# BIM AND OPTIMISATION TECHNIQUES TO IMPROVE SUSTAINABILITY IN GREEN CERTIFICATION SUBMISSION OF CONSTRUCTION PROJECTS

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## *ABSTRACT*

*Green Buildings are gaining popularity in the construction industry as a result of strict environment protocols and carbon neutral policies by the governments across the globe. In Australia alone, since the introduction of Green Star Certification 5.5 million square metres of buildings have been certified as green buildings. With more stakeholders involved, the green certification submission process has become more complicated with less focus on triple bottom line approach of sustainability. Research has shown that 85% of the green submissions are concentrated on environmental sustainability with less significance on economic and social aspects. Building Information Modelling (BIM) is a cutting-edge technology that allows effective decision making. The proposed research aims to develop a BIM model that can improve the sustainable decision making during green certification processes. Multi-objective optimisation techniques were developed to optimise the best design solution for different design criteria. A case study is employed to verify the functions of the platform suggested in the study. The results of the case study indicated a combination of green design options provide a maximum of 4.54% GHG emission reduction per unit cost increase. The outcomes of the research will be important to organizations who are keen on improving the environmental sustainability while minimising the economic implications.*

***Keywords:****Building Information Modelling; Cost; Green Buildings; Greenhouse Gas; Sustainability.*

## 1. INTRODUCTION

In Australia, the construction industry contributes to around 100 billion dollars to the country's Gross Domestic Product (GDP) and employs around one million people, which account for 7.8% of Australia's GDP and 9.1% of the workforce, respectively (Statistics, 2015 ; Love et al., 2005). Buildings are known contributor for energy consumption and environmental emissions throughout the life cycle. Research studies emphasize that decision taken during the design and conceptual stages will have more influence on reducing environmental emissions and energy consumption. The concept of green building was introduced to acknowledge the concept of sustainability by optimising the energy consumption and resource usage to minimise life cycle environmental impacts. In the current scenario, contractors and designers are in constant search for advanced technologies and new materials to improve the environmental performance of buildings. Despite these efforts research studies emphasize several impediments that restrict the opportunity to benchmark a particular green material or green construction technology.

Green Star rating system is the official rating system developed by Green Building Council of Australia (GBCA) to rate the buildings based on the environmental performance. Since the introduction of the rating system, 5.5 million square metres of buildings have been certified by GBCA as buildings. In spite of a well-addressed point system the absence of a systematic evaluation framework restricts the opportunity to select the most optimised selection to claim the green star points. For instance, using green construction materials in a building is subjected to availability of the material otherwise points may be lost for not using locally available materials. Therefore, a consistent assessment platform is required for optimising the available green design options to promote effective green building decision making.

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In most cases designers do not consider the practical limitations of certain construction technologies and resource usage which results in huge cost implications and unsustainable outputs. For example, use of prefabrication construction is found to be an effective and environmental friendly construction technique because of quick installation. However, studies have also highlighted transportation distance and longer waiting time may increase idle time and thus affect the construction time and environmental emissions (Sandanayake et al., 2017b; Frey et al., 2010). This also implies that sustainable decision of material usage or construction technique varies based on the types of project and other limitations. Often these complications are observed at later stages which results in reactive measures. Moreover, some of the environmental impact assessment platforms such as commercial LCA software requires complex modelling and expert opinions. Therefore, the requirement of a proactive comparison platform would really assist the decision makers to optimise their green decisions. Thus, the objective of the paper is to develop an evaluation framework using Building Information Modelling (BIM) that compliments the green star rating system and optimises the green designs and sustainable decision making for a building. The outcomes of the study is valuable for designers and contractors who are keen on achieving high environmental friendly construction without compromising the construction time and profit. A generic case study in Melbourne, Australia is used to demonstrate the functions and the capabilities of the framework.

## 2. LITERATURE REVIEW

Sustainability in building construction is defined as the use of building materials, techniques, equipment, and transport to minimize the economic, environmental and social impacts (Fowler & Rauch, 2006; Ding, 2008). However, the unique construction techniques and the site-specific limitations have been some of the major impediments in implementing sustainability at the construction stage. For example, it has restrained the current sustainability assessment tools by either ignoring or approximating the impacts during the construction stage of a building (Illankoon et al., 2017; Doan et al., 2017). The common challenge of minimization of economic impacts not complimenting the reduction of environmental and social impacts led the stakeholders to ignore sustainability aspects of building construction. With the pressure from government and public, the usually ignored aspects of sustainability should be back for consideration in the current construction design and implementation to maintain a healthy development environment with optimized economic benefits. For example, maintaining a balance between carbon emissions and construction cost without compromising the site-specific constraints from their construction activities is one of the objectives of next-generation development (Sandanayake et al., 2017a; Zhong et al., 2017; Fregonara et al., 2016).

