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Integrating web map service and building information modeling for location and transportation analysis in green building certification process

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ABSTRACT

In green buildings design and construction, evaluating the sustainable effects of site location and transportation to the ecosystem and human life is a critical and difficult task. Works regarding these matters require experience, time, labor, and manual calculations. In recent years, many studies have been conducted to enhance the application of Building Information Modeling (BIM) in green building certifications. However, the application of BIM to site location and transportation analysis is usually considered impractical due to the lack of a powerful map application in present BIM products. The aim of this research is to develop a framework for the integration of BIM and Web Map Service (WMS) technologies for location and transportation analysis in green building certifications. Using Autodesk Revit API and Google Maps API as the development tools, this research converts the integration model into the BIM-integrated plugin in Autodesk Revit. The plugin is used to streamline the certification process of site location and transportation analysis in LEED (Leadership in Energy and Environmental Design), one of the most popular and globally recognized green building standards.

1. Introduction

1.1. Location and transportation analysis in green building standards

1.1.1. Green buildings and LEED certification

It is widely perceived that the construction industry is among the heaviest consumers of natural resources and a significant contributor of CO_2 emission that leads to the global climate change [1]. According to the U.S. Green Building Council, buildings account for 38% of all CO_2 emissions, 73% of electricity consumption, 13.6% of all potable water and 40% of raw materials in the United States [2]. In response to this threat, construction professionals have embraced Green Buildings, a new trend involving environmentally friendly construction processes to reduce environmental impacts as well as building costs while conserving the earth's resources for future use [3,4].

Green Buildings is a growing trend across the globe: McGraw-Hill Construction [5] reported that 28% of architects, engineers, contractors, building owners and building consultants around the world are focusing their work on sustainable design and construction by making at least 60% of their projects green. The movement towards sustainability has brought about the development of various green building certification systems around the world. In 2000, the U.S. Green Buildings Council (USGBC) developed the LEED (Leadership in Energy and Environmental Design) certification system which has now become a popular and globally accepted standard for the design, construction, and operation of green buildings [6]. Among the various LEED systems for different types of projects, the LEED for New Construction (LEED NC) is the most adopted LEED system [7]. Under the LEED-NC 2009 (also known as LEED v3.0), buildings are judged via a 100-point credit system in five categories. The five categories and their respective points are:

- Sustainable sites: 26 possible points;
- Water efficiency: 10 possible points;
- Energy and atmosphere: 35 possible points;
- Materials and resources: 14 possible points;
- Indoor environmental quality: 15 possible points;

There are also 10 possible incentive points included in two additional categories for innovative strategies: Innovation in design (6 points) and Regional priority (4 points). Application documents and proofs can be submitted at the design phase.

1.1.2. Project site location and transportation analyses in green building standards

Project location and transportation are the critical components of a green building project as they affect the ecosystem and human life in

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Table 1
Credit SSc2 and SSc4.1 in sustainable sites category - LEED NC 2009.

Credits	Intents	Options	LEED points
Credit 2: Development Density and Community Connectivity	To channel development to urban areas with existing infrastructure, protect greenfields, and preserve habitat and natural resources.	Option 1: Development Density Option 2: Community Connectivity	5 points
Credit 4.1: Alternative Transportation - Public Transportation	To reduce pollution and land development impacts from automobile use.	Option 1: Rail station, Bus rapid transit station & ferry terminal Proximity Option 2: Bus stop Proximity	6 points

many ways. First, a project location has a significant impact on the connection of the building with the surrounding area. A building in developed land or near dense residential areas can make more intensive use of existing infrastructure, increase development density, and conserve construction material and land resources for future use. A building near essential services such as banks, parks, hospitals, schools and restaurants could reduce vehicle use and increase the chance of physical activities. Easy access to public transportation helps reduce CO_2 emission, traffic congestion and noise pollution.

Project location and transportation are featured in most popular green building standards. For examples, in Australia's Green Star, they are included in "Transport" and "Land use & Ecology" categories [8]; in Singapore's Green Mark, they are included in "Environmental Protection" categories [9]; In LEED NC 2009, project location and transportation are the important parts of the Sustainable Sites (SS) category, which is the second biggest category in terms of LEED points. SS includes 17 credits and 2 prerequisites, dealing with different matters such as revitalizing and using existing infrastructure, and reducing the impacts of buildings to the neighboring environment.

In LEED, two important credits concerning location and transportation are: **Credit SSc2: Development Density and Community Connectivity** and **Credit SSc4.1: Alternative Transportation - Public Transportation.** Both of them together account for the greatest points in the SS category: 11 out of a total of 26 points. The two credits have 4 options in total (Table 1):

1.2. Conventional location and transportation analysis in green building standards

Conventionally, the certification process of project location and transportation in a green building standard includes inputs collection, map analyses, points calculation, and documents preparation and submission. For example, the certification processes of LEED credits SSc2 and SSc4.1 are shown in the following figure:

In map analyses, map-related data are usually obtained manually or semi-manually from maps (either paper maps or online maps). This results in many disadvantages. In LEED, the disadvantages are as follows:

- **Lack of a map tool for calculation:** Maps are critically needed for location and transportation analyses. Using paper maps is straightforward but has restrictions and inconvenience such as fixed scales, limited map information, no panning and zooming, and so forth. Online maps, such as Google Maps, are more convenient but do not have dedicated functions to assist with the analysis. For example, in SSc2 – option 1, a "density circle" is needed with a radius correlated to the size of the project site area. Conventionally, this credit calculation requires manual work to determine the project site area and/or calculate the density radius. Since drawing a circle on a web browser is not practical, the calculation requires screen-capturing the map from a web browser to draw the density circle, and then identify the neighboring buildings and facilities inside the circle and calculate the development density. Each of these steps has to be done separately and manually, which is tedious and error-prone.
- **Manual inputs and calculations:** Project parameters usually need to be extracted from 2D CAD drawings or 3D Revit files. Each time a building design is changed, LEED points will have to be recalculated.
- **Map image export:** USGBC requires the submission of map images and relevant information, such as a list of neighboring buildings and facilities. The extraction of map images is usually followed by map image processing and labeling using software like Photoshop, which is time-consuming.

1.3. Potential of BIM and WMS integration for green building certifications

1.3.1. BIM information for location and transportation analysis

Currently, BIM software (e.g., Autodesk Revit) is able to simulate green building performance and export IFC (Industry Foundation Class) or gbXML (Green Building XML) outputs [10]. These outputs can then be used in green building designs and certification, such as LEED, to calculate points. (See Figs. 1 and 2)

However, there are two problems with such BIM-and-Green Building standard integration: 1) BIM is mainly capable of building performance analyses and not applicable to other categories; 2) manual operation is still necessary for the switching between applications and data import and export.

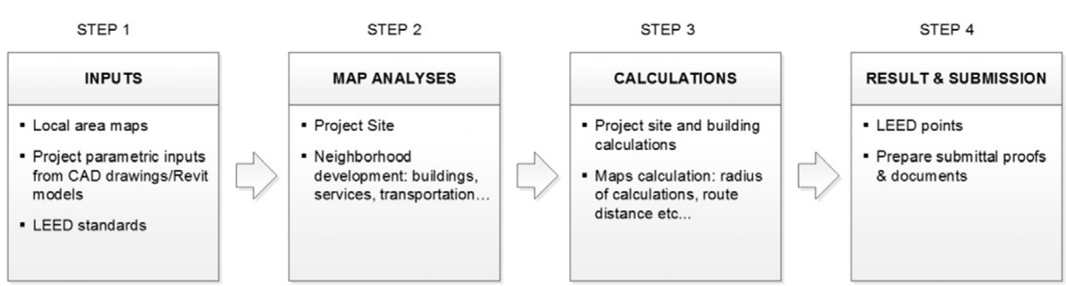

Fig. 1. Steps for conventional LEED location and transportation analysis.

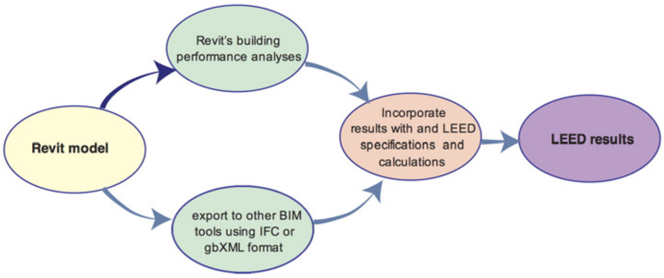

Fig. 2. Application of BIM to LEED certification.

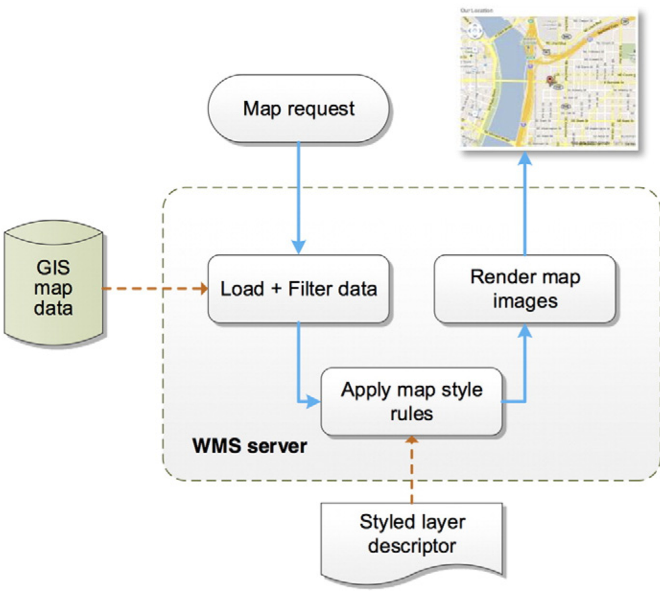

Fig. 3. Basic structure of Web Map Service (Source: Open Geospatial Consortium).

API (Application Programming Interface) can help developers extend functionalities of BIM authoring tools. API allows users to extract data directly and automatically from BIM models for different purposes. Through the use of API, users can solve the above-mentioned problems for the integration of BIM and green building standards: the limited functionalities of current BIM software and the need of manual switching between applications and data import/export.

