity. It is identified that the riskiest construction activity toward environmental impacts is earthwork (Risk Level= 198.53), and the least risky is masonry (Risk Level= 47.42). In addition, the risk levels are normalized to bring all of the variables into proportion with one another in order to provide approximately equivalent values for the better understanding of variables. Equation 2 shows the calculation of normal risk level (Etzkorn, 2011).

$$Xn = ((Xi - Xmin))/((Xmax - Xmin)) \qquad \text{Eq. (2)}$$

X_n: Normal Risk Level, X_i: Each Risk Level, X_{min}: Minimum Risk Level among all variables, X_{max}: Minimum Risk Level among all variables

TABLE 5: Environmental Risk Level of Construction Activities

Construction Activity	Risk Level	Normal Risk Level
Earthwork	198.53	1.00
Concrete placement	173.75	0.84
Reinforcing steel placement	78.31	0.20
Formwork installation	71.93	0.16
Masonry	47.42	0.00

5.3 Output of the SCPS

Project managers can greatly benefit from having a report that warns of the current environmental impacts of construction activities on their site and recommends effective sustainable strategies in order to mitigate the impacts of construction activities of their projects on the environment.

The SCPS includes automatic mode and manual mode. In automatic mode, the SCPS automatically produces the Sustainability report, consisting of the environmental impacts and recommended sustainable mitigation strategies related to the current day's activities. In the manual mode, the operators can customize the report by selecting the sustainable strategies. In this mode, users can even enter the sustainable strategies required for each task into the MS Project® file.

The output of the SCPS is a report including start dates, finish dates, environmental impacts, and sustainable performance for current construction activities. The environmental impacts are prioritized in order of risk levels so that the managers would be aware of critical environmental impacts. This attribute helps the project management team to be aware of which sustainable and protective measures should be considered for the current activities so as to improve their sustainable performance and mitigate negative environmental impacts.

5.4 Evaluation of the SCPS

Usability is defined as "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (Iso, 1998). In the construction field, usability assessment is used to evaluate proposed prototypes (Nourbakhsh et al., 2012, Yammiyavar and Kate, 2010). In this study, two instruments adopted by Davis (Davis, 1989) were used to evaluate the usefulness and ease-of-use of the SCPS. The perceived usefulness is defined as "the degree to which a person believes that using a particular system would enhance his or her job performance", and the perceived ease-of-use is defined as "the degree to which a person believes that using a particular system would be free of effort (Davis, 1989)." In general, if a system is useful and easy to use, it is expected to be accepted by users (Cheung et al., 2003). These two instruments are selected in this study to find the usability of the SCPS on sustainable construction performance, because of their proven psychometric quality such as reliability, content validity, and construct validity (Cheung et al., 2003).

During the meeting with five construction managers, first, the instructions for using the SCPS were described to the participants. At the end of the meeting, users filled a questionnaire to express their feedback regarding the ease-of-use and the usefulness of the SCPS as a sustainable planning tool. The questions of two instruments -adopted from Davis (1989)-which were discussed during evaluation are presented in Appendix 1.

The SCPS has two modes, automatic and manual mode. The automatic mode is recommended for less experienced users since the sustainability report can be automatically generated in two steps as shown in Figure 4. Figure 5 shows a part of the report of the SCPS for reinforcing as an example which involves task's start date and finish date, environmental impacts of reinforcing activity and required environmental strategies. In contrast, the manual mode is designed to enable experienced users to manipulate the schedule if a task requires specific attention regarding sustainable construction. Users can browse tasks on the schedule (Step 2- Figure 6), search the database looking for a specific sustainable regulation (Step 3- Figure 6), then based on the results obtained (Step 4- Figure 6), select an appropriate sustainable regulation and assign it to the task (Step 5- Figure 6). The SCPS creates a 'Sustainable' column in MS project® and saves all of the assigned regulations to the column towards related activities.

