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LEED embedded BIM for Construction Sustainability Analysis

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Abstract–During construction, designed sustainability aspects should be checked to gain credits from LEED. In addition, the construction processes should be evaluated to see if they meet the sustainable requirement. In this research, LEED document is reviewed and analyzed to decide what information should be collected during construction. A BIM model is developed and data collected will be integrated into the model. An automatic evaluation is carried out based on the BIM model and LEED document. Plug-ins are developed by using programming language, e.g., C#. A case study has been carried out to investigate the feasibility of the proposed methodology.
Keywords—sustainability, BIM, LEED, construction.

I. INTRODUCTION

Sustainability issues are the major concerns for building stakeholders to find a trade-off between environmental and financial aspects of designing a building. Buildings in our lives are indispensable and inseparable from a variety of architectural engineering activities in modern life, and natural environment is the basis of human life. Therefore, the relationship between environment and construction is closely linked and mutually restrained with each other. Sustainability issues are the major concerns for building stakeholders to find a trade-off between environmental and financial aspects of designing a building. According to United Nations Environment Program, more than 40 percent of global energy is consumed by buildings, and one third of global greenhouse gas is produced by buildings [1]. However, less consideration in terms of sustainability is taken into account during the construction process compared with design stage, which leads to excessive waste produced and environmental pollution. The sustainable construction aims for better management of resources and reducing the impact on the surrounding environment [2].

To provide a principal for sustainability concern, several green building standards, certifications, and rating systems were publicized in the last two decades. In 2000, Leadership in Energy and Environmental Design (LEED) rating system was released by the United State Green Building Council (USGBC), and now becomes the most popularly used standards over the world. Although LEED is initiated from the USA, it has established a global reputation as a benchmark of green buildings. In Asia, more than 500 projects have been accredited over the past five years, and most of these projects are from China and India [3]. It has been observed that many building developers in China favor foreign green building standards to attract international investors, and LEED becomes their first choice. LEED has accredited projects in 24 different countries, and there were 172 certified projects in China by March 2012 [4].LEED credits accreditation system covers the whole life cycle of a project, namely design, construction and operation phase, however the requirements of each clause are related to different combinations of phases.

Prerequisites and credits in the LEED system address 7 topics which are Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation in Design and Regional Priority. Credits that are gained from different phases will be updated by collecting information during associated phases.

Recent studies have identified that inefficiencies and waste in the construction phase happened due to the lack of proper integration of efforts between various stakeholders. Through early collaboration and the use of BIM technology, a more integrated, interactive, virtual approach to building design, construction and operation is emerging.

Building Information Modeling (BIM) is a new approach to design, construction, and facilities management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in a digital format [5]. Kryegiel and Nies [6] indicated that BIM can be applied in sustainability analysis widely while considering for example building orientation, building envelope, and construction materials. Recent research in the building construction industry reveals that Building Information Modeling (BIM) has not been popularly used to take the advantages of the new technology due to several reasons. Lack of knowledge and personnel that familiar with the technology are the major issues.

The present paper aims to provide a new method by integrating BIM and LEED and assessing the sustainability of the construction phase with an instant feedback. This paper is part of a big topic that assessing the whole life cycle of the buildings using the same research method. Related research background can be found in the authors' other publications, such as [7], [8], and [9].

II. RELATED RESEARCH

To facilitate the wide spread of sustainable buildings more effectively, professionals in Architecture, Engineering and Construction industry (AEC) have introduced Life Cycle Analysis (LCA) and Building Information Modelling (BIM) into sustainable buildings. LCA is a systematic method to assess the impact of buildings on the environment from multiple perspectives, namely design, construction, operation and demolition, among which construction phase is usually getting less concerns. Building Information Modeling (BIM) is a new approach to design, construction, and facilities management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in a digital format. With the introduction of BIM, different attributes of the building envelopes can be recorded in the digital database, for instance carbon dioxide emission, which facilitates the automatic sustainability assessments of buildings. Chen and Hsieh [10] developed a BIM-assisted rule-based approach to automatically check of greenhouse gas emission of buildings. The normal carbon dioxide emission was calculated from the building and the area of green plants; and then the result would be checked with relevant rules. However, most of these applications are limited to the design stage. Using BIM is also changing the manner of constructing buildings in the construction industry. The relationship of space and time can be accurately described in a systematic way in 4D modeling. Several approaches have been proposed in research to analyze conflicts and to improve safety and efficiency on site based on the spatiotemporal information provided by BIM [11]. Kiviniemi et al. [12] have used BIM as a 4D safety planning tool, in which the researchers have indicated that BIM technology can present a new way to solve site safety problems. Moreover, as indicated by Motamedi et al. [13], a more efficient facilities management system can be built by sharing and exchanging distributed data based on the integration of Radio Frequency Identification (RFID) systems and BIM. Li et al. [14] developed a BIM centered indoor localization algorithm to support building fire emergency response operations. They designed an environment-aware beacon deployment algorithm to support a sequence-based localization schema

