BIM-BASED INTEGRATION OF CARBON DIOXIDE EMISSION AND COST EFFECTIVENESS FOR BUILDINGS IN TAIWAN

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***ABSTRACT*:**

With industrial development, global carbon emission has increased rapidly. Countries around the world have launched environmental policies related to carbon dioxide reduction. In Taiwan, the government proposed "Sustainable Energy Policy" in 2008, which clearly revealed the targets and milestones for CO_2 reduction. Since Taiwan's construction industry accounts for nearly 27.22% of total carbon dioxide emission, it is necessary to improve and reduce carbon emission related to construction. In order to respond to the governmental policies, project owners will have to consider using low carbon materials for building design. However, low carbon materials are usually more expensive, and their performances on carbon reduction are hard to gauge. To meet this need, this study integrates building information modeling (BIM) software (Autodesk Revit), energy simulation software (eQUEST) and Microsoft Excel to calculate the lifecycle costs and CO_2 emission of construction materials. Based on the carbon taxes implemented in different countries, this study adopts compromise decision and net present value (NPV) methods to look for materials with low carbon emission and lifecycle costs. The cases in this study verify the feasibility of the proposed integration with a 5% margin of error. In the future, with more low carbon materials available, the integrated system will be more ready for practical use.

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KEYWORDS: Building information modeling (BIM), carbon emission, life-cycle cost

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1. INTRODUCTION

According to report published by Intergovernmental Panel on Climate Change in 2011 (IPCC, 2011), the world temperature has climbed up rapidly. The increase amount of green house gases, especially carbon dioxide, is mainly from the overuse of fossil fuel and excessive human activities. With the increase of global carbon dioxide emission, members of United Nations started to establish standards for carbon dioxide reduction. Taiwan's government also takes part in establishing related policies for environment protection in recent years in attempt to lower the environmental impact towards future. Taiwan's total carbon emission amount is ranked 22th in the world, and construction industry accounts for 27.22% of Taiwan's total carbon emission. The government also plans on charging carbon tax, therefore in future project, it's important to implement carbon emission control throughout the whole project phases. The amount of carbon emission during material's production and transportation stages are calculated by Chang (2002), who created a carbon emission database for construction materials. The carbon emission of main structure was evaluated by Lin (2012), who proposed carbon emission standards for RC residential buildings. The study also recommended that building license should be given according to the implementation of carbon control to have mandatory control in construction industry.

Now with the development of computational and visual technology in software, computer aided in architecture, construction and MEP (mechanical, electrical, and plumbing) systems has been widely adopted from a 2D-base to 3D-base. BIM (Building information modeling) serves as a digital database with comprehensive building information, 3D visualization, work simulation, schedule control characteristics. Hua (2011) integrated BIM in LEED EA credit1 design of Taiwan's building envelope, which used great amount of data in BIM to conduct the automatic parameter calculations. Mah (2012) used BIM to evaluate the carbon emission during construction stage. The above studies all demonstrated the possibility and enhanced efficiency in integrating BIM. Carbon emission evaluation conducted in construction industry is basically documented without a systematic management. BIM can create a platform for users to constantly update material information, creating a digital working environment for project participants. Cost is another concern when it comes to choosing an alternative construction material with lower carbon emission. In order to make appropriate decision, project manager needs an evaluation method to assess the environmental impact and also the potential increase in project cost.

1.1 Objectives

The main purpose of this study is to calculate the carbon emission of a building during construction and operation stage, and to propose an ideal combination of construction materials based assessment on cost, carbon emission and carbon tax.

2. METHODOLOGY

Methodology used in this study including data collection, computer simulation, mathematic analysis, financial analysis and case study. This study basically integrates BIM software and energy simulation software (eQuest) to evaluate carbon dioxide emissions. Evaluation flowchart is shown in Figure1:

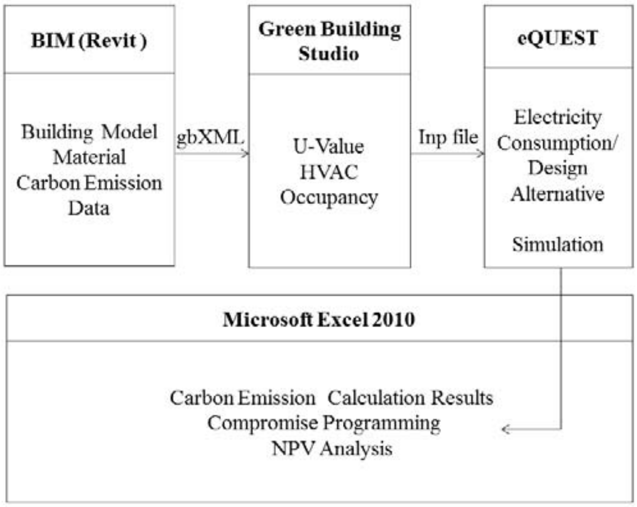

Figure1 Evaluation Flowchart

2.1 Study scope

The calculation of carbon dioxide emissions in this study focuses on material's production, transportation and operation stages. Also, according to Figure2, main structure, doors/windows construction and partition construction are taken into consideration. The total carbon dioxide emissions discussed in this study accounts for 84% of the whole building carbon emission.

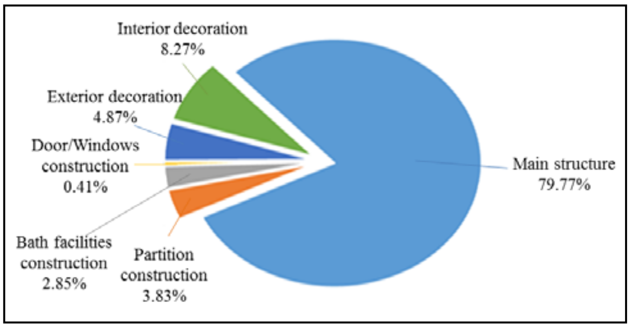

Figure2 CO_2 emission percentage (Chang, 2002)

2.2 CO_2 Data collection

Data are collected from previous study and through interviewing with material companies. Table1 shows the gathered material data. In material production stage, total electricity consumptions are multiplied with unit carbon emission amount to calculate the total amount. In transportation stage, average material transportation distance and average gasoline consumption (4km/L is used in this study) are two inputs in calculating total carbon emission.

Table1 Carbon emission data

Construction	Carbon Emission
Concrete	273.03(kg-CO_2/m^3)
Reinforcing bar	964.75(kg-CO_2/T)
Calcium Silicate board	16.66(kg-CO_2/m^2)
Gypsum wallboard	4.62(kg-CO_2/m^2)
Steel Frame (90X90)	6.69(kg-CO_2)
Alumni Frame (90X90)	39.59(kg-CO_2)
Low-E glass	1.2(kg-CO_2/kg)
Reflective glass	0.96(kg-CO_2/kg)
Mirror glass	0.93(kg-CO_2/kg)
HVAC	136198(kg-CO_2/type)

2.2 Carbon emission evaluation

Multiple tasks in dealing with carbon emission data are divided into four steps. Step1: Create model in BIM (Revit Architecture is used in this study). Material information of cost and collected carbon emission data are input into the model. A gbXML format file should be created and transferred to green building studio. Step2: Green building studio (GBS) compiles data required to input into eQuest, including weather file, material's U-value and HVAC design information. An inp format file will be generated by GBS will be used in eQuest. Step3: eQuest will read the inp file and conduct energy simulation in building's operation stage. Step4: Export energy consumption data and carbon emission amount in production stage to Excel.

3 Analysis based on carbon emission and cost

3.1Compromise decision model

The compromise decision method is a mathematical programming technique to find a compromise solution based on multiple criteria, providing the closest solution compared to the best one. It is now used in many fields including finance, engineering and management to help decision makers. The multicriteria in this study refers to cost and carbon emission. Figure3 demonstrates the idea of using compromise decision model in this study. Calculation formula is listed as follows:

$$\text{Min} \quad Z = \left(\sum_{i=1}^{k} w_i^p (f_i^* - f_i(x))^p\right)^{1/p} \quad \text{----- (1)}$$