In addition, many studies have attempted to quantify the environmental and economic benefits in building designs using various assessment models and techniques (Tsai et al., 2013; Doczy & AbdelRazig, 2017; Shen et al., 2007). Several input parameters such as GHG emissions, indoor air quality, and energy consumption have been considered with economics parameters to obtain the most sustainable design (Steinemann et al., 2017; Chen & Thomas Ng, 2016). Out of these, GHG emissions have been that major environmental parameter considered (Yan et al., 2010; Ji et al., 2017). This is majorly due to the overwhelming contribution of GHG emissions to the global warming potential. However, most of these studies have highlighted issues with data acquisition, management and usage issues associated with manual data handling (Zhang et al., 2017; Sandanayake et al., 2018b). Restrictions over comprehensive assessment was noted as the major limitation as a result of these issues. Building Information Modelling (BIM) has been identified as a potential tool that can eliminate these issues in manual data collection and management (Hardin & McCool, 2015; Zhong et al., 2017). BIM is a technique that also has the capacity to eliminate the potential silos in information management and thus promote the comprehensive sustainable assessment (Hardin & McCool, 2015; Cheng et al., 2016). The potential advantages of interoperability between the BIM model and decision making techniques can be exploited effectively to develop a platform that can acknowledge both green certification and sustainability aspects of a building (Li et al., 2017).

Environmental emissions of a building spreads over wide range along the life cycle starting from material extraction stage through to construction stage, maintenance and finally end-of-life cycle stage. A set of studies have concentrated on estimation of construction waste as means of assessment of environmental impacts of buildings (Li et al., 2014; Silva et al., 2014; Wu et al., 2016). The findings of the study emphasize the importance of recycling materials and the use of recycled materials in building construction. However, the major focus of building emission studies were on air emission calculations. This is due to the long life cycle and the huge energy consumptions. Majority of these air emission studies on buildings have emphasized the dominance of emissions at the use and maintenance phase overpowering the emissions at other life cycle stages. However majority of these studies have concentrated on estimating GHG emissions while giving less significance to other non-GHG air emissions (Mao et al., 2013; Sandanayake et al., 2018a; Aye et al., 2012). These studies have highlighted the 70-80% of use phase GHG emissions as compared to 4-12% construction stage emissions, 8 to 15% materials stage emissions and 3 to 5% end-of-life GHG emissions (Guggemos & Horvath, 2006; Guggemos, 2003).

Despite the lower life cycle contribution, Construction stage building emissions are associated with several emissions (Sandanayake et al., 2016a; Mao et al., 2013). These emissions can be GHG emissions and non-GHG emissions as a result of fossil fuel combustion. The importance of assessment of construction stage emissions and impacts are highlighted in a number of previous studies (Sandanayake et al., 2017b; Sandanayake et al., 2016b). These studies highlight the importance of assessing in-depth construction stage emissions because it leads to short-term and localised environmental impacts. Especially due to the direct emission release of non-GHG emissions as a result of fossil combustion, other environmental impacts such as acidification potential (AP), Photochemical Oxidation Formation Potential (POFP) and Human Toxicity Potential (HTP) can have major influence for the environment.

Therefore, it is important to investigate the possibilities of reducing the construction stage impacts without compromising the cost implications.

## 3. DEVELOPMENT OF FRAMEWORK

Based on the literature review and initial consultation with green building professional a framework is established that can help the decision making process. The framework is developed in two major steps. Step one is to develop the BIM enabled data management framework which enhances the data management process for sustainability assessment.