Presently, a BIM model contains a project's site coordinates and other information that are necessary for energy consumption, lighting, views, orientation, and thermal analysis. In Autodesk Revit, site coordinates and gross building areas are available through the "Project Location" and "Area" dialog boxes. This information can be extracted through BIM API functions, and associated with map applications for Location and Transportation analysis in green building certifications process.

1.3.2. Web Map Service

The recent advancement of the Internet and the Geographic Information System (GIS) has brought about the advent of the Web Map Service (WMS), sometimes referred to as the Online Map Service. WMS is the process of requesting map images from a map server with GIS databases through the web interface [11]. Fig. 3 illustrates the basic structure of WMS [12].

WMS maps have many advantages over conventional paper maps. Most of them are free and interactive (i.e., being able to zoom, pan, turn on/off layers, etc.) with easy access through a web browser. With the integration of BIM and WMS, the time required for Location and Transportation analysis in green building standards can be greatly reduced.

2. Studies about current BIM applications in green building certifications

Kriegel and Nies [4] found that BIM can help design in seven aspects: building orientation, building massing, day lighting analysis, water harvesting, energy modeling, renewable energy, and sustainable materials. Wong and Fan [13] concluded that BIM could help reduce the cost of design changes and select the best solution to reduce energy and resources consumption, and is also capable of enhancing the project delivery culture in the future. Azhar et al. [6] developed a conceptual framework to establish the relationship between BIM-based sustainability analyses and the LEED certification process. Roderick et al. [14] proposed a computational simulation, using software IES Virtual Environment to quantitatively benchmark the energy rating method under three popular green building systems: LEED, BREEAM and Green Star. Bank et al. [15] developed a decision-making framework to use BIM as a tool to calculate LEED credits. O'Keeffe et al. [16] used 5D-BIM model, which linked with schedule and cost, to perform certain LEED calculations. The concept of nD BIM framework is developed to facilitate sustainable design, including LEED certification [17]. The abundance of literature revealed the interests among researchers in how BIM can enhance LEED certification process.

Although studies showed that BIM is applicable to sustainable construction analyses [4,13], there is still a big gap between the current BIM software functions and the LEED certification process. Azhar et al.

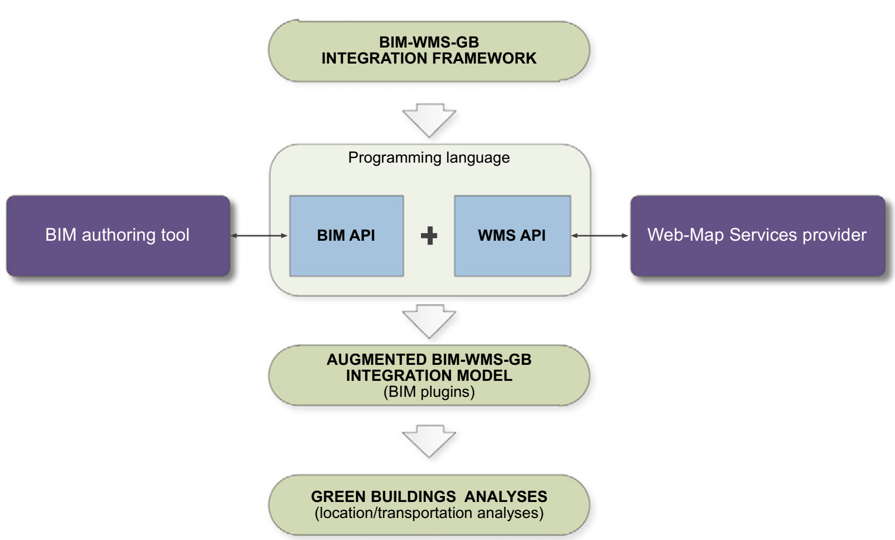

Fig. 4. Flow of BIM-WMS-GB integration.

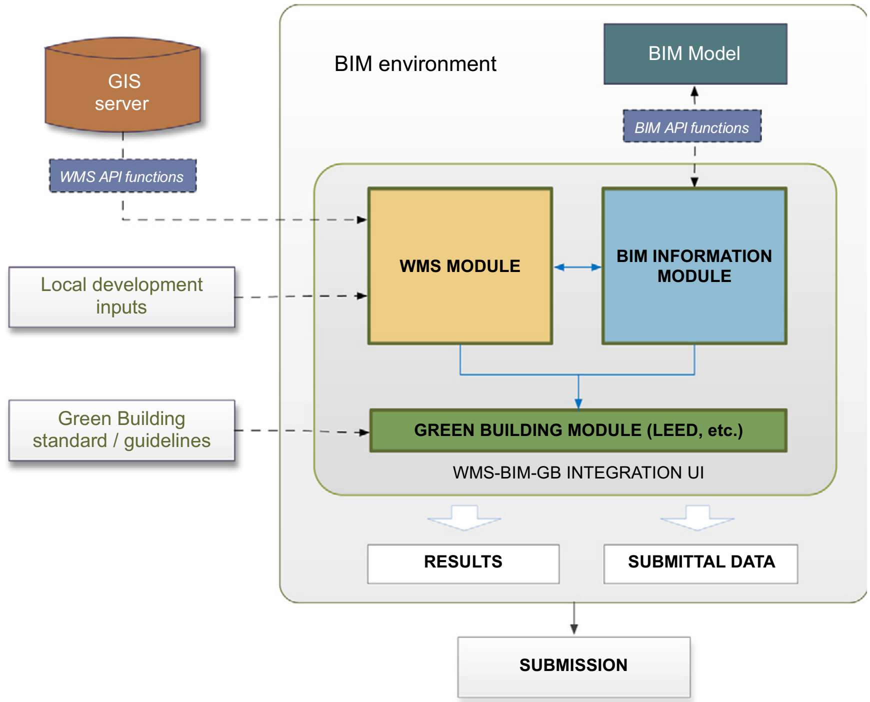

Fig. 5. BIM-WMS-LEED integration framework.

[6] mentioned that there is no one-to-one relationship existing between the LEED certification process and BIM-based sustainability analyses due to the lack of LEED integration features in the currently available software. Krygiel and Nies [4] also found that many of the tools used to measure the impact of sustainable design strategies might not be readily available within BIM software. Thus, data exchange between BIM and LEED software products is inevitable, which makes manual operations somewhat necessary.

In a survey conducted by Bynum et al. [18] to determine the existing trends of BIM applications in sustainable design and construction, most responders regarded the Sustainable Sites category (which includes SSc2 and SSc4.1 credits) has lower BIM applicability than other categories. Azhar et al. [6] and Roderick et al. [14] stated that BIM could directly or indirectly help prepare a number of LEED credits. However, credits SSc2 and SSc4.1 are marked as no potential to be earned through BIM software. Wong and Kuan [1] also discussed the application of BIM in Hong Kong's BEAM-Plus Green Building certification, which was also developed based on the LEED standards. While his study concluded that 26 BEAM-Plus credits could be assisted by BIM, only 4 out of 17 credits in the Site Aspect category (equivalent to LEED's Sustainable Sites) can be achieved by BIM. Credit SS2 Local Transport (equivalent to LEED's SSc4.1) and SA3 Neighborhood Amenities (equivalent to LEED's SSc2) are marked as not possible to be achieved by BIM.

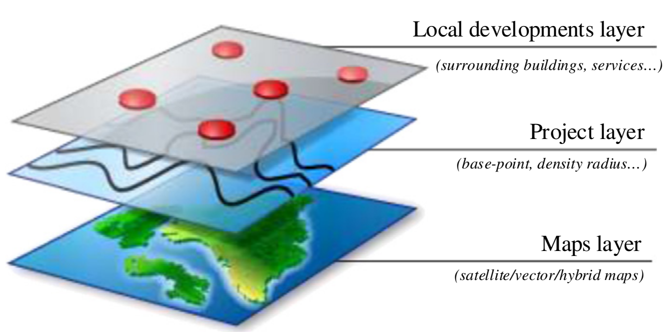

Fig. 6. Layers in the map interface.

3. Research objectives

The study aims to develop an integration framework of BIM and WMS in green building standards. With LEED being a globally recognized green building rating system, the framework is embedded into a BIM-LEED application. The focus of this study is on the Location and Transportation analysis related to credits SSc2 and SSc4.1 of LEED for New Construction v2009. Autodesk Revit (BIM software) and Google Maps (WMS) are adopted in this study due to their popularity. Plugins for Autodesk Revit have been developed to help with credits SSc2 and SSc4.1 in Location and Transportation analysis. The plugins are internally integrated into Autodesk Revit, extract BIM data directly to help automatically calculate SSc2 and SSc4.1 points (Note: These two credits are the major ones in LEED's Sustainable Sites (SS) category, accounting for 11 out of 26 points in SS). WMS could help users obtain map data, do route-planning tasks, prepare documents for LEED submittal, export proof map images with all required information marked on them, and generate an Excel file containing all location-related data. With the plugins, no manual switching between BIM software products and manual calculation of LEED points are needed.

4. Flow of BIM-WMS-green building integration

A programming language together with BIM API and WMS API are used for the integration of BIM, WMS and Green Building (GB) (Fig. 4). Supporting by the WMS API [19], the following functions are available in the developed plugins [20]:

- Searching for places;
- Changing map types;
- Adding pin markers of landmarks and locations; and
- Viewing path and calculating distance between two spots.

In the proposed BIM-LEED application, Autodesk Revit is selected as the BIM authoring tool, Google Maps is selected as the WMS provider. Microsoft C# programming language is used to integrate Revit API and Google Maps API to perform analyses of Location and Transportation in the LEED certification system.