where,

Z=Distance to the best solution

w_i=weighting factor

p=1,2

i=Number of targets

f_i^*=Value of best solution

$f_i(x)$=All possible solutions

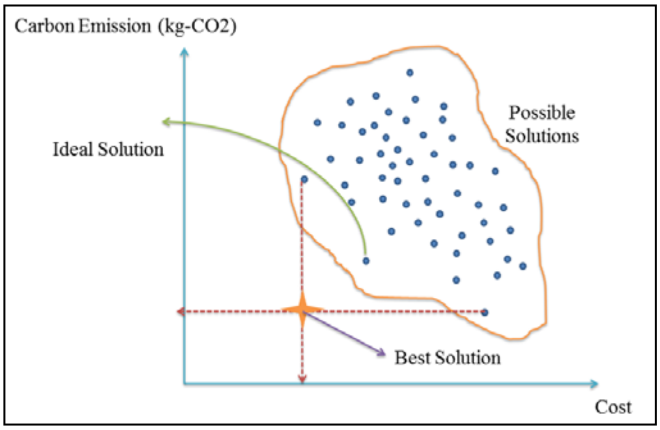

Figure3 Compromising programming method

3.2 Net Present Value (NPV)

NPV is often used in capital budget assessment to analyze the profitability of an invested project. The evaluation method is based on discounted cash flow (DCF) analysis, which considers the time value of money to conduct a life cycle cost analysis of a project. If NPV is negative, the project should be rejected. Financial analysis model is shown in Figure4. The study uses 50 years as life cycle years.

$$NPV = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} - C_0 \qquad \text{------------ (2)}$$

where,

CF =Cash flow of each period

C_0 =Cash flow of first period

T =Total period

t =The time of the cash flow

r =Discount rate

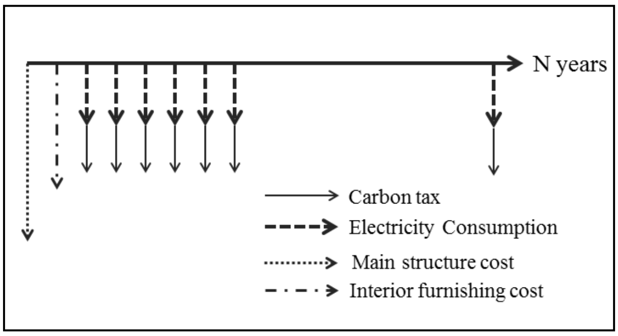

Figure4 Net present value evaluation

4. Case Study

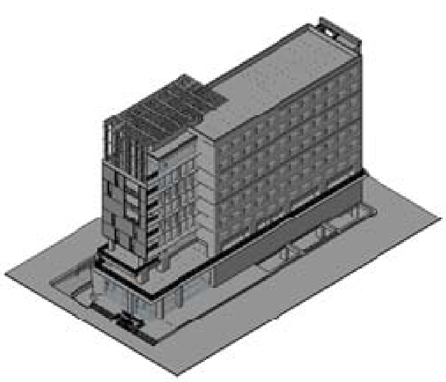

Figure5 Case study BIM model

Case study model is located in Taipei, Taiwan. It is an educational and research building, see Figure5. Occupancy period is basically 12 hours. The building was operated since 2008 with total area of 10000m^2 with 9 above ground floors and one basement floor. The second floor contains special seismic isolation design. This study simulates with two different rooftops, three facades and external walls, and four windows as material design alternatives shown in Figure5. The baseline model refers to the original designed construction material of this building. The material alternatives are shown in Table2.

Table2 Material Alternatives

Alternative Materials	Cost (NTD/unit)
Roof	
R1:Baseline Roof	1760/sqm
R2:Cool Roof	1850/sqm
Window (with frame)	
W1:Single-Clear(baseline)	3981/unit
W2:Single-Reflective	4402/unit
W3:Single Low-E	7275/unit
W4:Double Low-E	12399/unit
Exterior wall	
E1:Concrete Wall 25cm	587/sqm
E2:ConcreteWall 30cm (baseline)	705/sqm
E3:Concrete Wall 25cm	823/sqm

Material alternatives are designed based on eQuest material database, which provides a wide selection of different construction materials. Simulation results according to compromising decision model shows the best material combination without considering carbon tax is cool roof with 25 centimeter concrete and single Low-E window design. Total life cycle cost is 306 million NTD with total carbon emission 48.8 million kg-CO_2. If carbon tax is taken into consideration, the best material combination is cool roof with 25 centimeter concrete and single reflective window design. When tax is considered, evaluation results can be different due to different cost.