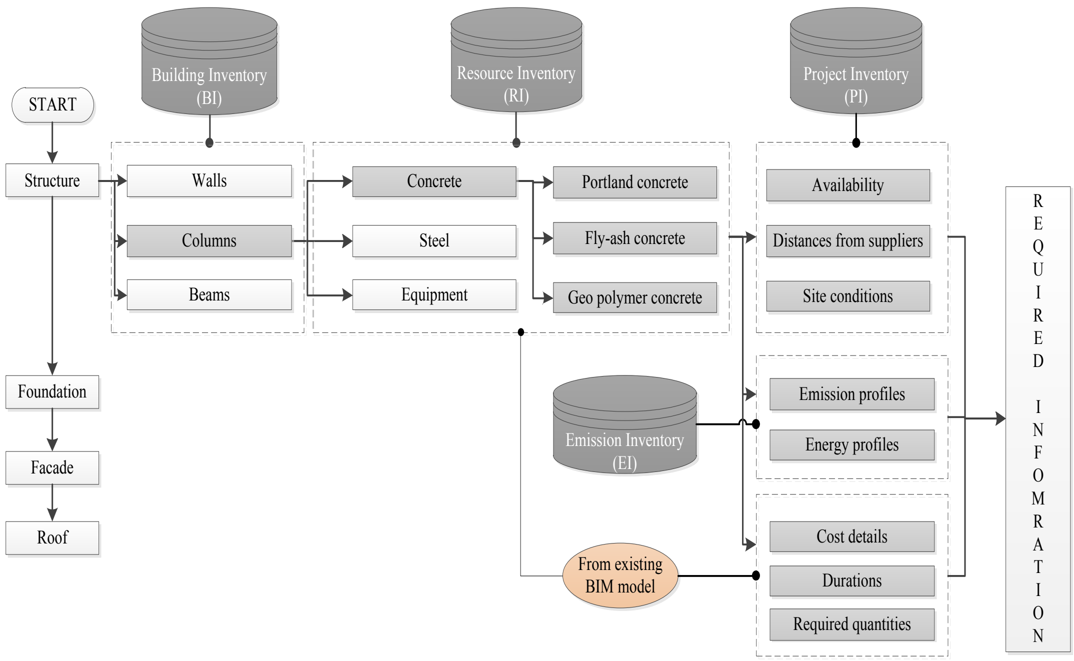


Figure 1: Information Flow in the Proposed BIM Enabled Data Management Framework

Step two is to divert the required information towards the optimisation assessment. Figure 2 highlights the decision-making framework proposed for decision making in green building design. However, the current study considers only the highlighted sections in Figure 2.