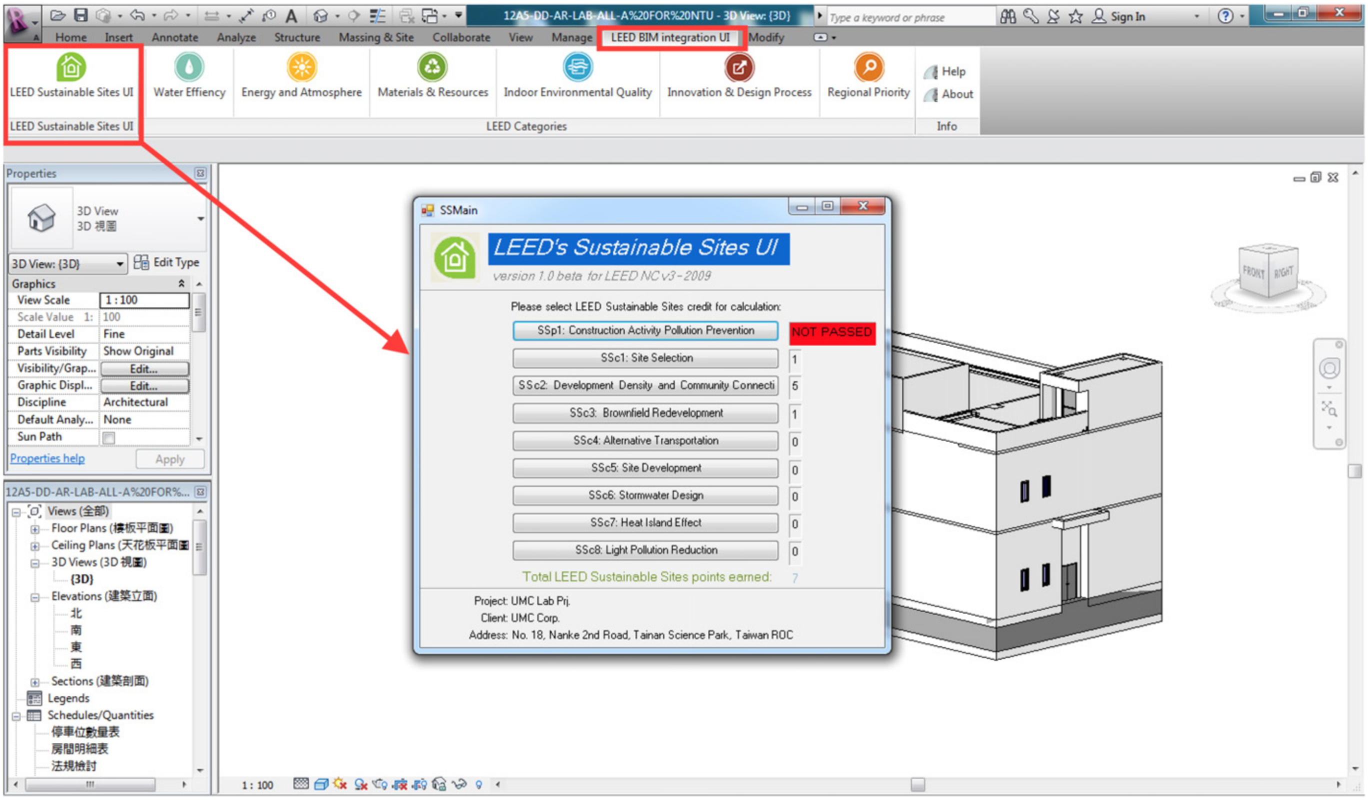

Fig. 7. LEED sustainable sites UI in Autodesk Revit.

5. BIM-WMS-green buildings integration framework

The BIM-WMS-Green Buildings (BIM-WMS-GB) integration framework is designed as a modular system, which contains three modules: **BIM information module**, **Web Map Service module** and **Green Buildings module** (Fig. 5). Being a modular system, the framework is flexible and customizable because it gives users the capability to customize each individual module to work with their preferred BIM or WMS tools, while reusing the integration framework and programming codes of other modules in the developed software.

The three modules in the integration framework are explained in detail below:

- ***BIM information module***:

- Extracts required information from the Revit model for calculation using BIM's API data extraction functions. When the plugin is opened, the required BIM information for green building analyses is automatically loaded;
- Functions as a bridge between the map interface and the Revit model. Any changes made at the map interface will be reflected in the Revit

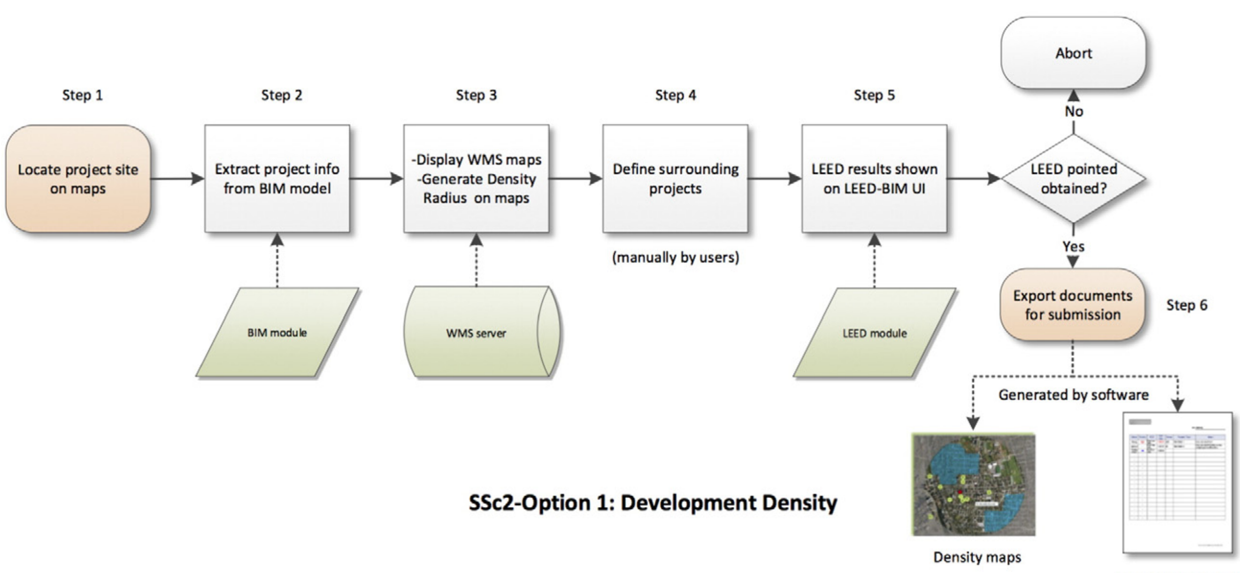

Fig. 8. Steps of SSc2 Option 1.

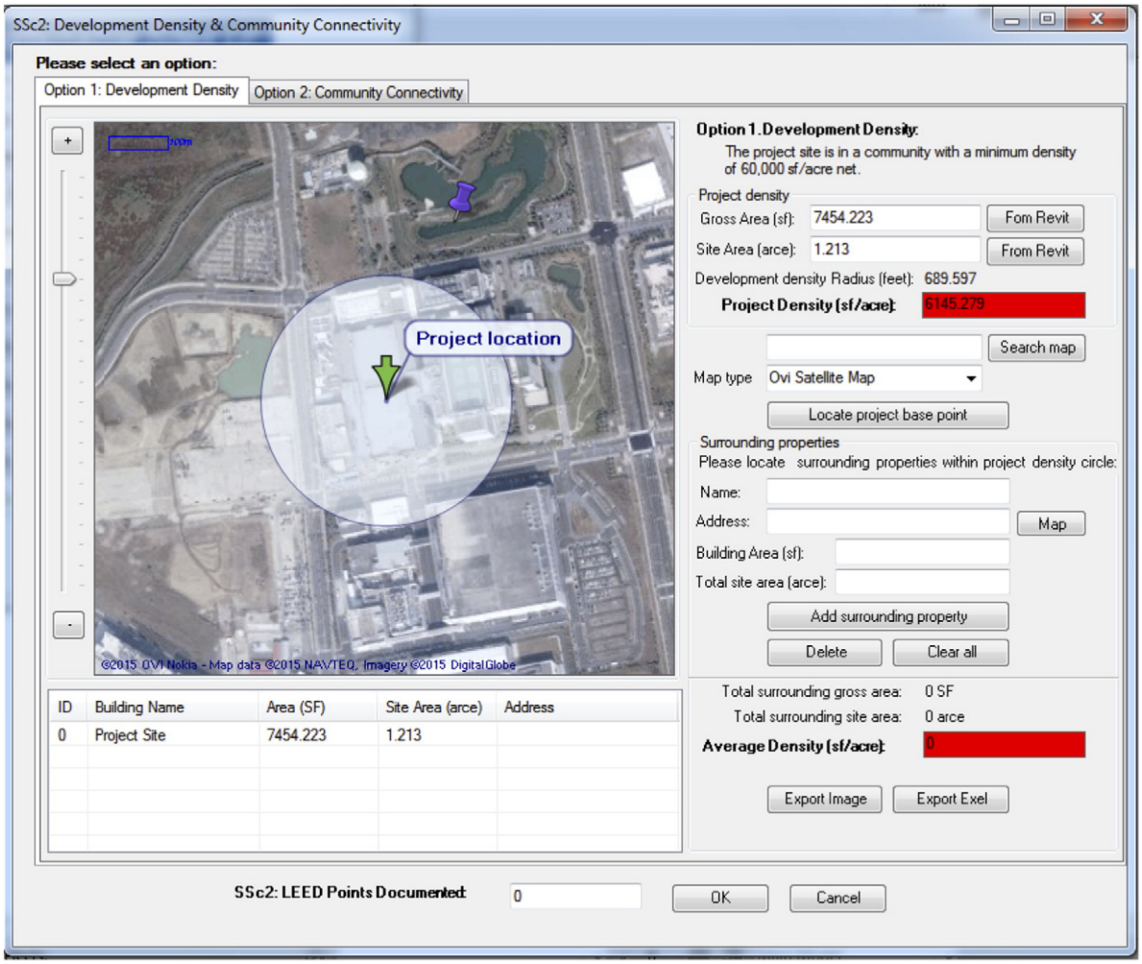

Fig. 9. SSc2 Option1 user interface.

model's site coordinates and vice versa; and

- Stores analyses results directly in the parameters of the Revit model.

- ***Web Map Service module***

The Web Map Service (WMS) module uses WMS's API, such as the **Google Maps API,** for several tasks: searching for locations, adding place markers, calculating the distance between two places, etc.

