A BIM TOOL FOR CARBON FOOTPRINT ASSESSMENT OF BUILDING DESIGN

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Abstract. The objective of this research is to develop a tool for assessing carbon footprints of a building in the design process using BIM technology. Life cycle assessment and carbon footprint assessment are the two basic criteria in evaluating the emission reduction of CO2e. International assessment standards have been established for mass-produced merchandise and organizational operations. However, the existing standards cannot directly disclose the hotspots of carbon footprints in the building life cycle. An assessment method concerning local climate, living culture, ecology and local construction style is required for building design. This research work presents a framework by which a BIM-enabled data visualization tool is developed to support the carbon disclosure in the building design process.

Keywords. Carbon Footprint Assessment; BIM; BCF.

1. Introduction

Building carbon footprint (BCF) (Lin, 2014) evaluation measures the carbon dioxide in relation to environmental impact over the building life cycle. Recent studies have shown the importance of a whole building life cycle assessment of carbon footprints during the design process. (Baek, et al, 2013)

A number of organizations in AEC industry have identified the lack of tools to conduct carbon footprint assessment and are exploring the new tools associated with BCF methods. Building information modelling (BIM) opens up opportunities to assess carbon footprints of a building in the design pro-
cess. (Sanguinetti, et al, 2012) Few BIM-enabled software tools have been developed for using life cycle assessment methods to assess carbon footprints of a sustainable building. How to use BIM technology that enables architects and designers to assess building carbon footprints instantly for design decision making becomes an important issue. (Jrade and Jalaei, 2013) Moreover, how to integrate BIM procedures and buildings’ life cycle evaluation as part of the design process is also a big challenge.

One of the major challenges is Carbon Disclosure. The common low-carbon green buildings are mostly based on building performance simulation, and increase the building’s ventilation, lighting, or use green material during design stages. However, it is hard to apply the material supply chain or facility management stage to building life cycle. How to use visualization methods to reveal carbon footprint as reference for designers is an important issue. (Lin and Gerber, 2014)

The other challenge is related to Carbon Footprint Evaluation Theory. PAS2050, ISO14067 are the standardization of world carbon footprint currently. Many industrial products also adopt the standardization to build up carbon label or carbon disclosure. However, there’s no suitable standardization for architecture industry. The major reason is because the difference of inventory scope. Most of the products’ inventory scopes are B2C (business to consumer), calculate from production to consumer usage. For AEC industry, most applications are business to business, calculate from production to construction. In this sense, the BCF evaluation in architectural industry should have an independent standardization.

2. The Framework

The research aims to establish a tool that assists BIM software in selecting the local carbon footprint data with local carbon footprint evaluation theory. The designer, who knows the consuming status of carbon footprint during the whole design process, will find out the carbon reduction spot and modify the design immediately. The items (e.g. air conditioning, lighting, electrical appliances, plumbing, electrical transport equipment, and heating equipment) that affect the consumptions of carbon footprint during use phase are obvious, especially for air condition and lighting. (Baek, et al, 2013) Therefore, we select Daily Energy Use (CFeu) in BCF design phase (BCFd) to be the example to calculate the carbon footprint consumption from lighting.

Carbon footprint has regional characters, include: 1) database, 2) evaluation theory, and 3) regulation review and classification method. Take database as an example, the major electricity generation facilities are different country by country. Hence, the carbon footprint of consumed electricity is
different as well, and it causes the carbon footprint of each architectural material to become different. Even though the current carbon footprint database or searching platforms, such as SimaPro, GABI, VJK, JEMAILCA, etc., have great amount of carbon footprint data already, however, the regional characters and different preferences of target users caused the database cannot be directly applied in local areas.

This research aims to build up universal system framework that can be applied to varied sustainable building design processes. We present the evaluation method and carbon footprint database among the system architecture as the breakthrough point for other countries to modify, and better fit with regional characters.

In this research, we focused on developing the BIM-BCF evaluation system by applying Taiwan’s local BCF method to proceed to the carbon footprint calculation as listed in Table 1. In the future, the carbon footprint database and evaluation methods can be correspondingly replaced by locations.

We create a series of BIM API and BIM Objects (or Components) to enhance the evaluation in design phase in order to provide immediate feedback to the designers. It will provide guidance to the designers in choosing the right scheme and appropriate materials in design alternatives and making design adjustment easily by watching the fluctuation of BIM-BCF evaluation.
results. (Biswas and Wang, 2008) As depicted in Figure 1, the BIM-BCF evaluation system developed in this study can be divided into three portions: (1) Carbon Footprint Database, (2) BIM Tools, and (3) User Interface. The modules in this framework are explained as follows:

![Figure 1. BIM-BCF Assessment System Framework](image)