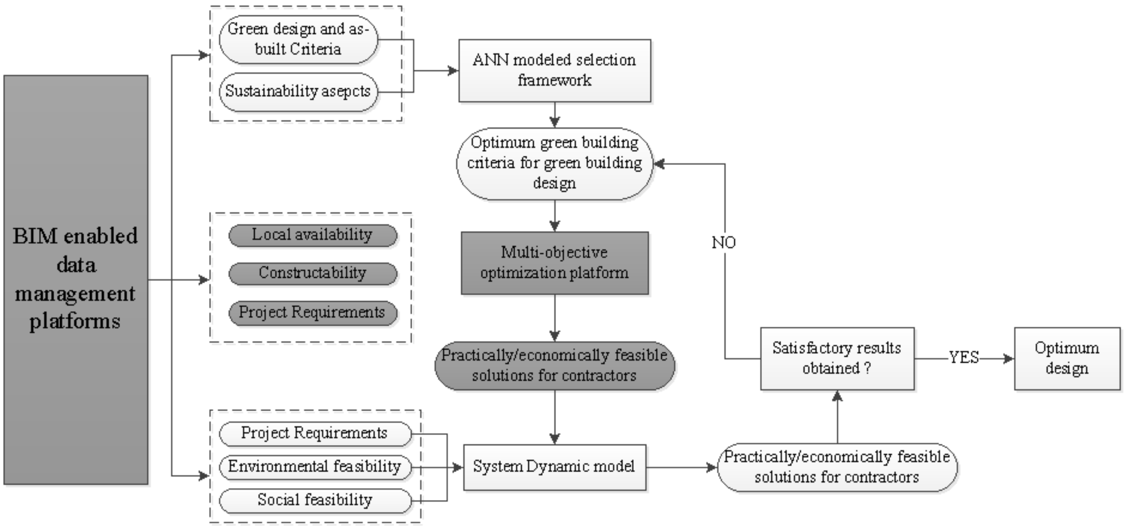


Figure 2: Integrated Decision-Making Framework

## 4. RESEARCH MODELS AND METHODOLOGY

### 4.1. *THE SCOPE AND SYSTEM BOUNDARY OF THE STUDY*

Majority of the sustainable building decisions are made during the conceptual stage of a building and often involves emissions and impacts of all life cycle stages of a building. While acknowledging the importance of considering all life cycle stages impacts in decision making, the current study aims to include the construction stage impacts in decision making of green building design. Air emission is the major emission type considered in the current study. Both GHG and non-GHG emissions are present in construction stage due to combustion of fossil fuel. $CO_2$ emissions are considered as GHG emissions because majority of the GHG emissions are $CO_2$ emissions especially with fossil fuel combustion. Therefore, GHG emission substances are chosen as they are the pre-dominant pollutant substances associated with fossil fuel combustion.

The most comprehensive system boundary for emissions and impacts at building construction should include embodied emissions from materials, emissions from equipment usage and transportation and emissions due to electricity consumption. These impacts can either be direct or indirect emissions based on the location and the severity. Even though there is a controversial opinion of including embodied emissions from materials in the construction stage, several studies have included it to maintain the inclusiveness of the analysis. Therefore the study considered three major emission substances including embodied emissions of materials ($E_M$), emissions due to machines and equipment usage ($E_i$) and emissions due to transportation ($E_{Ti,j}$). Emissions due to electricity usage is mainly due to equipment use and thus is included in $E_i$ calculations.

LCA is the major methodology used for assessing environmental emissions and impacts of a building life cycle. Out of the three major LCA methodologies (Input-output, Process and Hybrid), process based quantitative approach is selected to assess the environmental impacts. This is because a lot of information for the case study was readily available and for a comparative assessment process-based models are found to be the most effective approach (Yan *et al.,* 2010; Mao *et al.,* 2013).

### 4.2. *EMISSION ESTIMATION MODELS*

Air emissions have been the major research consideration when building construction is considered. In general, total emissions (*TAE*) from building construction can be expressed as follows:

$$(TAE)_i = [\sum_{i=1}^{n}[(M\{\lambda, m\} + EQ\{t, f, \eta, p, \varepsilon\} + T\{d, f, \varepsilon\} + EL\{p, t, \eta\}] \qquad \text{Eq. (01)}$$

Where, *M* is the emissions from materials; *EQ* is the emissions from equipment; *T* is the emissions from transportation and *EL* is the emissions from electricity for the $i^{th}$ pollutant type.

Emissions from materials are obtained from the following equation (Mao *et al.*, 2013).

$$E_M = \sum Q_i * e_{im} \quad \text{Eq. (02)}$$

Where, *EM* is the embodied emission of materials (*i*) used in the construction phase in kg of pollutant-eq, *Qi* is the amount of $i^{th}$ material used in kilograms and $e_{im}$ is the energy factor or the emission factor for $i^{th}$ material in kg-pollutant equivalent-eq/kg.

Emissions due to transportation are calculated using the equation below (Sandanayake *et al.,* 2017b).

$$ET_{i,j} = \frac{A_{i,j} * EF_{i,j}}{1000} \quad \text{Eq. (03)}$$

Where: $ET_{i,j}$ is the $i^{th}$ emissions from the fuel type (j), $A_{i,j}$ is the activity type for calculating emission type i. For greenhouse gas emissions it is equivalent to the multiplication of quantity of fuel consumed in kL and energy content factor for fuel type (j) in GJ/kL and *EFj* is the emission factor for the fuel type (j) in kg-emissions/GJ. For non-GHG emissions the $A_{i,j}$ is calculated using characteristics such as the power of the machine (kW) and the deterioration of the vehicle and the cumulative distance travelled (km).

Similarly, emissions from construction equipment can be estimated as mentioned in the following equation (Sandanayake *et al.,* 2016a).

$$E_i = EF_i * P * T * LF \quad \text{Eq. (04)}$$

Where: $EF_i$ is the emission factor for the emission element i considered in g/(kW-hr); *P* is the rated power output of the equipment considered in kW; *T* is the hours of use of the equipment for the activity considered; *LF* is the load factor which is the fraction of available power during the operation of equipment.