This module includes the map interface, which comprises three layers of information (Fig. 6):

- **Maps layer:** This is the bottom layer and shows the maps that are downloaded from **GIS servers** through the Internet. The user can switch between different types of maps: satellite, vector, and hybrid. Maps from various WMS providers, e.g., Google™, Bing, OpenStreetMap™, Nokia™, and Yahoo™, are available in this layer and can be selected from a drop-down menu, which enables the user to select the map with the best quality and most updated information.
- **Project layer:** When the interface is on, the project layer would automatically connect with the BIM module to locate the project site based on the Revit file's site coordinates or the project's address (which is available in Revit's project information dialog box) and display the project base point. This layer also uses information from the BIM module to determine the density radius and draw the density circle, followed by selecting relevant buildings and facilities for the Location and Transportation analysis.
- **Local developments layers:** This is the top layer and includes user-input local development information such as surrounding buildings, services, rail or bus stations that are of concern in the analysis. In SSc2, the user can define the locations of surrounding buildings and their area properties, such as the building area and total site area.

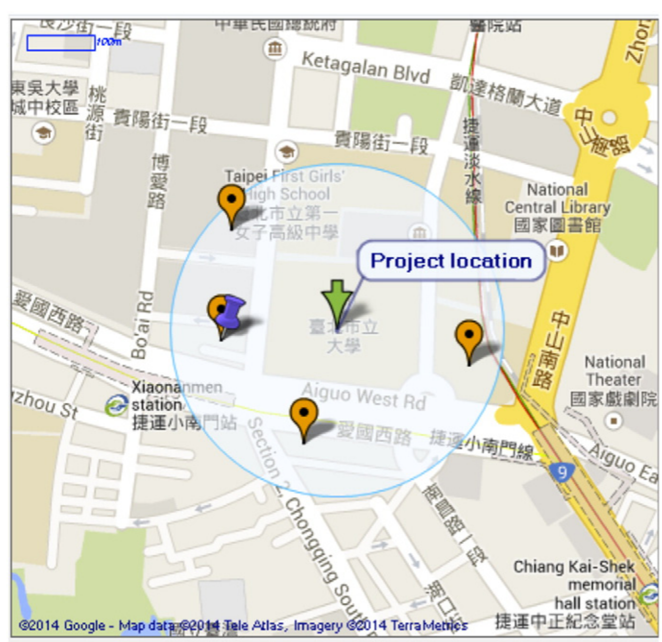

Fig. 10. SSc2 Option1 exported map.

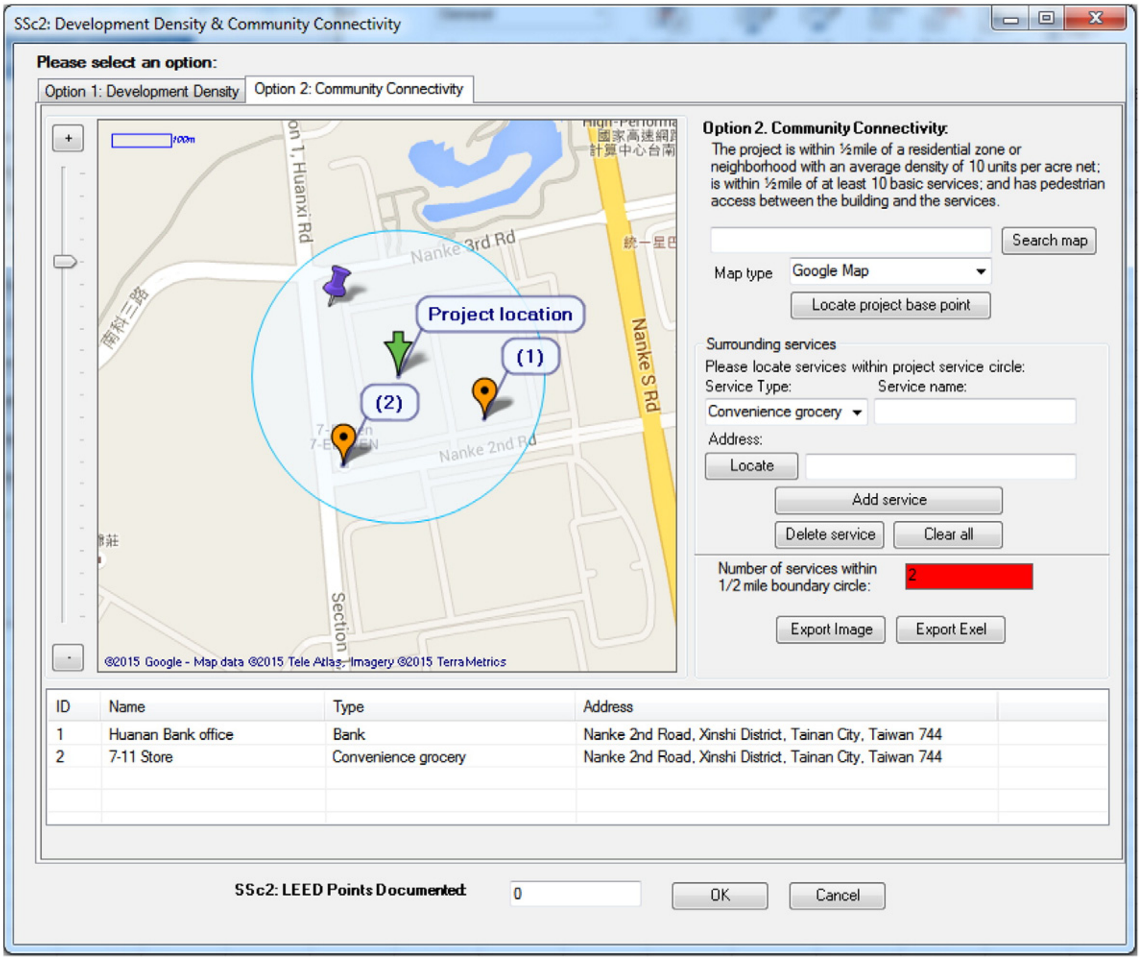

Fig. 11. SSc2 Option 2 user interface.

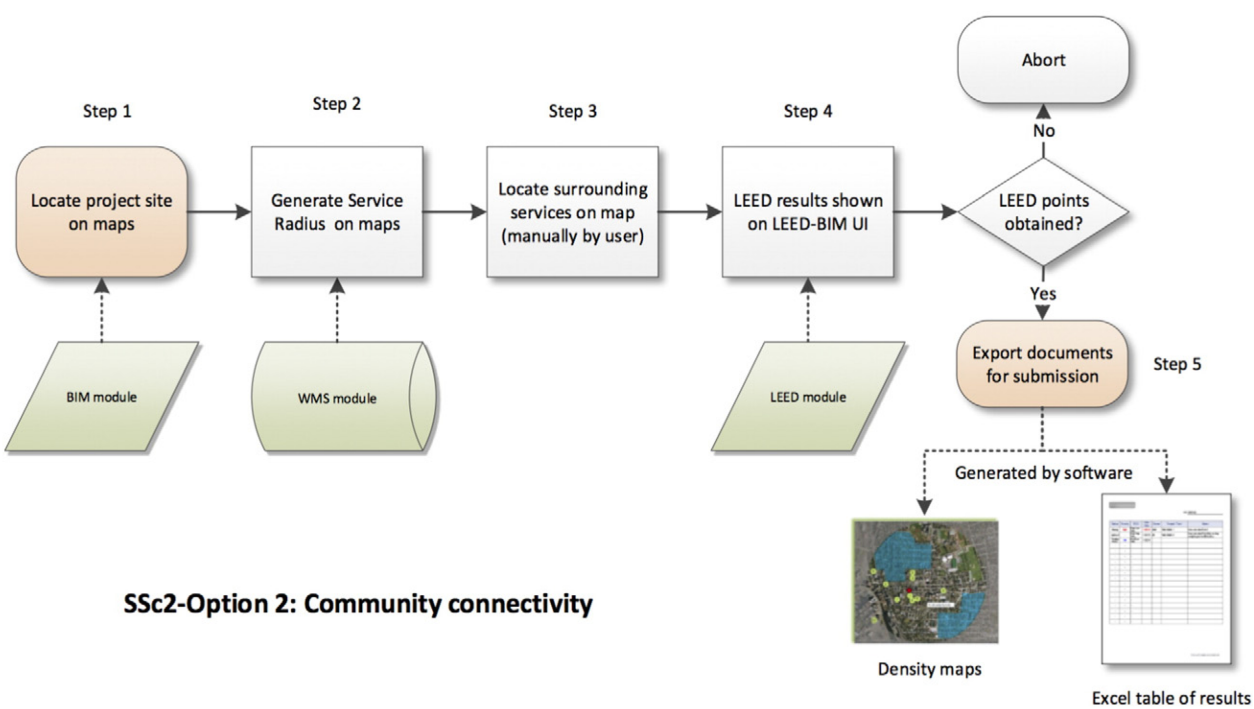

Fig. 12. Steps of SSc2 Option 2.