In the present research, a lifecycle assessment on the sustainability of buildings is proposed, building aspects related to sustainability design, such as the selection of reusable material, and a long-term continuous performance monitoring, e.g. electricity and water consumption, and spatial analysis are integrated with BIM. First of all, building aspects that cannot be parameterized will be extracted and assessed by using predefined rules. The more aspects of building are considered and assessed in this system, the more convincing the overall sustainability assessment result will be. In addition, this categorization helps the designers to pay more attention to those requirements which cannot be translated to digital expression. Second, the sustainable performance will be monitored during the whole life-cycle. The assessment includes annual power and water consumption and survey on occupants. The gathered information can be recorded to assess life-cycle sustainability and to guide future sustainable design. In some situations, high energy consumption may be due to the behavior of occupants rather than the building design, and the results collected from continuous assessments will help people find the true cause of high energy consumption.

The present paper focuses on the construction phase, where a lot of scattered data should be collected and the as-planned BIM model should be updated and reevaluated according to LEED requirements.

III. PROPOSED METHODOLOGY

First of all, LEED Documents are reviewed thoroughly and all credits in LEED documents are grouped into two categories. The requirements of some credits can be assessed by retrieving parametric aspects of specific elements from the BIM model. While other credits rely on more information should be manually input during construction. For example, in Material and Resource Credit 2 the percentage of construction and demolition debris that is redirected to manufacturing process needs to be reflected during construction. Next, in the construction phase, the project manager needs to check the feasibility of the building materials according to local resource availability and modify the initial design if necessary. If any recommendations are made, the change should be reflected in the model and the expected performance should be updated. The construction contractors also need to report their construction documents, namely construction method, construction schedule, and waste management plan. These construction documents will be used to assess the sustainability at the construction phase according to LEED standards. Recent studies have identified inefficiencies and waste in the construction phase due to the lack of proper integration of efforts between various stakeholders. Therefore, a Lean Construction (LC) approach can be applied using BIM as a core database for schedule, cost and other related information. An RTLS is designed in this research to collect data from tagged objects. This system is designed together with the structural, the MEP, and other main components from the planning and design phase. Radio Frequency Identification (RFID) can be used to monitor construction materials, pre-cast components, steel structure components, HVAC components, etc. to enable lean construction, and improve safety on construction site [15]. The collected data will be used to update the BIM model so as to facilitate a second-round evaluation based on the current situation of the building.