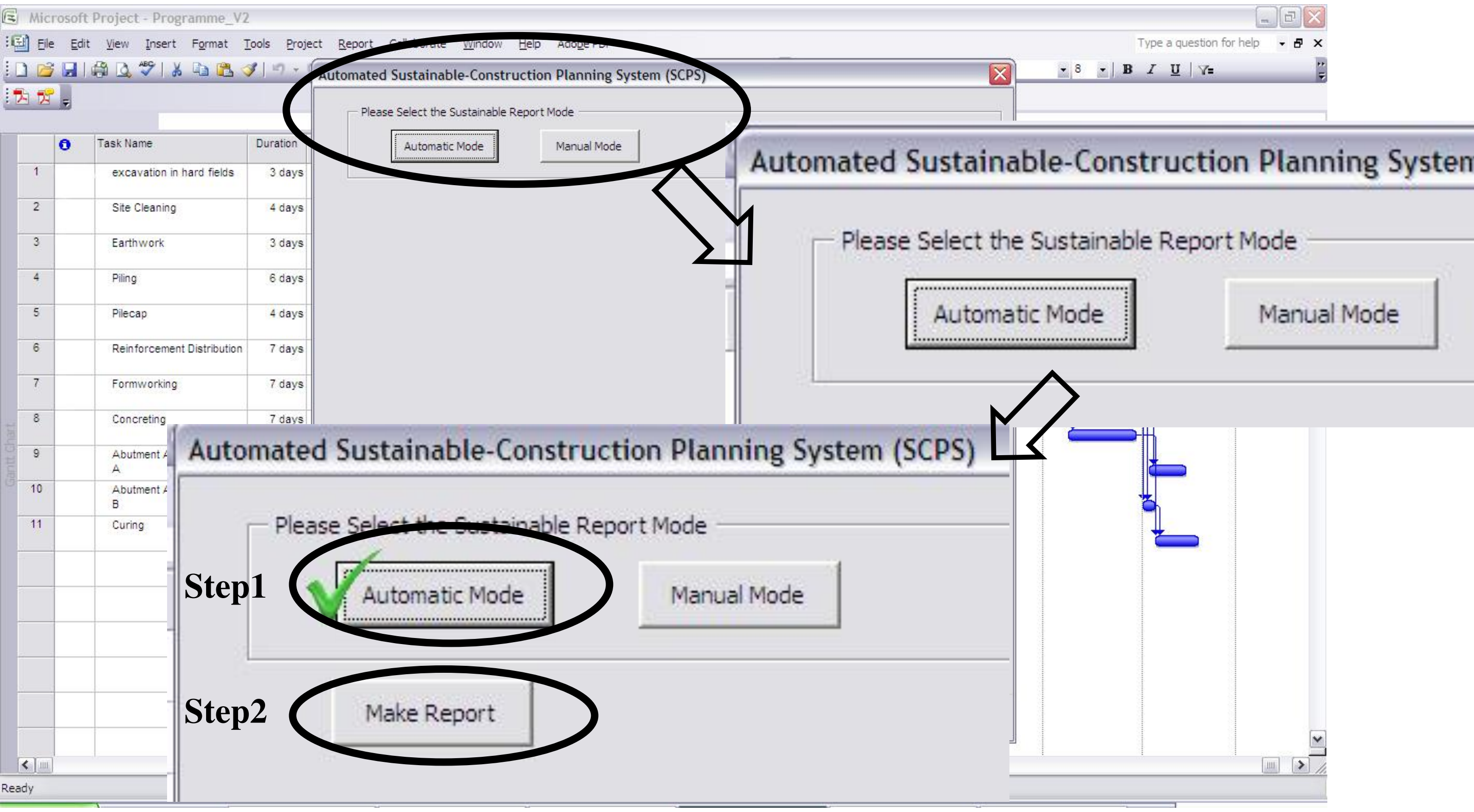

FIG. 4: Interface of the SCPS- Automatic Mode.

Priority	Task Name	Task Start	Task Finish	Environmental Impacts	Environmental Strategies
3	Reinforcement Distribution	8/9/2011	8/17/2011	Electricity Consumption	Specifying particle board and fiberboard to conform to relevant standards
				Generation of Inert Waste	Avoiding burning the waste of plastic foams, PVC, plywood, resin and polymer-bonded slates, organic coating, synthetic fibers, carpet fibers, rubbers, etc., onsite
				Generation of Special Waste (Dangerous Waste)	Implementing a waste management plan
				Raw Materials Consumption	Recycling and/or salvaging at least 50% (by weight or volume) of construction, demolition, and land clearing waste
				Resource Deterioration	Listing out the materials to be salvaged for reuse in the contract documents
				Transportation Resources	Training provision to working staff for waste reduction
				Waste generation	Coordinating the ordering and delivery of materials among all contractors and suppliers to ensure that the correct amount of materials is delivered and stored at the optimum time and place
					Providing access for waste collection vehicles

FIG. 5: Interface of the SCPS's report.