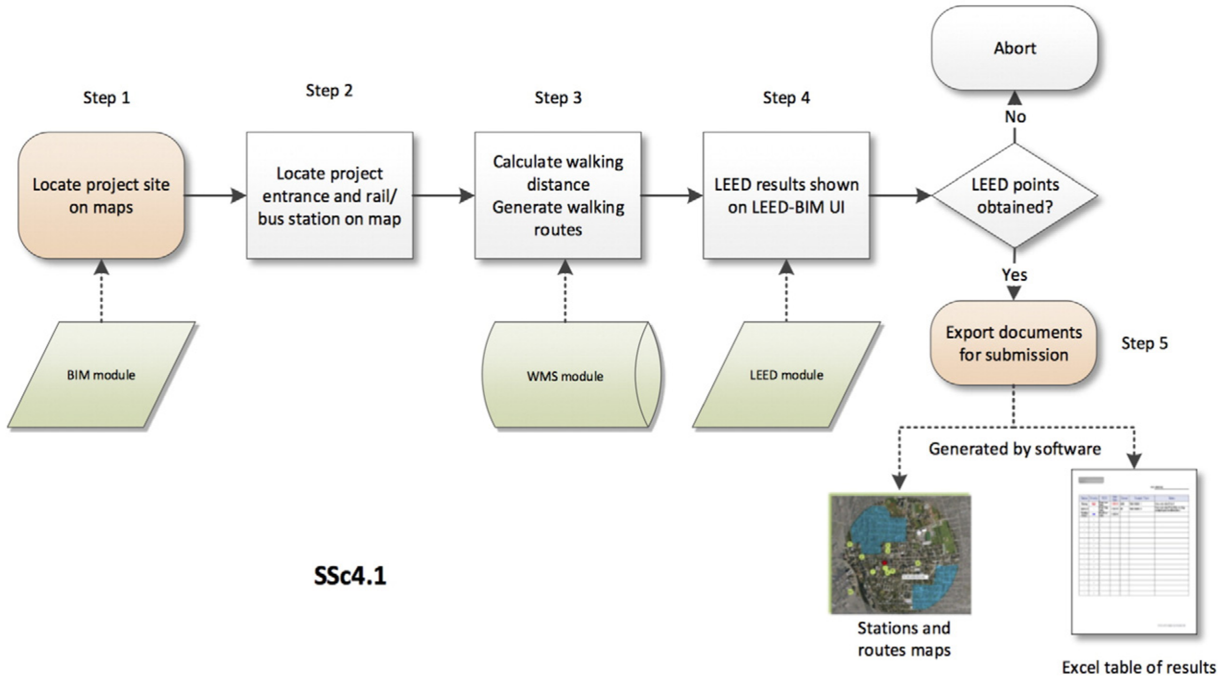

Fig. 13. Steps of SSc4.1 Options 1& 2.

- ***Green Buildings module:*** This module incorporates Green Building standards, such as the LEED certification, with the inputs from the BIM and WMS modules to calculate certain sustainable outcomes. The results are automatically displayed on the user interface.

Last but not least, the user interface of the BIM-WMS-GB integration framework is able to export processed map images and detailed results for other purposes, for example the preparation of LEED proofs and documents, which could save the user lots of time.

The BIM-WMS-GB framework can be tailored to foster many applications of sustainable design and construction. For example, in the design stage, the maps layer can be used to analyze the project site surroundings, which can help with the design of the mass and orientation of the project BIM model. The volume of building materials obtained from the BIM model can be associated with the transportation distance from the exploited areas to the construction site, to calculate the total material transportation cost. Different green building specifications or standards can be embedded into the Green buildings module to do the location and transportation analyses, such as the LEED SSc2 and SSc4.1 of the Sustainable Sites category.

Presently, most BIM software and WMS providers provide their API to developers to extend their software functionalities. The methodology and framework can be applied to other BIM solutions, not limited to Revit, as long as the BIM software includes the location information in the BIM model and provides API for the developer.

6. Autodesk Revit LEED plugins

In this study, the BIM-WMS-GB framework is translated in to a Revit-LEED plugins. The developed plugins can generate a BIM-LEED toolbar (in which the BIM-WMS-GB framework is embedded) in Autodesk Revit, and the credits SSc2 and SSc4.1 can be accessed through the LEED Sustainable Sites UI (User Interface) under the BIM-LEED toolbar (Fig. 7). The Sustainable Sites UI displays the result of each credit, as well as total LEED points in the Sustainable Sites category.

6.1. SS credit 2 (SSc2): Development Density and Community Connectivity

6.1.1. Option 1 - Development Density

This option requires the project building to be constructed or renovated on a previously developed site and in a community with a minimum density of 60,000SF/acre. Figs. 8 and 9 show the steps and the user interface for SSc2 Option 1, respectively. The following set of symbols is used for the equations in the steps:

A_P	Total land area of the project site
A_{Pi}	Land area of a lot *i* of the project site
GFA_P	Total Gross Floor Area of the project
FA_i	Floor area of floor *i* of the project
DD_P	Development density of the project
A_i	Land area of a other building i
GFA_i	Total Gross Floor Area of other building i

Table 2
Changes of Credits SSc2 and SSc4.1 in LEED v4.

Changes in LEED v4	Credit SSc2	Credit SSc4.1
Name	- Credit title renamed to “Surrounding Density and Diverse Uses”	- Credit title renamed to “Access to Quality Transit”.
Evaluation criteria	- Multiple thresholds to reward different density levels and amounts of diverse uses. - Projects earn points in the density and the diverse uses options separately. - Warehouse and distribution center requirements added to encourage development near commercial or industrial sites or near transportation infrastructure.	- Multiple thresholds to reward varying transit service levels. - Metric of radius changed to walk distance. - Frequency of transit included in metric.

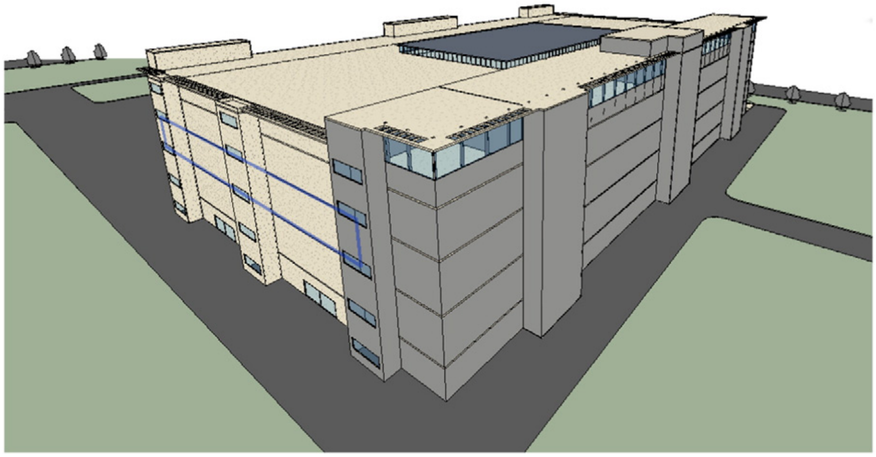

Fig. 14. The Revit model of a LEED Gold certified project. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

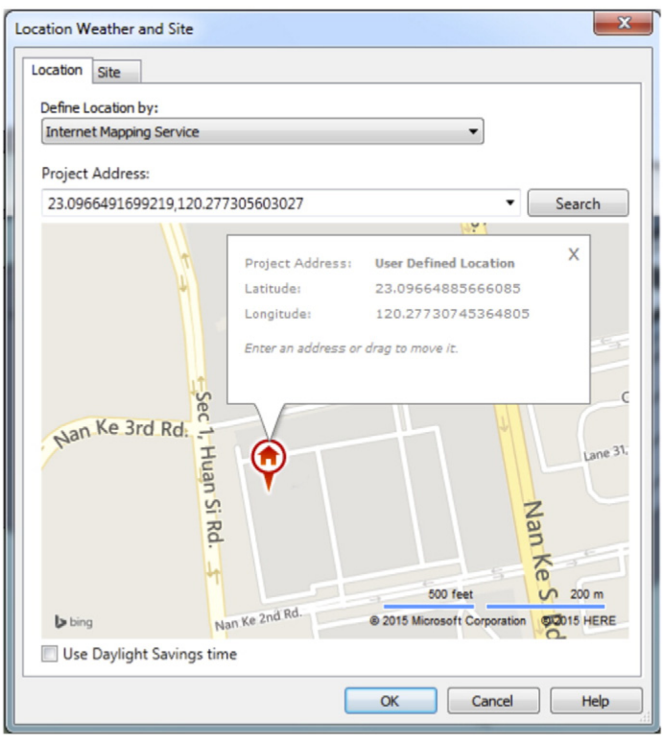

Fig. 15. Revit's project location dialog box.

DR Density radius for the density boundary area
DD_{area} Development density of the surrounding area

Step 1: Locate the project on the map

The Web Map Service (WMS) module could automatically locate the project site based on the following BIM information in Revit: the site coordinates in the Project Site location tab or the "address" parameter in the Project Information dialog box. The user can also manually define the project site location on the map interface, and the coordinates defined by the user will be recorded directly in the BIM model. The downloaded map and project base point are shown on the Maps Layer of the map interface.

Step 2: Extract information from BIM

The BIM module uses Revit API data extraction functions to retrieve two parameters for calculation:

- Total land area of the project site A_P
- Gross Floor Area of the project GFA_P

In Revit, the site boundary is defined by the Property Line, which can be created in the Site tab. The Revit API extracts the area parameter from the Property Line to calculate Total land area A_P. In case the project comprises more than one lot, A_P (acre) can be calculated using Eq. (1).

$$A_P = \sum A_{PLi} \tag{1}$$

The building gross area GFA_P can be defined by the Gross Area schedule in the Architecture tab. In Revit, the process of creating the Gross Area schedule must be done manually since the selection of floors must be done through human judgment. The Revit API extracts the

Table 3
Analysis results obtained using the developed plugin.