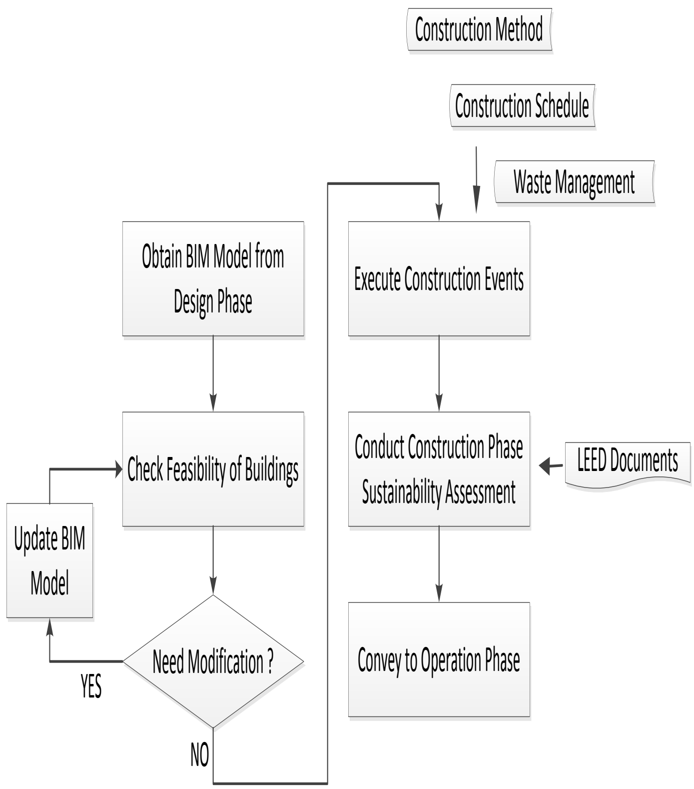

Fig. 1 Framework of sustainability assessment during construction stage

Fig. 1 shows the proposed framework of sustainability assessment during construction stage. The core part of the system is based on rules developed according to the LEED requirement, and the three main steps of rule-based assessment are *Input*, *Analysis* and *Output*. Inputs vary according to the requirements of different credits. For example, MR Credit 3 describes the percentage of reusable material of the total value of materials on the project, based on cost. Theoretically, this information can be retrieved by either parameterized properties or manual description. If it is obtained from parameterized properties, the reusable material pertaining to individual instance or type should be specified, and then the whole percentage can be calculated. Alternatively, the percentage of reusable material in the whole project can be input directly by designer through an interface. The later choice is preferable due to pragmatic consideration. The inputs also include external supplementary information, for example RSMEANS construction market unit price, because this information is vital to calculate the percentages of materials to the total materials, based on cost.

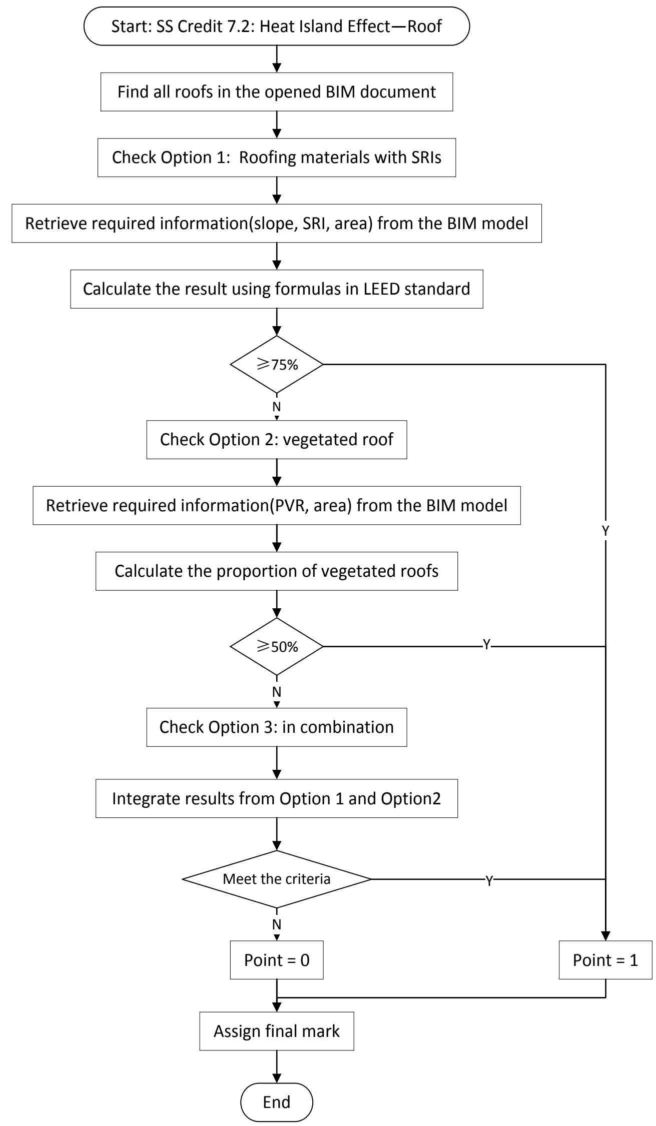

Fig. 2 Example of a rule-based assessment

The *Analysis* part is to calculate the result based on the *Input* and rules for each credit. The rules are embedded in the BIM environment. Taking the example of Hot Island Effect evaluation of a roof, there are three options to fulfill the requirements of this credit, and the three options can be represented by a series of parametric calculations, as shown in Fig. 2. Finally, the *Output* shows relevant parameters of this credit, credit this project can achieve and feedback about further improvements.