- **Carbon Footprint Database**: It includes the CO$_2$e (carbon dioxide equivalent) of raw materials and recycled materials. And it also provides precise records of relevant values through the process of production and transportation.
- **BIM Template**: This is the key step for linking BIM to BCF assessment. As depicted in Figure 1, the local footprint data are stored in a BIM template which allows the software directly capturing the corresponding values. In addition, the template also allows defining formula and parameters to improve the precision and usability of data processing.
- **Subset Data**: The key issue in supporting design is to correctly extract the appropriate data from the database. If BCF information is directly integrated with the material or space type chosen, then the users will be able to quickly visualize the carbon footprint situation in design operation.
- **BIM API**: As the carbon footprint consumptions are mainly happened at the phase of Daily Use, it also implies that the greatest potential in energy conservation may happen in this phase. Therefore, we chose the BCF evaluation of daily lighting as the major topic in following studies. The process of BCF evaluation normally requires dimensioning, making notations on the drawing and also with table lookup manually. Therefore, how to develop BIM APIs to simplify the tedious process of geometric calculation and table lookup in order to input the right values for the parameters then become the challenge of this study. These APIs, which introduce BCF regulations into BIM, will become the major contribution of this project. (Figure 2 Left)
BIM Object/Component: In order to analyse the day lighting area of each floor, we defined a window component, i.e. CFlWindows, to calculate the area of window lighting. As shown in Table 2 the component is composed of exterior shading, window elements, and invisible floor for calculating the day lighting area on it.

3. The Implementation

In order to focus this study on evaluating the CF impact from lighting energy savings, how to figure out the value of ERli then become an important issue. Based on the BCF principle of self-comparison, the value of ERli in the base case is setup as 1, which means no design is done for lighting energy savings. For actual design projects, the value of ERli has to be acquired by the calculation from building geometry and table lookup. The value of ERli is greatly affected by the geometric parameters of window (e.g. the size of opening and the depth of exterior shading…etc.) because natural lighting will indirectly reduce the use of lighting equipment and lead to the impact to BCF.

Table 2 “CFlWindows” Component Setting

<table>
<thead>
<tr>
<th>Code Factor</th>
<th>BIM Component Parameters</th>
<th>Express</th>
</tr>
</thead>
<tbody>
<tr>
<td>WindowsTL</td>
<td>Effective_NL_Width_L</td>
<td>if(effective_NL_width_L&gt;4m,4m,effective_NL_width_L)</td>
</tr>
<tr>
<td>WindowsTR</td>
<td>Effective_NL_Width_R</td>
<td>if(effective_NL_width_R&gt;4m,4m,effective_NL_width_R)</td>
</tr>
<tr>
<td>d</td>
<td>Depth_Of.getExternal_Shading</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Depth_Of_Natural_Lighting</td>
<td>if(WindowsH&lt;10.5m,(if(d&gt;2m,(5m-(d-2m)),5m) * (1 + ((WindowsH/3.5m) - 1) * 0.5)) ,10m)</td>
</tr>
<tr>
<td>W</td>
<td>Width_Of_Natural_Lighting</td>
<td>WindowsTL + WindowsTR + WindowsW</td>
</tr>
<tr>
<td>NAi</td>
<td>NAiw</td>
<td>W * D</td>
</tr>
</tbody>
</table>

Figure 2. Left: API interface for CFeu / Right: Designer’s operational process
The built-in functions of “Key Schedule” in Autodesk Revit enable the input process of CO₂e and EUI values. After passing the values to the built-in functions and APIs for multiplying the area EUI value with ERli, then the BCF from lighting can be calculated immediately.

The operational process of BCFd-BIM evaluation system includes 4 steps: (1) preliminary Setup, (2) BIM Model Build, (3) Carbon Disclosure by Revit API Processing, (4) Design Adjustment and back to step (3). The above process will help the designers comparing the BCFd results of different lighting schemes. (Figure 2 Right)

The building type also affects the selection of default values and related reference tables in BCF evaluation. As the residential buildings are the major type in the building industry, it is chosen as our test bed in this research. The case studied here is a private house in design phase. For a small house with simple and precise functions, the holistic energy consumption will be dominated by building envelope design. The project operation process is demonstrated as follows:

3.1. REVIT INTERFACE OPERATION

- Tagging a Room by the EUI Space Classification (Figure 3)
- Import the component-CFIWindows (Figure 3 Right)
- Adjusts component (Figure 4)

![Figure 3. 1F-2F EUI Space Classification](image)

![Figure 4. Component Adjustment](image)
3.2. API OPERATION

- Get every floor's area by using the function of the API;
- Calculate D multiplies W, get the lighting area of NAi
- Import NAi and AFli to the equation(3)(5)(6), led to NL, RL, ERli value
- Import the ERli values into the formula (2) to calculate the value of CFl
- Import CFl values to formula (1) to calculate the value of CFeu

3.3. PROJECT ADJUSTMENTS

- **Adjust component**
  A. Windows size / position - adjust the position to change the parameters include WindowsH, WindowsW, WindowsTL, WindowsTR.
  B. Depth of external shading - adjust the external shading will affect the effective lighting depth.
- **Adjust the Project**
  A. Change the mass geometry will affect the area of each floor, replace the component and calculate by API again will get the new carbon footprint value.
  B. Change the configuration and adjustment of external relations will affect the indoor area on each floor

4. The Result

4.1. BIM API TOOL

The above implementation provided a valid tool for BCF assessment in design stage using BIM technology. The API demonstrated in this paper is feasible in evaluating the BCF resulted from the daily use of lighting. It helps measure the geometry of building property, transfer the values to the equation and generate the result of ERli. Then based on the equation (2) in Table 1, the calculation of lighting energy carbon consumption can be completed directly by the API. Moreover, the process and product model developed in this research introduced a useful method in developing all the other assessment items in BCF evaluation.