### 4.3. COST ESTIMATION MODEL

Total construction cost (*TCC*) including direct (*D*) and indirect (*I*) costs can be represented from the following generic equation.

$$TCC = [(MC)_D + (LC)_D + (EC)_D + (TC)_D + (GC)_I] \quad \text{Eq. (05)}$$

Where, *MC* is material cost, *LC* is labour cost, *EC* is equipment cost, *TC* is transportation cost and *GC* is green cost.

### 4.4. BIM MODEL AND DATA EXTRACTION METHOD

A typical residential building located in Melbourne, Australia is used as the base case for the analysis. The floor area of the building is 231 square metres. The construction site was flat without any major excavations. The local environment of the construction site was observed suburban. The building consists of four bedrooms with a living room, family room, two bathrooms and a garage. The soil type was classified as class "H" based on the soil reactivity. Waffle pod slab was utilised as the foundation for the building. Using Revit BIM the 3D model is developed for the case study to obtain the necessary information for the optimisation assessment. Figure 3 and 4 illustrate the developed BIM model and the building plan of the case study used.

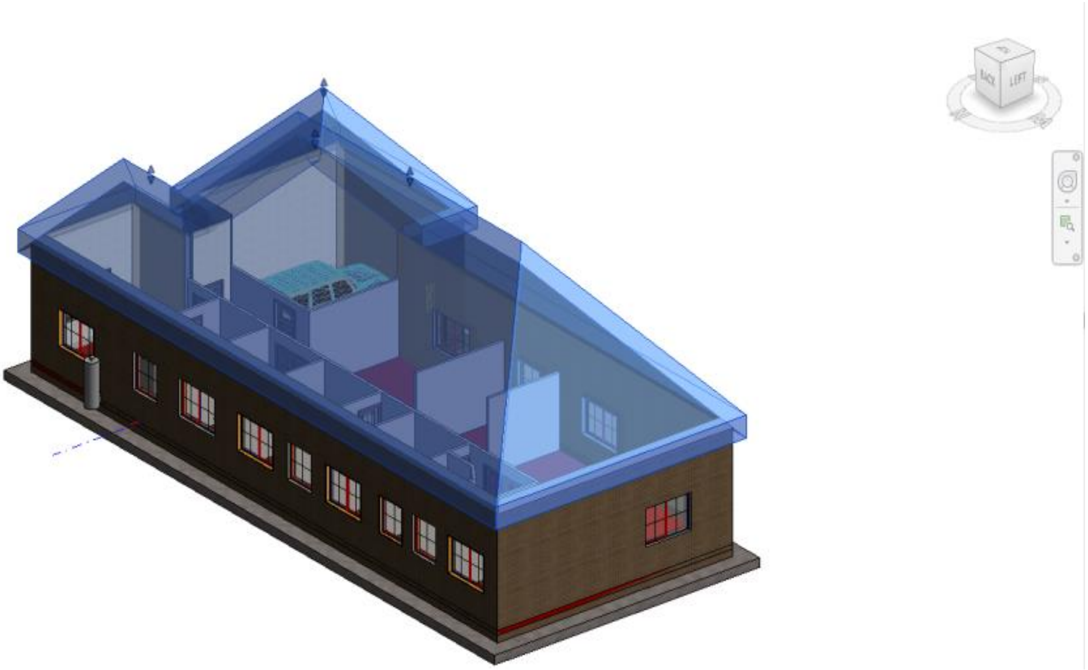

Figure 3: Modelled House Using Revit BIM

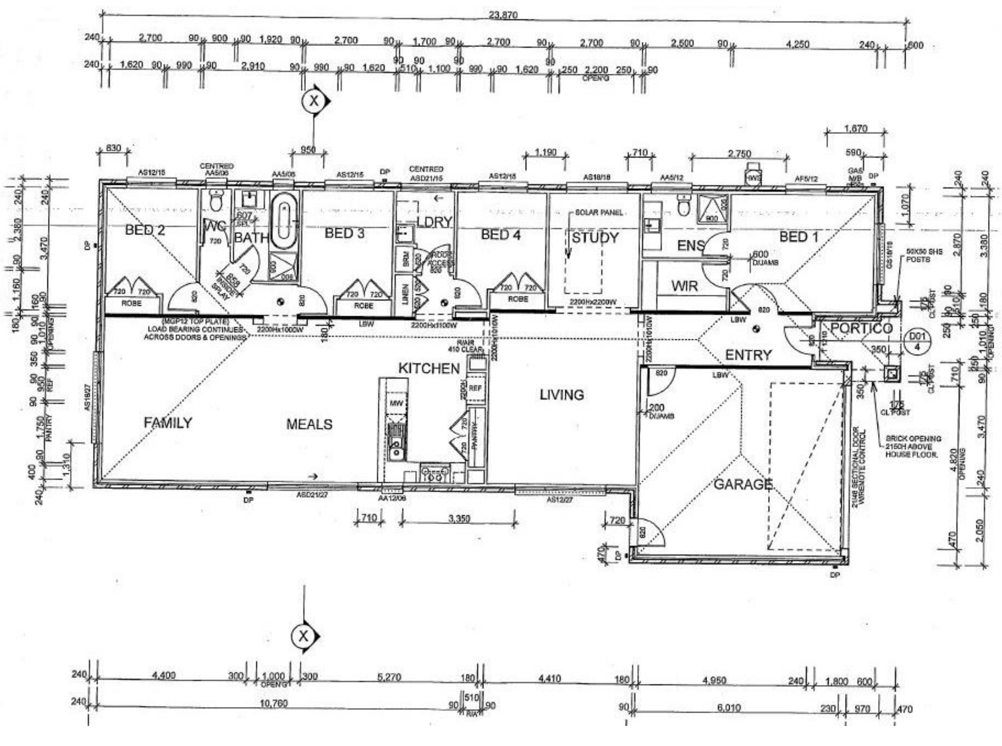


Figure 4: Building Plan Used for the Case Study

### 4.5. *OPTIMISATION TECHNIQUE AND OBJECT FUNCTIONS USED*

Precise modelling is required to incorporate the critical project parameters in these model components to increase the accuracy of the optimization process. For instance, using a locally unavailable sustainable material may reduce the material and green costs but the transportation and labour costs may be higher than the locally available material. Therefore, multi-objective optimisation based algorithm is developed to investigate cost and emission aspects of building construction.