4.1 Verification

The calculation results are compared with actual electricity consumption results (shown in Table3). According to Taiwan's research, average carbon emission is calculated according to formula (3). The results are within margin of error raging from 0.2% to 11%.

$$C = 0.768 * EC \quad \text{--------------------} \ (3)$$

where,

C=Carbon emission (kg)

EC= Electricity consumption (kg/kWH)

Table3 Verification Result

Month	Actual Data (kg-Co2)	Simulation Data (kg-Co2)	Error
1月	65878.06	71578.37	8.65%
2月	60855.58	65991.17	8.44%
3月	85077.60	76957.44	-9.54%
4月	85626.93	76203.26	-11%
5月	87124.15	84482.30	-3.03%
6月	88875.18	85512.96	-3.78%
7月	85202.80	90438.91	6.15%
8月	85821.31	95141.38	10.86%
9月	81485.80	79930.37	-1.91%
10月	80290.25	83712.00	4.26%
11月	74275.00	71178.24	-4.17%
12月	74328.55	71859.46	-3.32%
Total	954841.20	952986.60	-0.2%

4.2 Carbon tax

This study also considers different carbon tax charged by different countries. Table4 shows the proposed material combination with its carbon tax charged. In future, if carbon tax becomes mandatory policy, it can be a huge expense for companies. The control and improvement towards the amount of carbon emission can be very significant.

Table4 Carbon tax in different countries

Cities	Best material combination	Carbon tax(NTD)/year
Shanghai-China	R2:Cool roof E1:Concrete Wall 25cm W3:Single Low-E	3,355,997
Incheon-Korea	R2:Cool roof E1:Concrete Wall 25cm W2:Single Reflective	8,393,243
Paris-France	R2:Cool roof E1:Concrete Wall 25cm W3:Single Low-E	5,573,678
Copenhagen-Denmark	R2:Cool roof E1:Concrete Wall 25cm W2:Single Reflective	5,104,008
Canberra-Australia	R2:Cool roof E1:Concrete Wall 25cm W3:Single Low-E	5,398,925

5. Conclusion

This study combines BIM and energy simulation software eQuest to evaluate construction's carbon dioxide emission. Also, cost and financial factors are considered to find out the optimal combination of building material. In the study, it is concluded that the cool roof can efficiently reduce carbon dioxide emission. After verifying with case study, the proposed evaluation methodology provides a good accordance with actual data. With the process of evaluating material with cost and carbon dioxide emission, developers can create more environmental friendly projects without spending too much cost. Further research can work towards creating building material database, providing a wide range of material selections for developers.

REFERENCES

Autodesk https://gbs.autodesk.com/GBS/

Bureau of Energy, Taiwan: http://web3.moeaboe.gov.tw/ECW/populace/home/Home.aspx

Chang, Y.S. (2002). *Life cycle assessment on the reduction of carbon dioxide emission of buildings.* (Doctor), National Cheng Kung University, Tainan.

Chen, L. (2012). *BIM-based integration of energy saving and cost effectiveness for building envelopes.* National Taiwan University, Taipei.

Hua, C.F. (2011). *Create a Prototype System for Application of BIM in Assisting Automatically Energy Design and LEED EA Credit 1.* (Master), National Taiwan University, Taipei.

IPCC 2011. *Special Report on Renewable Energy Sources and Climate Change Mitigation,* United Kingdom and New York, NY, USA, Cambridge University Press.

Lin, S.C. (2012). *A study of carbon dioxide emissions control of building construction - for example in Taipei RC residential buildings.* (Master), National Taiwan University, Taipei.

Mah, D. et al (2011). House construction CO2 footprint quantification: a BIM approach. *Construction Innovation: Information, Process, Management, 11*(2), 161-178.

Taiwan Construction Cost Index http://prj.tcri.org.tw/pmsweb/default.aspx

Zeng, X.D., & Zhao, A. (2006). Study on the application of energy efficiency building design based on BIM technology. *Journal of Chongqing Jianzhu University, 28*(2), 33