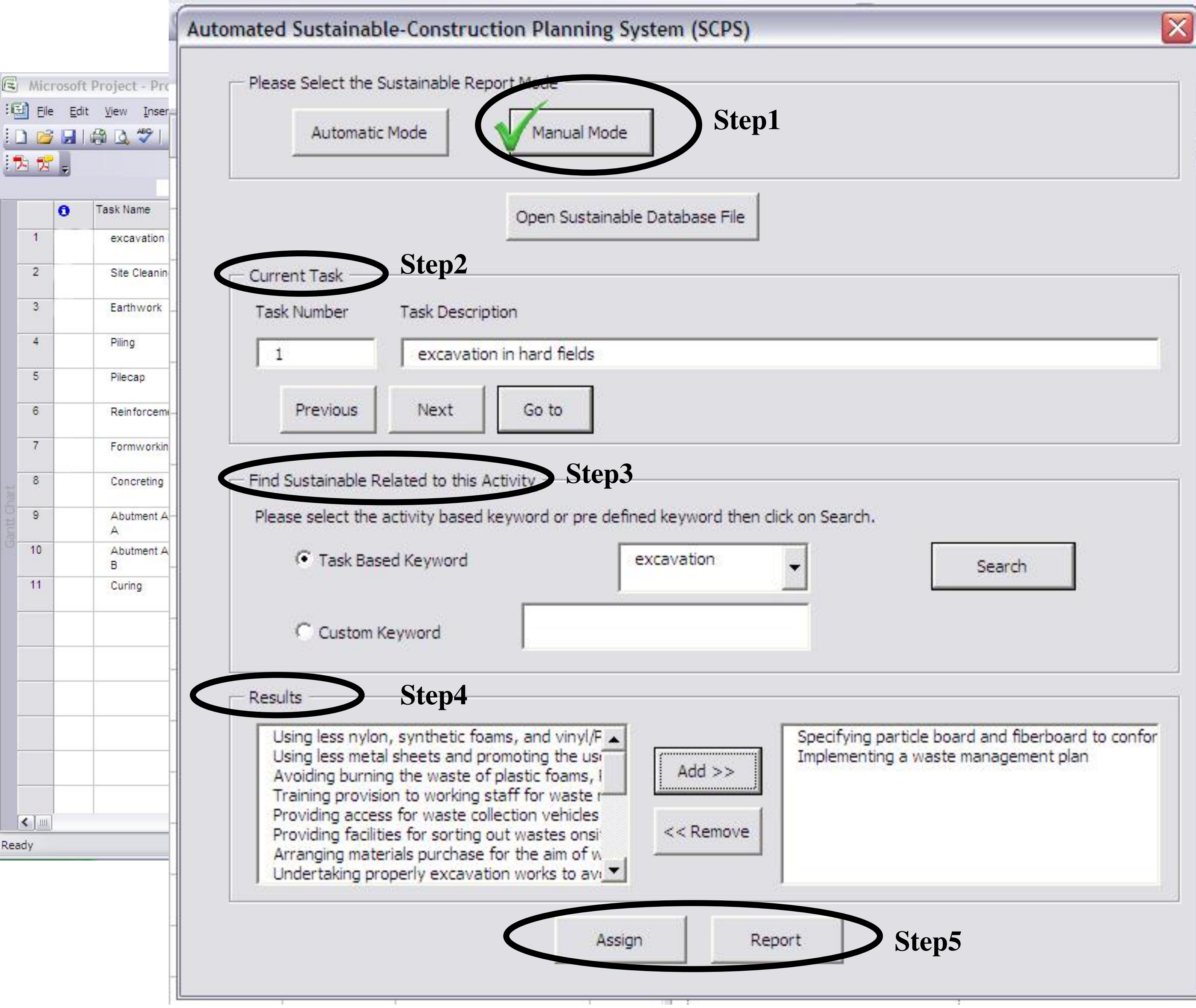

FIG. 6: Interface of the SCPS- Manual Mode.