Credits	SSc2		SSc4.1	
	Option 1	Option 2	Option 1	Option 2
Results	Project Floor Area: **33,897.25 ft2** Site Area: **40.67 acre** Density radius: **3993 ft.** Average Density: **7184.8.3 sf/arce**	Service radius: **0.5 mile** No. of found services: **02**	Number of Rail station: **01** Walking route distance: **2.145 mile**	Number of bus station: **01** Calculated walking distance: **0.145 mile**
LEED point	0	0	0	6
Submitted to USGBC	N	N	N	Y

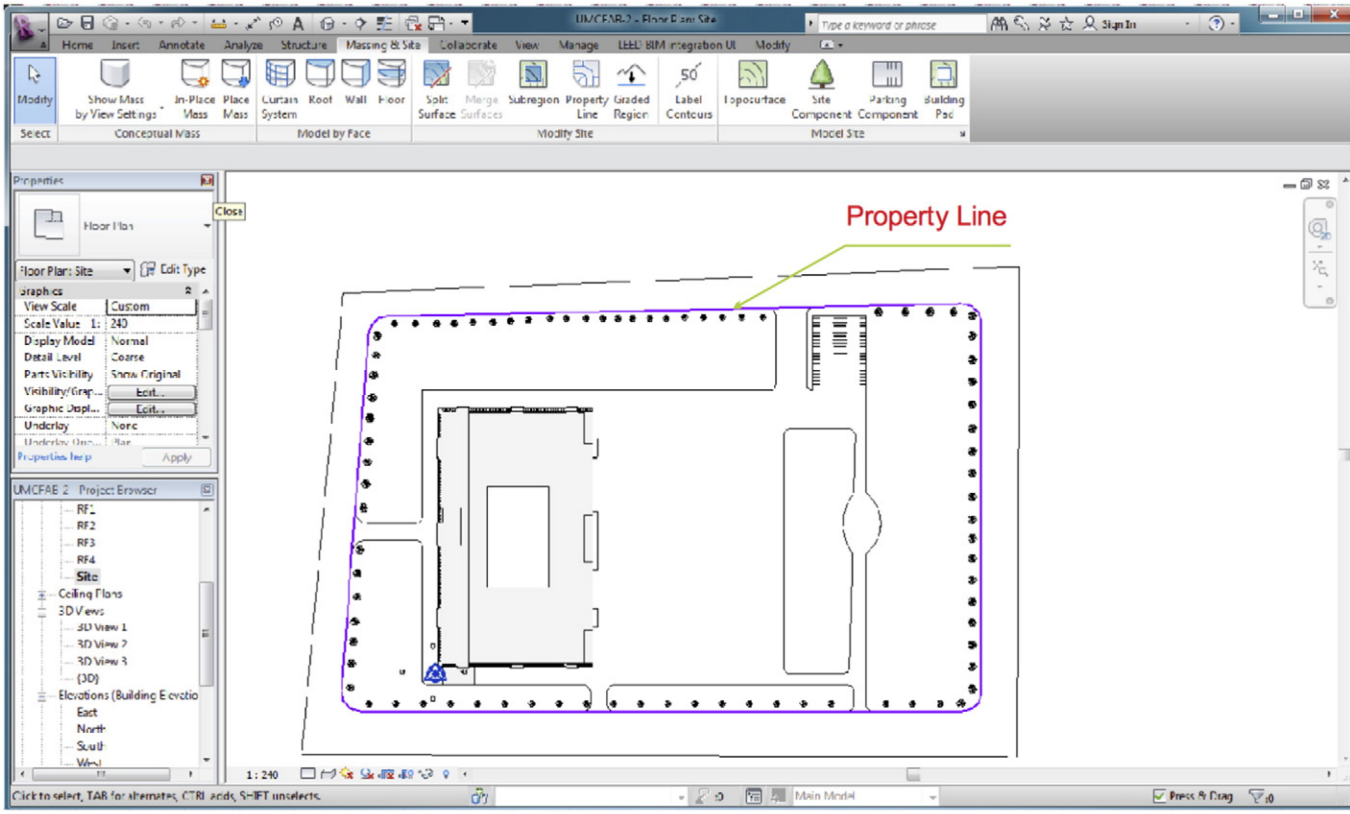

Fig. 16. Project site boundary sketched in Revit's site plan view.

area parameter of each floor to calculate gross area FA_i, then sum up to find the total building gross area GFA_P (ft^2) of all floors (Eq. (2)).

$$GFA_P = \sum FA_i \tag{2}$$

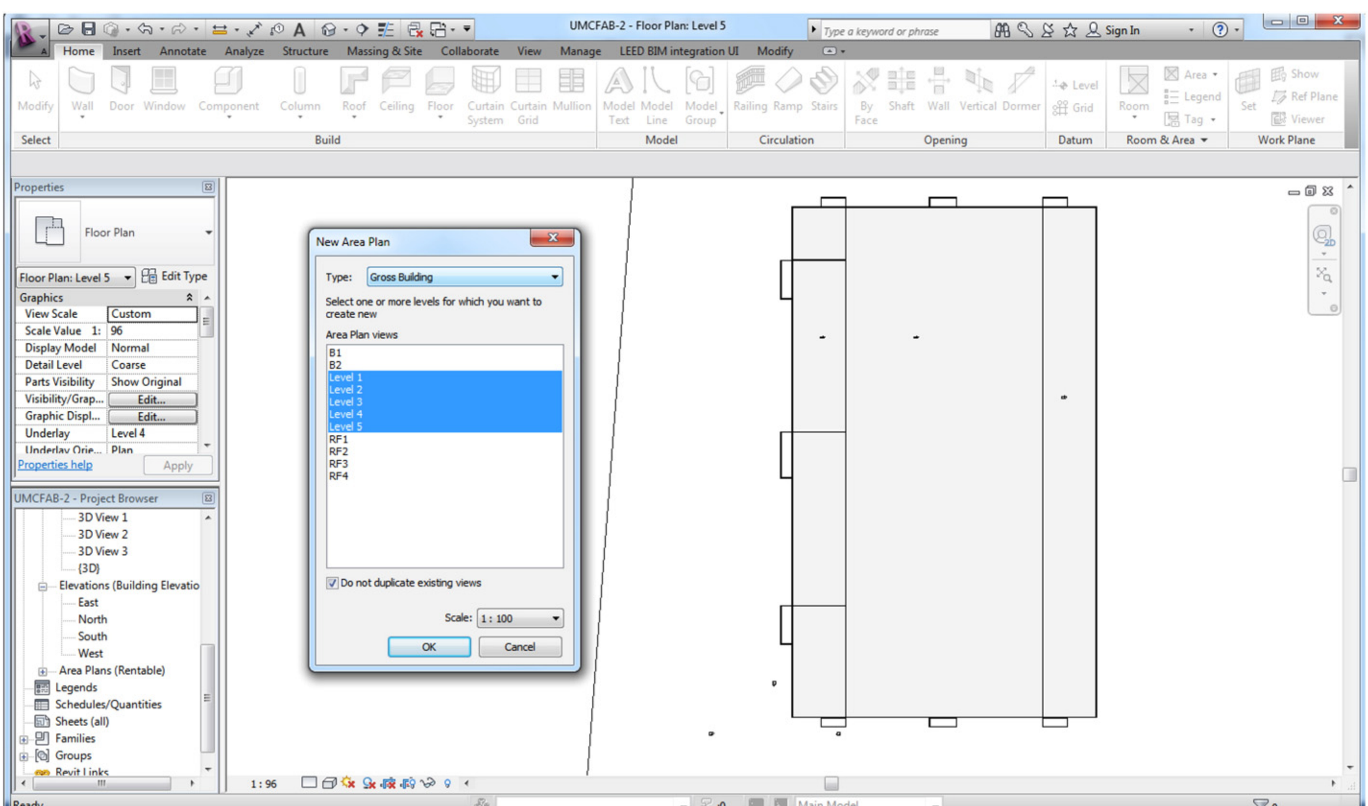

Fig. 17. Gross building area plan created from the existing rooms and spaces.

At the design stage, the gross area can be automatically updated whenever there is a change in building design.

Step 3: Generate the density circle and vicinity map

With A_P (from Eq. (1)), the development density radius DR can be calculated using the following Eq. (3).

$$\mathrm{DR} = 3 \times \sqrt{A_P} \tag{3}$$

A density circle is automatically generated on the map by the WMS module to help designer identify the adjacent buildings and facilities within the circle.

Step 4: Add surrounding buildings and facilities

Using the map interface and the generated density circle, the user can mark surrounding buildings and facilities on the map interface, together with the information of these buildings and facilities, such as building names, site areas and gross areas.

Step 5: Calculate LEED points

Project density and development density of the area can be calculated using Eqs. (4) and (5), respectively.

$$DD_P = \frac{\mathrm{GFA}_P}{A_P} \tag{4}$$

$$DD_{area} = \frac{\sum \mathrm{GFA}_i}{\sum \mathrm{A}_i} \tag{5}$$

where $\sum GFA_i$ and $\sum A_i$ in Eq. (5) are the "sum of gross building areas" and "total site area of all buildings within the density circle," respectively.

If $\mathrm{DD_P} \geq 60{,}000$ ($\mathrm{ft^2}$/acre) and $\mathrm{DD_{area}} \geq 60{,}000$ ($\mathrm{ft^2}$/acre), then LEED point = 5

Step 6: Export the map image and Excel file

If the LEED points are successfully obtained, the map image can be exported with the marking of project location, density circle, and surrounding buildings and facilities (Fig. 10). An Excel file with the detailed information of the surrounding buildings and facilities can also be exported.

6.1.2. Option 2: Community connectivity

This option requires the project building to be constructed or renovated on a previously developed site and within half a mile of a residential area or neighborhood with an average density of 10 units/acre net, and within half a mile of at least 10 basic services with pedestrian access between the building and the services [21]. Figs. 11 and 12 show the user interface and steps of SSc2 Option2, respectively.

The below figure depicts the steps how the application model works:

Step 1: Locate the project on the map

This is similar to Step 1 of SSc2 Option 1.