4.2. SMART COMPONENT

In this study, the built-in parametric function is applied to develop the component in creating the simulated floor surface for day lighting area calculation. The surface geometry is dynamically interrelated to the size of window and the depth of exterior shading. By manually adjusting the effective day lighting width, the natural lighting area adopted from the window then will be figured out.
5. Discussion

Compared with previous literatures, this study reveals significant difference in the immediate carbon footprint computation and the localized value-input while processing the modelling phase. Though there is one similar energy simulation program called GEM-21P, yet its value-input process still needs a variety of conditions in order to accurately assess the energy consumption. (Baek, et al, 2013) This study expect to intercept values directly from the modelling software, furthermore, keeping the ability to modify its value directly back to the modelling software. The benefits are discussed in the following sections.

5.1 AUTOMATIC GEOMETRIC INFORMATION PROCESSING

The CFeu tool uses Revit API in BIM processing. The outcome and future research plans derived from the three methods introduced here are compared below:

5.1.1 The integration of common program module

This research employed three kinds of program modules used in code auto checking system which are filtering elements, retrieve attribute, and assigning parameter. (Autodesk, 2014) These procedures are reflected to several geometric processing tasks as fallowed:

- **Filtering elements:** Utilizing `FilteredElementCollector.OfClass()` and `FilteredElementCollector.OfCategory()` function of Revit API can opt the floor and CFIWindows components.
- **Retrieving attribute:** The `Element.get_Parameter()` function can retrieve the attributes of floor element and CFIWindows components (e.g., floor area, sill height and window width).
- **Assigning parameter:** Utilizing `Parameter.Set()` function can set processed information into properties fields of CFIWindows component (e.g., NAi and sun shading object).

5.1.2 Get the shelter information by Ray Projection

We use the `ReferenceIntersector.Find()` (Autodesk, 2014) function to find the shelter component and calculate the D value. It effectively captures the surrounding shelter object adjacent to the window.
5.1.3 Automatic calculation of the effective natural lighting area

The effective value of natural lighting area value (NAi) is depended by window width and depth of shading (equation 5). In this study, the API can be used to automatically calculate the effective lighting area of each window, and show the result visually.

5.2 DECISION-MAKING ASSISTANCE ON DESIGN

CFeu tool’s interface can assist decision-making for designers in four levels of functions:

5.2.1 Automatic Priority Sorting

CFeu tool then can re-arrange the NL value on the interface according to each window’s NL value, and let designers to prioritize the design parameters in modification, such as size of window components, size of shutter, proximity objects design. In this research, the sorting method we used includes: NL value, and grouping related groups. However, the NL number with highest value doesn’t mean the most worthy component to modify. To correct window components should consider multi-score according to multiple factors and select the most worthy window that needed to correct, such as sun shading property, window size, adjacent objects and etc.

5.2.2 Multiple Schemes Parallel Comparison

The use of carbon footprint calculation, a base case has to be proposed in the first place. Then, calculate the values in the design cases. In this sense, we can evaluate the benefit of carbon emission reduction by comparing values between base case and design cases. In the early design stage, users can propose several design alternatives. The interface we proposed is capable of recording multiple values in design cases, and display in parallel. Users can overview the carbon footprint performance of multiple design cases at the same time, and cross-compare between cases.

5.2.3 Performance Information Visualization

In this research, we use two methods to visualize the design performance:

- **Generating outline for effective natural lighting area (NAi):** The NAi value related to depth of sun shading and window dimension, generate from calculation formula. This interface can process formula calculation automatically, and display lighting projection outline in the model scene.
• **Displaying NL value of each window with colour blocks:** CFeu tool can display analysis with colour blocks, which uses colour filling window components with different materials according to each window’s NL value. Users can evaluate the most worthy window to modify via the shade of colour.

5.2.4 **Real-time feedback for design solution**

Currently, carbon footprint calculation can only evaluate after the design case is finalized, rather than real-time display in the design process. CFeu tool can instantly recalculate the performance right after any modifications on design cases, and produce real-time feedback for users.

6. **Conclusions**

In this research, we developed functions of BIM software, API, and components and establish the real-time BCF disclosure information especially for the phase of daily use which dominates carbon footprint consumption in building lifecycle. Using the API tools developed in this study, it will undoubtedly assist the designers in manipulating the building performance in subtlety in order to achieve a low-carbon architectural environment.

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