The results of the evaluation show that the SCPS is an innovative tool to promote sustainable performance to protect the natural ecosystem. In addition, the SCPS proposes a new tool, which facilitates daily monitoring of sustainable performance. During the evaluation, interviewees emphasized that the user interface of the SCPC was easy to understand and did require having prior knowledge of the subject. They added that using the SCPS enhances construction parties' awareness of the possible environmental impacts of building construction and the essential sustainable construction strategies. This advantage will help to undertake the required sustainability measures to minimize the impacts of construction process on the environment. The users mentioned that using SCPS made it easy for them to ensure that the necessary sustainability measures would be accomplished in the right sequence, and any nonconformity would be easily found and corrected. They expressed that managers could use toolbox in daily meetings to provide clarification to workers about environmental impacts and sustainability measures of daily construction activities. Thus, construction participants will be motivated to precisely act in accordance with the sustainable construction strategies. In addition, the SCPS integrates the sustainable components (environmental impacts and sustainable strategies) with the project's schedule (construction activities) which has two advantages: a) environmental impacts of each activity can be recognized before starting actual work, b) sustainable indicators which should be considered in the daily construction activities can be easily selected. Moreover, the sustainable-monitoring task is simplified when using the report from the SCPS to compare with actual sustainable construction performance on site. The integration of the construction schedule with environmental impacts and sustainable construction strategies can create a clear and mutual understanding among the project team. Finally, it was mentioned that the SCPS's report assists construction participants to diminish the negative environmental impacts of construction activities by paying more attention to the riskiest activity. Overall, the interviewees highly recommend using the SCPS as a tool to improve sustainable construction performance.

6. CONCLUSION

This research developed and tested an algorithm to automate evaluation of activity-level environmental issues which then becomes the foundation for a sustainable-construction planning plug-in for construction managers that incorporates sustainable strategies into the project planning process. To do so, first this study investigated the common environmental impacts across construction activities of residential buildings in order of their risk level. It was found that the most negative environmental impacts are resource transportation, noise pollution, and dust generation with construction machinery. In contrast, the least negative environmental impacts resulted from construction activities are greenhouse gas emissions and waterborne Toxicities. In addition, summation of risk level of different environmental impacts related to each activity illustrated that earthwork is the riskiest construction activity compared to others.

The risk assessment results were used to develop a Sustainable Construction Planning System (SCPS), in which sustainable construction can be automatically planned. The SCPS helps with reporting the riskiest activities on a site as well as the environmental impacts and sustainable construction strategies associated with scheduled activities. It provides reports that make management teams aware of the main environmental impacts and required protective measures; thus, the possibility of overlooking these environmental impacts and the required sustainability measures will be mitigated. The SCPS helps with easily identifying the potential environmental impacts of construction activities in order to address them before starting the activity. The SCPS also can be used as a useful tool to assist designers in identifying the negative impacts of construction activities on the environment and integrate sustainable construction strategies in the design stage. The results of the evaluation indicated that the outputs of the SCPS are accurate and also useful to promote sustainable performance by mitigating the negative impacts of construction activities on the environment as well as enhancing the project participants' knowledge and awareness.

The contribution of this study is to develop and test a prototype to integrate construction schedules with sustainable construction indicator databases: Environmental Impacts databases, Construction Activities databases, risk assessment databases, and Sustainable Strategies databases. Although the SCPS can be integrated to any construction schedule, the developed databases are limited to residential construction projects. This study could be a platform for developing automated sustainable construction planning systems that can be used widely in construction projects. Future research needs to investigate environmental impacts and sustainable strategies related to different construction projects such as high-rise buildings and commercial buildings. In addition, these databases cover five common construction activities such as earth working, reinforcing, concreting, form working, and masonry. Future research will investigate additional construction activities and related environmental impacts as well as applicable sustainable strategies so as to design comprehensive sustainable planning and monitoring systems. Moreover, it is recommended to undertake research to develop automated sustainable-construction planning using green building standards such as LEED® and the Green Building Index (GBI®).

7. REFERENCES

Autodesk (2005). Building Information Modeling for Sustainable Design. http://www.kelarpacific.com/resources/Documents/bim_for_sustainable_design_jun05.pdf.

Ayyub, B. M. (2003). Risk Analysis in Engineering and Economics, University of Maryland at College Park, Chapman & Hall/ CRC.

Azhar, S. and Brown, J. (2009). BIM for Sustainability Analyses. *International Journal of Construction Education and Research,* Vol. 5, No. 4, 276-292.

Azhar, S., Carlton, W. A., Olsen, D. and Ahmad, I. (2011). Building information modeling for sustainable design and LEED® rating analysis. *Automation in Construction,* Vol. 20, No. 2, 217-224.

Banias, G., Achillas, C., Vlachokostas, C., Moussiopoulos, N. and Papaioannou, I. (2011). A web-based Decision Support System for the optimal management of construction and demolition waste. *Waste Management,* Vol. 31, No. 12, 2497-2502.