Step 2: Generate the density circle and vicinity map

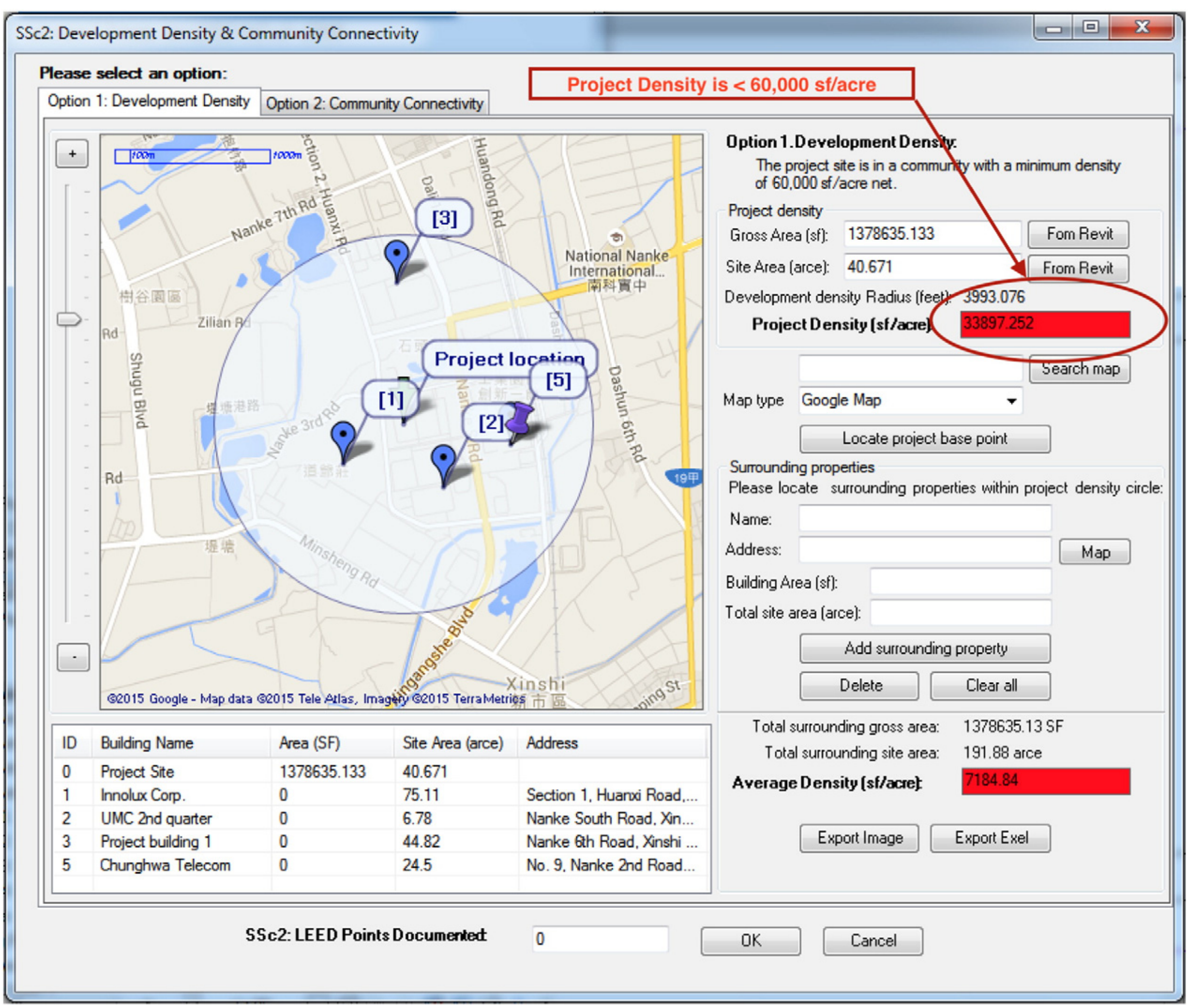

Fig. 18. SSc2 – Option 1 user interface.

The density circle is generated by the WMS module, with the density radius fixed at half a mile, as specified in LEED.

$$\mathrm{SR} = 0.5\ (miles) \qquad (6)$$

Step 3: Locate surrounding services

Combining the map and the generated density circle, the user can input each of the surrounding services, such as school, laundry, etc., by placing a marker on the map.

Step 4: Calculate LEED points

If Number of Services > = 10, then LEED points = 6.

Step 5: Export map images and Excel files

Similar to SSc2 Option 1, the user is able to export map images and Excel files.

6.2. SS credit 4.1 (SSc4.1): Alternative transportation – Public transportation access

6.2.1. Option 1: Rail station, bus rapid transit station and ferry terminal proximity

This option requires a project building to be located within half a mile walking distance from the building entrance to the nearest commuter rail, light rail, subway station, bus rapid transit station or commuter ferry terminal.

6.2.2. Option 2: Alternative transportation

This option requires a project building to be located within quarter a mile walking distance from the building entrance to the nearest bus stop.

Options 1 and 2 have the similar calculations. The difference is in option 1, the maximum distance to the rail station is 1/2 mile, and in option 2 the maximum distance to bus station is 1/4 mile. Fig. 13 presents the steps of SSc4.1 (both Options 1 & 2).

Step 1: Locate the project on the map

This is similar to Step 1 in SSc2.

Step 2: Locate the project entrance and nearby transportation services

The user needs to identify the project entrance and nearby transportation services on the map.

Step 3: Compute the walking distances and routes

When the user identifies a nearby rail station or bus stop, the WMS and LEED modules could work either in the automatic or manual mode.

Automatic mode: In this mode, the walking route is automatically generated and the distance is calculated using the Google Maps engine.

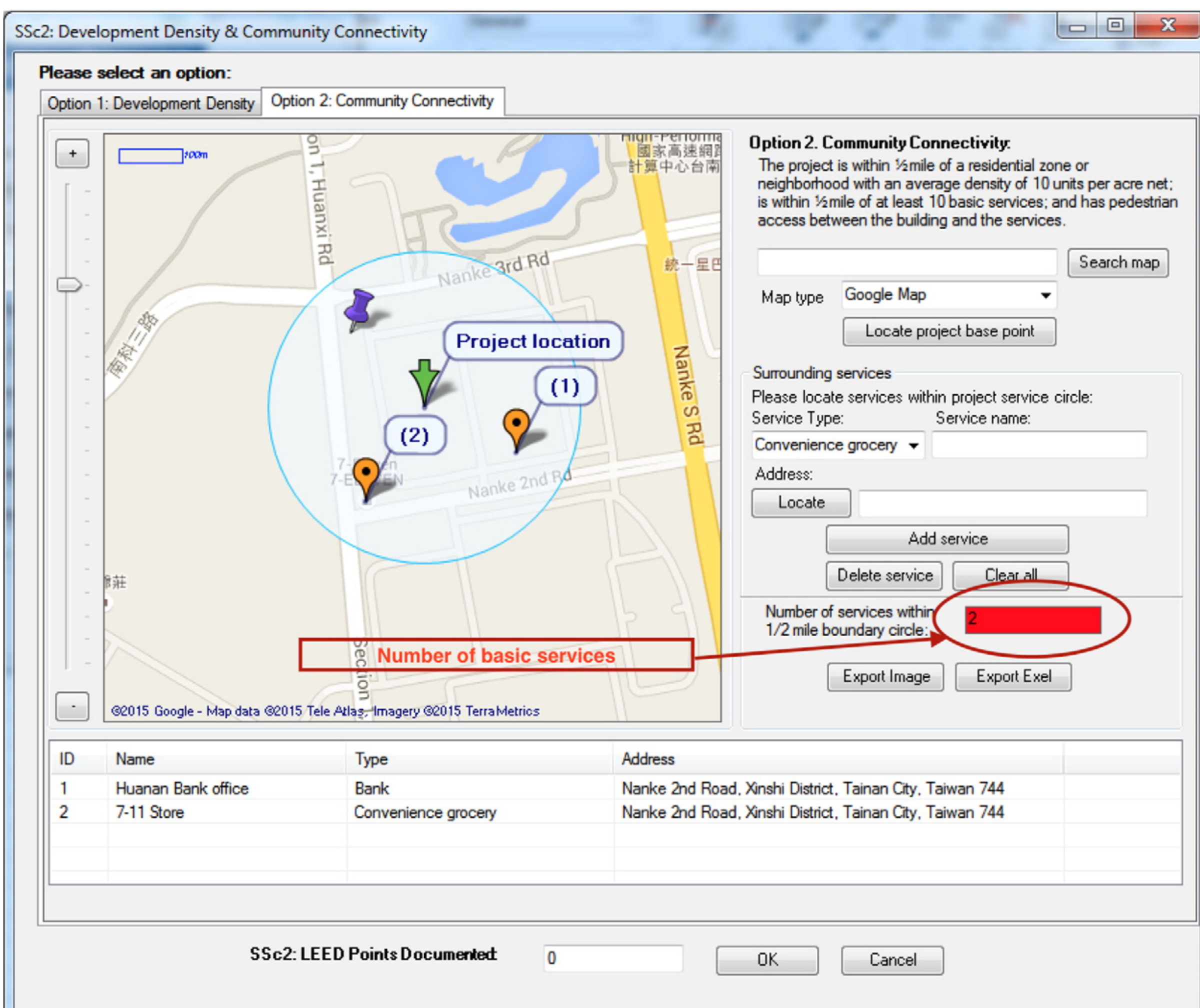

Fig. 19. SSc2 – Option 2 user interface.

Manual mode: Since LEED accepts rail stations, bus stop, and roads/streets that are under planning or construction, sometimes the user will have to input bus stops, rail stations or walking routes that are not available on the map. After the input of data on the user interface, the Google Maps engine will calculate the distances.

Step 4: Calculate LEED points

Option 1: If the Walking Distance ≤ 0.5 miles, the Rail Station is accepted.

If Number of Rail Stations ≥ 1, then LEED points = 6.

Option 2: If the Walking Distance ≤ 0.25 miles, the Bus Stop is accepted.

If Number of Bus Stops ≥ 1, then LEED points = 6.

Step 5: Export the map image and Excel file

The map image and Excel file will be exported in this step.

7. Migration capability to LEED version 4.0

In late 2013, the U.S. Green Building Council (USGBC) introduced the new LEED version 4 (v4), in which the credits regarding location and transportation under the Sustainable Sites category in LEED version 3 (v3) (introduced in 2009) have been relocated to the new Location and Transportation category. The intents, concepts and analyses of SSc2 and SSc4.1 in LEED v3 are almost identical to those in LEED v4, only with some minor adjustments. The changes of SSc2 and SSc4.1 in LEED v4 are shown in Table 2 [22].

Although this study is mainly for LEED v3, the developed system in this study can easily migrate to LEED v4 with minor adjustments, such as adding multiple point thresholds, etc.

8. Case study

The case study is a LEED Gold certified wafer factory project (based on LEED v3) located in the Southern Taiwan Science Park and owned by a leading semiconductor manufacturing company in Taiwan (Fig. 14).

The location of the project is set in the project location dialog box (Fig. 15).

In the case study, to calculate LEED points, LEED AP had to screen-capture maps from a web-browser, then manually do the calculation. For example, to calculate the distance to rail/bus stations, users have to measure the distance of each section of the path, then combine together and multiply with the scale of the maps to have the total length.

The developed BIM-WMS-LEED integration plugin was used to analyze the SSc2 and SSc4.1 credits, and then compared to the results obtained using manual calculation. Table 3 shows the analysis results obtained using the developed plugin.