The optimization algorithms and prototypes are based on multi-objective particle swarm optimization (PSO). PSO concept is developed by Kennedy and Eberhart (Kennedy *et al.*, 2001) based on the social behaviour of birds. The population of candidate solution is called a "swarm" and each individual in the space is called a "particle". The PSO procedure used in this research study is shown in Figure 5. The initial step is to identify the swarm objective function (Isus). The basic parameters for optimization such as environmental parameters, cost parameters and site specific parameters were then be obtained from site working sheets and from site management reports. The initially randomly generated solution for the object function is then evaluated in each step. With each iteration, the economic environmental parameters are assessed subjected to the local demands. The fitness of the swarm is then calculated to determine global best position for the particle. The objective functions and the relevant constraint functions are explained in the equations below.

Objective function:

Minimise, $f_1$ = *total air emissions (TAE)*

*f2 = total construction cost (TCC)*

Subjected to constraints:

Fly ash quantity (x), $0 \geq x \geq Qi/2$ ($Q_i = 118\ m^3$)

Slag concrete (y), $0 \geq y \geq Qi/2$

Recycled coarse aggregate (z), $0 \geq z \geq qi/2$ ($q_i = 94\ m^3$)

Recycled construction waste (ñ), $0 \geq ñ \geq (0.10)\ Qi/2$

The objective function is to minimise GHG emissions and construction cost explained in Eq. (01) and (02) for the considered design inputs described in the following section. 50% of green materials are used in the optimisation study because geo-polymer concrete should be off-site fabricated due to heat curing and thus foundation cannot be off-site fabricated. The beams, columns and wall panels are assumed to be off-site fabricated with green materials for Scenario 1 (SC1). In Scenario 2 (SC2) and Scenario 3 (SC3), 50% replacement of in-situ concrete and 50% recycled coarse aggregate is used respectively to maintain the uniformity of the analysis. However, in real case analysis this assumption is not necessary. Table illustrates the major details of the design scenarios considered for the study. In the study recycle of construction waste refers to concrete waste recycling.