Bansal, V. and Pal, M. (2009). Construction schedule review in GIS with a navigable 3D animation of project activities. *International Journal of Project Management,* Vol. 27, No. 5, 532-542.

Cheung, W., Li, E. Y. and Yee, L. W. (2003). Multimedia learning system and its effect on self-efficacy in database modeling and design: an exploratory study. *Computers & Education,* Vol. 41, No. 3, 249–270.

Cho, Y. K., Alaskar, S. and Bode, T. A. (2010). BIM-Integrated Sustainable Material and Renewable Energy Simulation. *In:* Ruwanpura, J., Mohamed, Y. and Lee, S., eds. Construction Research Congress 2010. Innovation for Reshaping Construction Practice, 2010 Banff Alberta, Canada. ASCE, 288-297.

Cidb Malaysia (2007). Strategic Recommendations for Improving Environmental Practices in Construction Industry Lembaga Pembangunan. *Kuala Lumpur: CIDB Publisher*.

Dave, B., Boddy, S. and Koskela, L. (2010). Improving information flow within the production management system with web services. 2010. National Building Research Institute, Technion-Israel Institute of Technology, 445-455.

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly* Vol. 13, No. 3, 319-340.

Department of Design and Construction of New York (Ddcny) (1999). High-Performance Building Guidelines. Department of Design and Construction, New York, NY.

Enache-Pommer, E., Horman, M. J., Messner, J. I. and Riley, D. (2010). A Unified Process Approach to Healthcare Project Delivery: Synergies between Greening Strategies, Lean Principles and BIM. *In:* Ruwanpura, J., Mohamed, Y. and Lee, S., eds. Construction Research Congress 2010. Innovation for Reshaping Construction Practice, 2010 Banff Alberta, Canada. ASCE, 138-138.

Etzkorn, B. (2011). *Data Normalization and Standardization | Ben Etzkorn* [Online]. Available: http://www.benetzkorn.com/2011/11/data-normalization-and-standardization [Accessed June 29 2012].

Gannoruwa, A. and Ruwanpura, J. Y. (2007). Construction noise prediction and barrier optimization using special purpose simulation. *Proceedings of the 39th conference on Winter simulation: 40 years! The best is yet to come.* Washington D.C.: IEEE Press, 2073-2081.

Geyer, P. (2012). Systems modelling for sustainable building design. *Advanced Engineering Informatics*, No. 0, In Press.

Haron, Z., Oldham, D., Yahya, K. and Zakaria, R. (2008). A Probabilistic Approach for Modelling Of Noise from Construction Site for Sustainable Environment *Malaysian Journal of Civil Engineering,* Vol. 20, No. 1, 58-72.

Hong Kong Productivity Council (Hkpc) (2001). A Guide to Green Construction Practices, Hong Kong Productivity Council.

Irizarry, J. and Gill, T. (2009). Mobile Applications for Information Access on Construction Jobsites. *ASCE*

International Workshop on Computing in Civil Engineering, Vol., June 24-27, 2009, Austin, TX.

Iso (1998). Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs). *Part 11, Guidance on Usability, International Organization for Standardization, Standard 9241-11.*

Jeong, K.-S., Lee, K.-W. and Lim, H.-K. (2010). Risk assessment on hazards for decommissioning safety of a nuclear facility. *Annals of Nuclear Energy,* Vol. 37, No. 12, 1751-1762.

Lam, P. T. I., Chan, E. H. W., Chau, C. K., Poon, C. S. and Chun, K. P. (2011). Environmental management system vs green specifications: How do they complement each other in the construction industry? *Journal of Environmental Management,* Vol. 92, No. 3, 788-795.

Leggett, J. (1990). Global Warming—The Greenpeace Report Oxford*,* Oxford and New York.

Levin, H. (1997). Systematic Evaluation and Assessment of Building Environmental Performance (SEABEP). *Proceedings of the Second International Conference of Buildings and Environment Performance.* Paris, 9–12 June.

Modarres, M. (2006). Risk Analysis in Engineering: Techniques, Tools, and Trends*,* Boca Raton, FL, U.S.A., CRC Press, Taylor & Francis.

Nourbakhsh, M., Rosli, M. Z., Irizarry, J., Zolfagharian, S. and Gheisari, M. (2012). Mobile Application Prototype for On-site Information Management in Construction Industry. *Engineering, Construction and Architectural Management,* Vol. 19 No. 5.