The results showed that only six points from SSc4.1 – option 2 were obtained. The results were identical to the results from manual calculation, which have been submitted to USGBC.

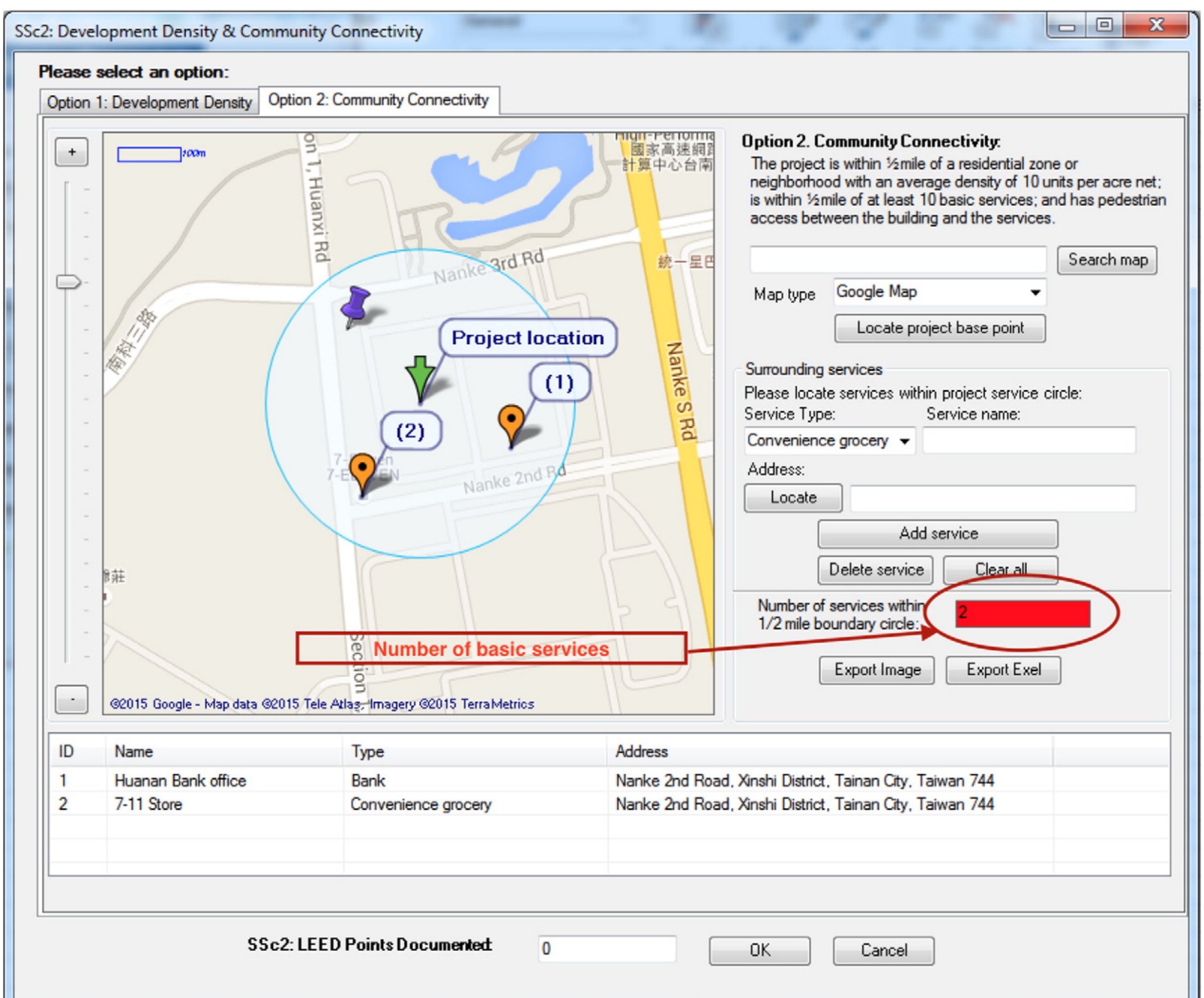

Fig. 20. SSc4.1 – Option 1 user interface.

8.1. Credit SSc2.1

8.1.1. Option 1 – Development density

The case study was built in a new industrial development area and there was no building in the neighborhood during its construction. For Option 1: The project density was 33,897.25 (SF/acre), less than the required 60,000 (SF/acre) (Figs. 16-18). Therefore, no point was earned from this option.

8.1.2. Option 2 – Community connectivity

This option requires at least ten basic services inside the service radius. As can be seen in Fig. 19, only a grocery store and a bank were found within the radius. Thus, no point was earned from this option.

8.2. Credit SSc4.1

8.2.1. Option 1 – Rail station proximity:

The nearest rail station, Nan-ke Rail Station, is 2.154 miles from the project entrance, greater than the required 0.5 miles, and, thus, no point was earned (Fig. 20).

8.2.2. Option 2 – Bus station proximity

Since there is a bus station 0.145 miles from the project entrance, less than the required 0.25 miles, six points were earned (Fig. 21).

9. Conclusions

Building information modeling (BIM) has been applied to green building certification, especially the LEED standards of the U.S.A., in the past years. However, BIM was mostly applied to building-envelope-related calculation under LEED's Energy and Atmosphere category. In this study, the integration of BIM and LEED's Sustainable Sites category (LEED v3) was explored with the assistance of Web Map Services (WMS). The developed BIM-LEED framework and plugin could help calculate the points of the two most important credits under the Sustainable Sites category, Credit 2 (denoted as SSc2) and Credit 4.1 (denoted as SSc4.1), in an efficient and effective way.

The application of WMS and BIM integration is not limited to LEED or any specific green buildings certification. The integration model can be tailored for other sustainable development cases, such as site analyses, construction materials transportation etc. Like other services that employ WMS Google Maps in their solutions, there is a limitation in the integration of WMS in this paper: there are places where WMS providers are still not updated or the quality of image is not good. In the research, the developed BIM-LEED plugin can help reduces this limitation by adding multiple WMS servers (e.g., Google, Bing, Yahoo, etc.) to ensure the user to have the best quality map information. This can help save the user's time in physically checking the buildings and facilities in the project neighborhood and verifying the accuracy of paper maps. Through the presented case study, the practicability of the developed system is proven.

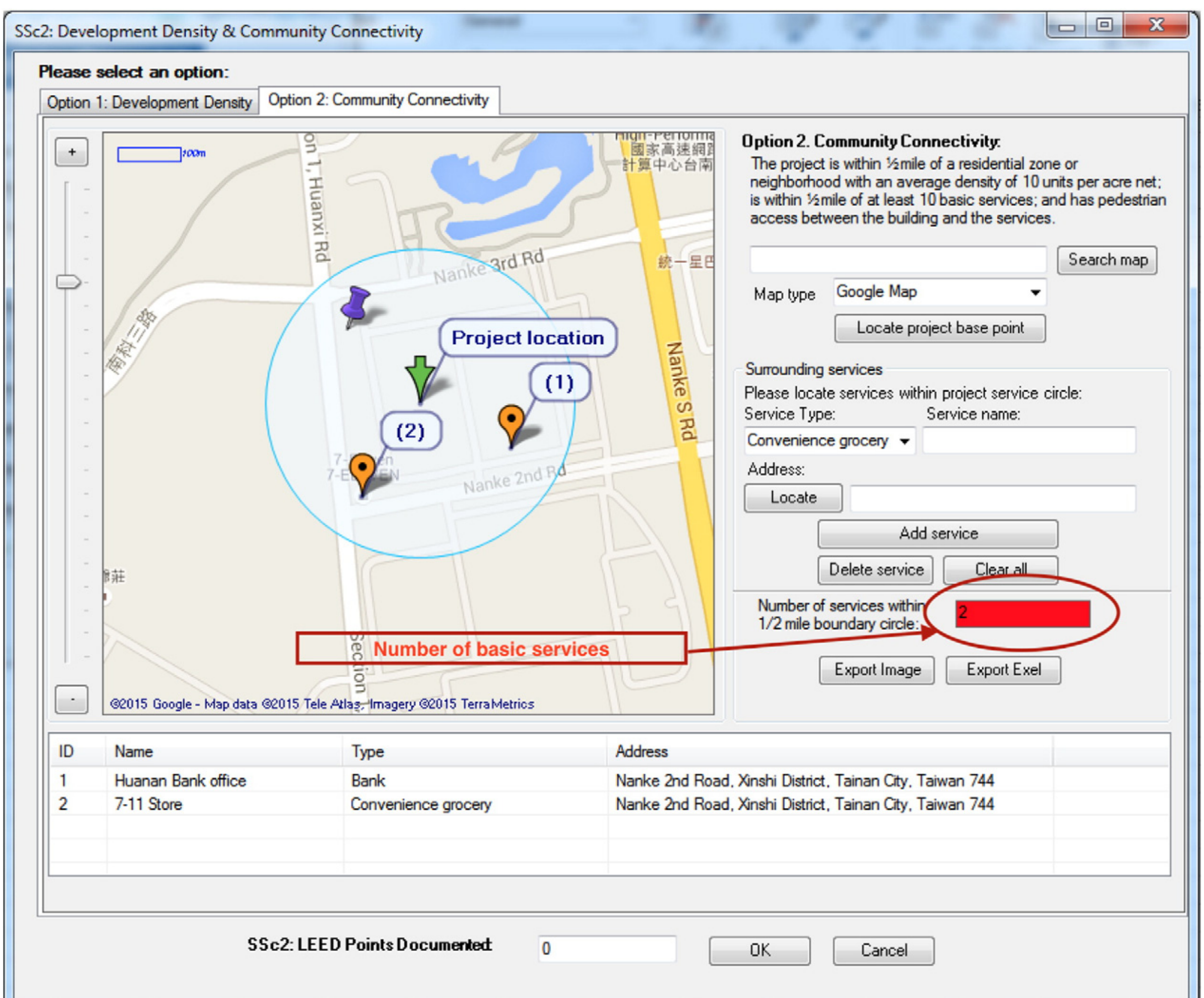

Fig. 21. SSc4.1 – Option 2 user interface.

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