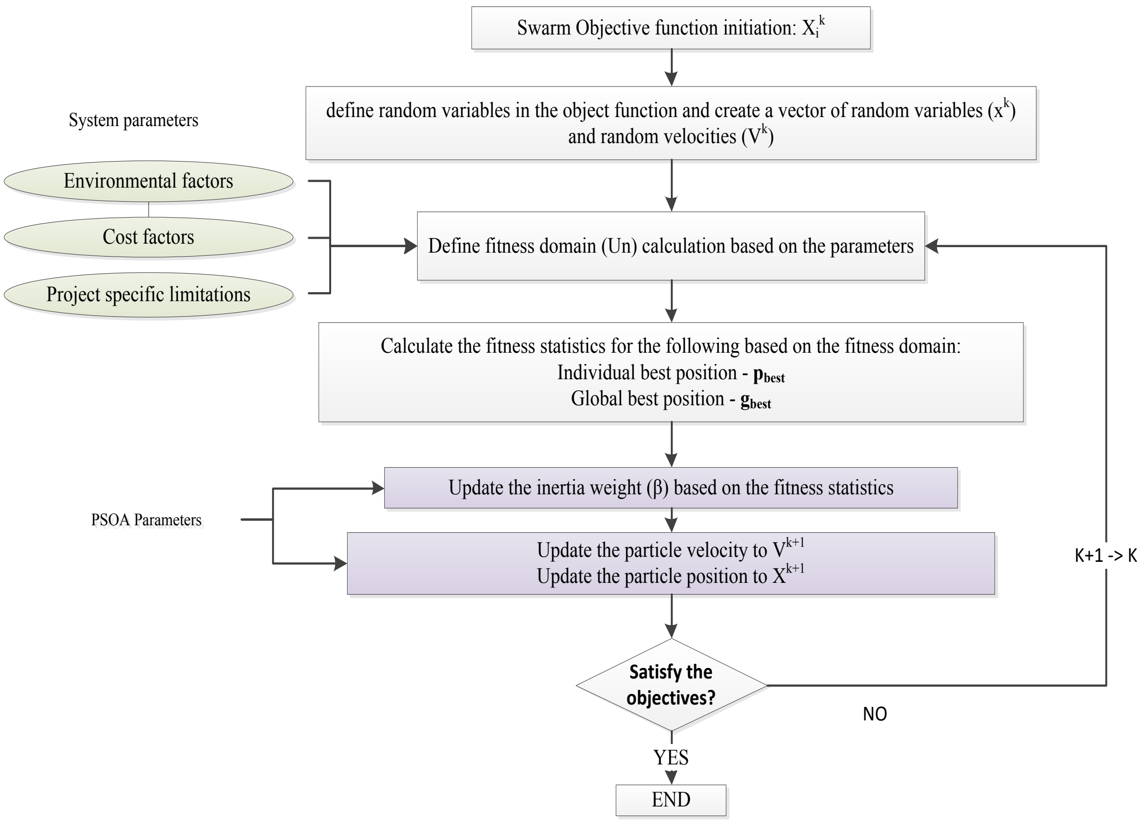


Figure 5: Flowchart for the Swarm Particle Optimization Procedure

Table 1: Design Inputs Considered for the Optimisation Study

| Notation | Design input | Description |
|---|---|---|
| **SC1** | **Use of green materials – Option 1** | In this scenario 50% of in-site concrete is replaced with fly-ash Geopolymer concrete. |
| **SC2** | **Use of green materials – Option 2** | In this scenario 50% of in-situ concrete is replaced with slag concrete |
| **SC3** | **Use of recycled materials** | In this scenario 50% recycled coarse aggregate in concrete |
| **SC4** | **Recycling of construction waste*** | The scenario considered 80% recycled construction waste for the case study |

* (Sandanayake *et al.,* 2018a)

## 5. RESULTS AND DISCUSSIONS

The case study developed using Revit BIM is used to demonstrate the functions described in step 2 of the framework described in Section 3. Data and information from BIM model and other inventories have been used for the optimisation assessment. Since the BIM enabled data management platform is not developed the automation could not be demonstrated. For explanation purposes, the variation of GHG emissions with construction cost is discussed in the results section. Based on number of results obtained from the optimisation assessment eight discrete results were selected to demonstrate the significance of the results. The corresponding results of the optimisation assessment is shown in Table . The base case (reference) scenario observes GHG emissions of 54.8 tons-$CO_2$-eq while the construction cost is found to be $ 28,320. Seven major outputs with different combinations of scenarios show discrete reduction/increase GHG emissions and construction cost.