O'keeffe, S. E., Shiratuddin, M. F. and Fletcher, D. (2009). LEED certification review in a virtual environment. 9th International Conference on Construction Applications of Virtual Reality, 2009 November 5-6. http://mfsksa.fatcow.com/fairuz_website/publications/conferences/2009/okeeffe_shiratuddin_fletcher_LEED_Certification_Review_in_a_VE-[FINAL]-[rev2].pdf.

Ofori G, B. C., Gang G, Ranasinghe M. (2000). Impacts of ISO 14000 on construction enterprises in Singapore. *Construction Management and Economics,* Vol. 18, No. 8, 935–947.

Ofori, G., Gang, G. and Briffett, C. (2002). Implementing environmental management system in construction: lessons from quality systems. *Building and Environment,* Vol. 37, No. 12, 1397-1407.

Rensis, L. (1932). A Technique for the Measurement of Attitudes. *Archives of Psychology,* Vol. 22, No. 140, 1–55.

Ruiz, M. C. and Fernández, I. (2009). Environmental assessment in construction using a Spatial Decision Support System. *Automation in Construction,* Vol. 18, No. 8, 1135-1143.

Shelbourn, M. A., Bouchlaghem, D. M., Anumba, C. J., Carillo, P. M., Khalfan, M. M. K. and Glass, J. (2006). Managing knowledge in the context of sustainable construction. *ITCON,* Vol. 11, 57-71.

Shen, L.-Y., Lu, W.-S., Yao, H. and Wu, D.-H. (2005). A computer-based scoring method for measuring the environmental performance of construction activities. *Automation in Construction,* Vol. 14, No. 3, 297-309.

Shen, L.-Y., Tam, V. W. Y., Tam, L. and Ji, Y.-B. (2010). Project feasibility study: the key to successful implementation of sustainable and socially responsible construction management practice. *Journal of Cleaner Production,* Vol. 18, No. 3, 254-259.

Tah, J. H. M. and Abanda, H. F. (2011). Sustainable building technology knowledge representation: Using Semantic Web techniques. *Advanced Engineering Informatics,* Vol. 25, No. 3, 547-558.

The Hong Kong Building Environmental Assessment Method (Hkbeam) (1999). Center of Environmental Technology (CET).

U.S. Green Building Council (Usgbc) (2001). Leadership in Energy and Environmental Design—Rating System Version 2.0. U.S. Green Building Council.

Wetherill, M., Rezgui, Y., Boddy, S. and Cooper, G. S. (2007). Intra- and Interorganizational Knowledge Services to Promote Informed Sustainability Practices. *Journal of Computing in Civil Engineering,* Vol. 21, No. 2, 78-89.

Woolley, T., Kimmins, S., Harrison, P. and Harrison, R. (1997). Green Building Handbook: A guide to building products and theirimpact on the environment, E & FN Spon, an imprint of Thomson Science &Professional.

Wu, W. and Issa, R. R. A. (2010). Application of VDC in LEED projects: framework and implementation strategy. Proceedings of the CIB W78 2010: 27th International Conference, 2010 Cairo, Egypt, November 16-18.

Yammiyavar, P. and Kate, P. (2010). Developing a Mobile Phone Based GUI for Users in the Construction Industry: A Case Study

Human Work Interaction Design: Usability in Social, Cultural and Organizational Contexts. *In:* Katre, D., Orngreen, R., Yammiyavar, P. and Clemmensen, T. (eds.). Springer Boston.

Zainul Abidin, N. (2010). Investigating the awareness and application of sustainable construction concept by Malaysian developers. *Habitat International,* Vol. 34, No. 4, 421-426.

Appendix1. Evaluation of the SCPS - (Adopted from Davis, 1989)

A. Perceived usefulness

Using SCPS in my job would enable me to accomplish tasks more quickly.

Using SCPS would improve my job performance.

Using SCPS my job would increase my productivity.

Using SCPS would enhance my effectiveness on the job.

Using SCPS would make it easier to do my job.

I would find SCPS useful in my job.

B. Perceived Ease of Use

Learning to operate SCPS would be easy for me.

I would find it easy to get SCPS to do what I want it to do.

My interaction with SCPS would be clear and understandable.

I would find SCPS to be flexible to interact with.

It would be easy for me to become skilful at using SCPS.

I would find SCPS easy to use.