IV. IMPLEMENTATION

Autodesk Revit is selected in this research as a platform to develop the system. C# is used to develop plug-ins using Autodesk Revit .NET API. A user friendly interface is designed to facilitate the input process. The analysis is done based on information retrieved from the BIM model and additional data input by the user during construction.

In this research, a user friendly interface is designed to facilitate input and output process. All credits are listed explicitly and the user can click one credit and then enter sub-interface to deal with one specific credit. In the sub-interface, the data from BIM model is retrieved and presented automatically, for example quantity of concrete. Some external supplementary information can be input at this stage for example unit price of concrete, percentage of fly ash used in the concrete as a supplementary material of cement. For some credits which are assessed purely based on the description, we provide several potential options and user can select the one which is closest to the anticipated situation from drop-down list.

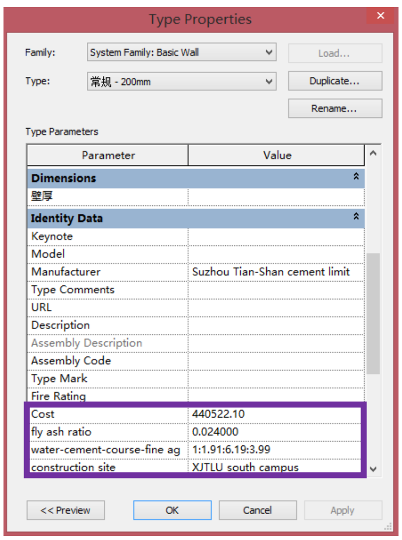

Fig. 3 Wall Properties with Customized Items

To retrieve data automatically as much as possible, more information should be input to the properties. The properties can be customized using “project parameters” function in Revit. New parameter type, parameter data and categories are defined as required. Project parameter and shared parameter types can be selected accordingly. As shown in Fig. 3, new properties are added to the Walls to facilitate the assessment.

In the current research stage, our focus is on Materials and Recourses. The quantity of the material should be estimated to calculate the credits gained. Quantity take-off is one of the most useful information that can be easily retrieved from the BIM model. Several credit evaluations are based on cost, which requires a detailed analysis of quantities. For example, the intention of Material and Resources (MR) credit-3 is to encourage reuse of building materials, in order to reduce demands for virgin materials and reduce waste. The credit requires that the sum of reused materials accounts for at least 5 or 10 percent, based on cost, of the total value of materials. In this case, materials' cost can be calculated based on the quantities take-off from the model and the unit price that need to be input by the user. That requires a design for inputting more information during the design phase. Generally, the BIM model has not only geometric information of objects, but also other valuable information about the attributes of these objects, for example materials of objects and specific attributes for energy analyses usage. After a thorough review of the LEED document, the required information is summarized for each type of building components, such as Roof, Wall, Floor, etc. That extra information is required to be input by the user during the design phase. A hierarchy of element defined in BIM makes this process more efficient. More details can be found in [8].

Rules are developed based on the requirements in LEED to fulfill automatic assessment. Since the main focus of the present paper is on Materials and Resources, to be more specific, the implementation focuses on Recycled Material, Material Reuse, Regional Material, and Waste Management.