Table 2: GHG Emissions and Total Cost for Different Combinations

| No | Combination | | | | GHG emissions (tons$CO_2$-eq) | % difference* | Total Cost ($) | % difference* |
|---|---|---|---|---|---|---|---|---|
| | SC1 | SC2 | SC3 | SC4 | | | | |
| Ref | - | - | - | - | 54.8 | - | 28,320 | - |
| 1 | 50% | - | - | - | 47.51 | - 13.3% | 37,608.96 | + 32.80% |
| 2 | - | 50% | - | - | 44.23 | - 18.2% | 30,343.41 | + 7.14% |
| 3 | - | - | 50% | - | 52.12 | - 4.89% | 29,100 | + 2.75% |
| 4 | - | - | - | 80% | 53.1 | - 3.10% | 29,300.54 | + 3.5% |
| 5 | 20% | 20% | 20% | 80% | 44.8 | - 18.25% | 29,458.95 | + 4.02% |
| 6 | 35% | 20% | 50% | 80% | 42.4 | - 22.60% | 31,357.75 | + 10.73% |
| 7 | 20% | 43% | 30% | 63% | 44.1 | -19.52% | 30,015.13 | + 6.0% |

* (-) refers to a reduction and (+) indicates an increase

The comparative results indicates that scenario 2 (SC2) and scenario (SC3) provide the most optimum results when only one scenario is considered. As such SC3 provides 4.89% GHG emission reduction per 2.75% cost increase and SC2 provides an 18.2% GHG emission reduction with 7.14% cost increase. Thus, it further highlights that SC3 1.78% GHG reduction per unit cost increase while SC2 highlights 2.55% GHG reduction per unit of increase. However, the important notice here is that none of the options provides a cost decrease. This is because all the green/sustainable design options carry an additional cost as compared to traditional designs.

The results in the table also highlight various combinations that provides GHG emission reduction. Out of three combinations, set 5 with 20% from SC1, SC2, SC3 and 80% from SC4 provides an 18.25% GHG emission reduction per 4.02% cost increase which gives a 4.54% GHG reduction per unit cost increase. This is also the best obtained result among all the combinations considered. The results further justify the importance of having an integrated decision making framework that provides the most optimum design for minimising emissions with minimum cost implications. A similar analysis can be conducted for other pollutant substances and thus final decisions can be made based on the priority and the requirements of the green design submission.

## 6. CONCLUSIONS AND FURTHER RESEARCH

Green rating is a popular benchmark to evaluate the environmental friendliness of a building. However, with the lack of acknowledgement between the environmental emissions and construction cost the contractors are faced with the dilemma for optimised decision making. With the increased cost and lack of availability of some of the green materials there is a contemporary requirement for decision makers to optimise the available options that minimise both cost and emissions without compromising the project limitations.

Therefore, the study considered four different material options to investigate the emissions and cost variations to select the optimised selection for green building design. Four design options involving use of green materials (SC1 and SC2), use of recycled material (SC3) and recycling construction waste (SC4) are considered for the optimisation study. The results indicated that a combination of various design options provide the most optimum output. Observations from the analysis highlighted a maximum of 4.54% GHG emission reduction per unit cost increase using combination of different scenarios as compared to a maximum of 2.55% GHG emission reduction per unit cost increase considering only one scenario. However, these results are case study specific and could vary for different building case studies based on project specification factors material availability, transportation distances and site location. The results obtained in the analysis further justify the importance of optimisation between various designs prior finalising the design for green/sustainable building construction.

The paper presented an initial analysis of using BIM and optimisation techniques to upgrade the green building decision making process. The authors are in the process of developing a BIM enabled sustainable decision making platform that promotes the green building submission processes. The current study used the BIM generated input design information to manually conduct the optimisation assessment for sustainability assessment. However, once developed, the full decision making platform will enable automated decision making to improve the material selection, construction technique, resource management at building site and waste minimisation to obtain the optimum green rating points.

The current study only considered construction cost in cost optimisation model. Moreover, only material specific design options were considered for the optimisation study. The optimisation study also didn’t consider any project specific constraints or limitations. The research team is planning to include all the life cycle stages of a building into the decision making platform to upgrade the decision making process. Future studies are also encouraged on conducting comprehensive assessment including the life cycle cost, project specific limitations to discover several design aspects in green building design and submission.

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