The intention of MR credit 3 is to encourage reuse of building materials, in order to reduce demands for virgin material and reduce waste. Opportunities to incorporate reused materials are limited, which mainly includes salvaged brick, structural timber, stone and pavers. The credit requires that the sum of reused materials accounts for at least 5 and up to 10 percent, based on cost, of the total value of materials. The purpose of MR Credit 4 is to increase demand for the recycled material in order to reduce the influence of demand from extraction and processing of raw materials. The sum of postconsumer recycled and half of the preconsumer content should constitute at least 10% and up to 20% of the total material used in the project, which is calculated based on percentage of the material cost. Corresponding points (i.e., one or two points) can be assigned based on the percentage reached in the project. Since extra information has been added to the Properties to the components of the building, such as the fly ash ratio in the concrete, as shown in Fig. 3, the quantity of the recycled materials can be obtained automatically and unit price can be input through an interface, the percentage of the material in terms of cost can be calculated and corresponding points will be assigned automatically.

MR Credit 5 aims to increase demand for the materials and products that are manufactured and extracted within region, thus supporting the use of local resource and reducing the environmental pollutions resulting from transportation. To meet this requirement, at least 10% and up to 20% of the materials should be procured within a certain radial distance of the project site. The percentage is calculated based on cost. Materials or products can be transported by train, air or water, whose total distance of the project site should be determined by the following formula: (Distance by train) ⁄ 3+(Distance by inland waterway) ⁄ 2+ (Distance by sea) ⁄15+Distance by all other means $\leqslant$ 500 miles (800 kilometers). This extra information will be input to the system by the project manager, and the results will be assessed based on the rules developed to calculate how many credits can be obtained.

MR credit 2 aims to divert construction and demolition debris from disposal in landfills and incineration facilities. Redirect recyclable recovered resources back to the manufacturing process and reusable materials to appropriate sites. It requires to develop and to implement a construction waste management plan that identifies the materials to be diverted from disposal and whether the materials will be sorted on-site or comingled. Calculations can be done by weight or volume, and the minimum percentage debris to be recycled or salvaged is at least 50% and up to 75%. Recycling metal, mineral fiber panel, glass, wood, plastic, wallboard, insulation, cardboard, gypsum and carpet can be considered in this category. Construction debris can be classified as a recycled content of commodity that has a certain value in market, for example, alternative daily cover material, wood derived fuel, and these may be utilized to construction waste calculation. The construction site should be assigned a certain area for segregated or comingled collection of recyclable materials, and the waste material, especially in recycled and reused material, must be tracked throughout the whole construction processes. At meanwhile, the recyclers and haulers are responsibility for the designated materials in construction processes, it note that diversion may contain charity donation of material and on-site emergency treatment. All this information is collected and integrated into the BIM model to show a waste management plan does exist and calculation will be done to check if the requirement can be fulfilled.

An RFID system is used to collect real-time data, including location data and data saved in the tags, e.g., energy consumption, through the construction and the operation of the building. A 2.4G Hz RFID system is selected to be tested in this research. Passive and active tags are both used to test the visibility and effectiveness. Those tags are registered/represented in the BIM as temporary or permanent objects depending on the requirements of construction and operation. Location information together with other data (energy consumption collected from other sensors) stored in the tags are read and saved in the BIM database for further analysis related with spatial aspects. For example, energy consumption for a specific area or room. In this way, energy consumption can be analyzed in a way that the spatial issues can be taken into account. Plug-ins are developed to load data collected from the RFID tags into BIM and to create the corresponding tags in the model. A new object family is created to represent tags in the BIM model as shown in Fig. 4. Tag ID, Location, Reference object, Host, etc. are stored in the Properties. Those data can be updated automatically or modified manually. Each RFID read-and-write (RW) tag can store 4KB data, where information including the tag ID, reference objects, etc., can be written to the memory at any stage of the construction. That information will be read and saved to the Properties of each tag after the tag is detected on site. In addition, once the information in the Properties of each tag is updated, the same information can be written to the memory of the RFID tag as well. An experimental investigation of using FRID integrated BIM model for safety and facility management can be found in one of the authors' publication [15].

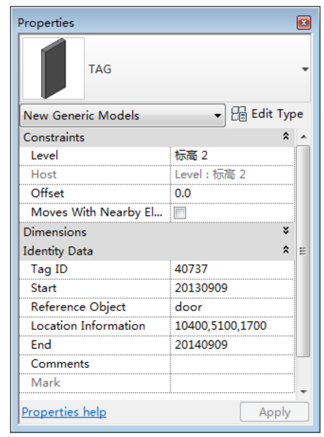

Fig. 4 RFID Data Representation in Properties

V. Case Study

The project selected for the case study is the Engineering Building at Xi'an Jiaotong-Liverpool University. A BIM model was created by using Revit based on 2D AutoCAD drawings. It is a U-shape building with 5 floors. LEED 2009 for Schools New Construction and Major Renovations (2013) is integrated in the BIM model. Fig. 5 shows the user interface of LEED evaluation.

Fig. 6 shows a report of the ingredients of the concrete used in the project, where data of the weight of various raw materials that include cement, course aggregate, and fine aggregate, fly ash, mineral power, as well as admixtures are extracted from the report and added to the properties of different components that constructed using concrete. The fly ash in concrete is around 2.4%.

Fig. 7 shows an example of floor schedule exported from Revit to calculate the total cost of fly ash used in the project. A simplified calculation is shown as: Cost of Fly ash = 2.4%*7202.68*275=47,537.7, where 7202.68 is the total volume of concrete used for floors, 275 is the unit price of fly ash in cubic meter. Together with other material cost in the project, the percentage of all the recycled content can be

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calculated, and the corresponding credits obtained are checked.

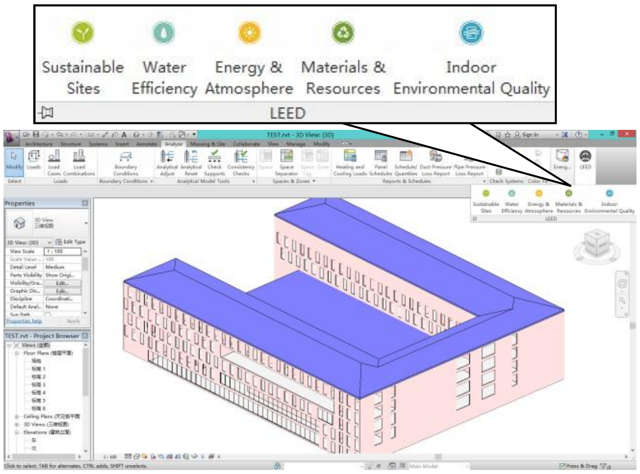

Fig. 5 Interface of LEED evaluation plug-in

国产实业(苏州)混凝土有限公司
混凝土配合比报告

报告编号: 151856　　报告日期: 2015-4-19

用户单位	江苏省建设集团有限公司									
工程名称	西交利物浦大学新建项目				浇注部位	3#3-13-3-14轴后浇带				
强度等级	C40P6 微膨胀	配合比代号	G6362EA	水胶比	0.35	坍落度(mm)	160±30	砂率(%)	39.0	
原材料	水　泥:	P.042.5	生产厂家:	宜兴天山水泥有限责任公司						
	碎　石:	5-25连续级	产　地:	浙江湖州						
	砂:	II区中砂	产　地:	江西南昌						
	粉煤灰:	II级	生产厂家:	昆山鑫源环保热电有限公司						
	矿　粉:	S95	生产厂家:	张家港恒昌新型建筑材料有限公司						
	外加剂1:	PCA®-I	生产厂家:	江苏苏博特新材料股份有限公司						
	外加剂2:	膨胀剂SY-K【8%】	生产厂家:	上海申御特种建材有限公司						
	外加剂3:	------	生产厂家:	------						
配合比	原材料	水	水泥	碎石	砂	粉煤灰	矿粉	外加剂1	外加剂2	外加剂3
	每方混凝土用量(kg/m³)	170	289	1054	674	58	98	5.05	35.6	-----
	原材料复试编号	-----	C15034	G15077	S15069	F15014	K15011	AD15021	P15028	-----
备注	1. 方量(m3): 40									
	2. 混凝土标记: A-C40-160(S4)-P6-GB/T 14902									
	3. 本配合比所用原材料质量请查阅有关检验报告。									
	4. 当原材料品种规格变化时，本配合比无效。									
	5. 如砂浆为润泵砂浆，无强度，不宜泵入结构部位。									
	6. 本公司外加剂1是加入水中计量的，因此计算混凝土容重时外加剂1不计算在内。									

试验室(章):　批准:　复核:　设计:

Fig. 6 Concrete ingrdients report

Fig. 8 shows an example of Material Reuse Assessment. At this stage, it is assumed that the total material cost has already been estimated. Then, the percentage of reuse material out of total material cost can be calculated.

Floor Schedule					
Area	Volume/ m	Perimeter	unit pri	Cost	weight of fly ash
			430		
1964 m²	710.8	207100	430	305644	17.0592
1961 m²	710.02	207100	430	305308.6	17.04048
6075 m²	2199.09	382200	430	945608.7	52.77816
5674 m²	2054.06	382400	430	883245.8	49.29744
total	5673.97		430	2439807	136.1753

Fig. 7 Floor schedule exported from Revit

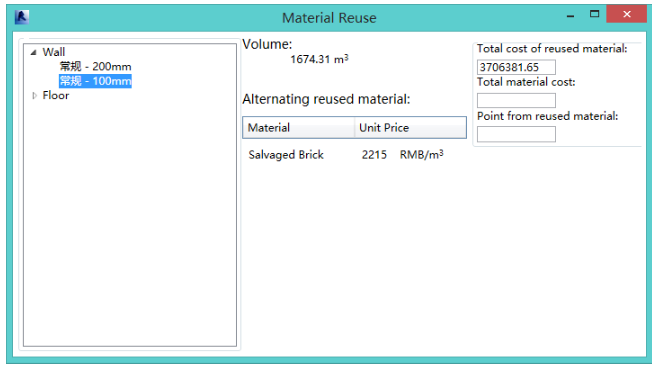

Fig. 8 Material Reuse Assessment

In BIM model, the geographic location of the project can be input as shown in Fig. 9. All the materials that are regarded as regional materials are checked to ensure the transportation distance is within range. Then, the quantities of materials can be obtained from the model while the unit costs and production locations of the materials need manual input. The percentage of the regional materials is calculated automatically based on rules developed.

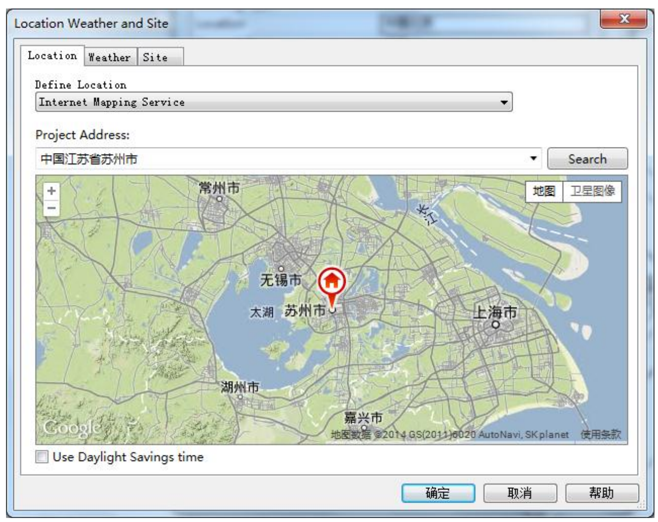

Fig. 9 Location of Project in Revit

Fig. 10 shows a waste management plan integrated in the BIM model. An URL is given in the Property to direct the user to a detailed document describing the detailed plan. Pictures are taken from the construction site showing the waste storage sites and attached to specific component of the model. In this case, one of the façade of the building is selected to attach the pictures.

VI. DISCUSSION

This paper proposes a method to automatically assess building sustainability during construction phase by using BIM and LEED. Information collected from the construction phase is integrated into the BIM model to calculate the credits gained according to LEED accreditation requirements. LEED standards are embedded in the BIM model and automatic evaluation is done based on information either retrieved from the model or input by the user manually. A rule-based system is developed to calculate the credits gained from the construction activities. A preliminary prototype system is developed to investigate the feasibility of the proposed methodology and a case study is carried out to test the system. The benefits of the proposed research could be: (1) Provide an effective tool to evaluate the construction processes' impact on sustainability of buildings. (2) Give a quick feedback on credits gained from LEED regarding the construction activities. (3) Evaluate the project based on as-built situation. Our future work focuses on integrating more credits and more data required to fulfill those credits.

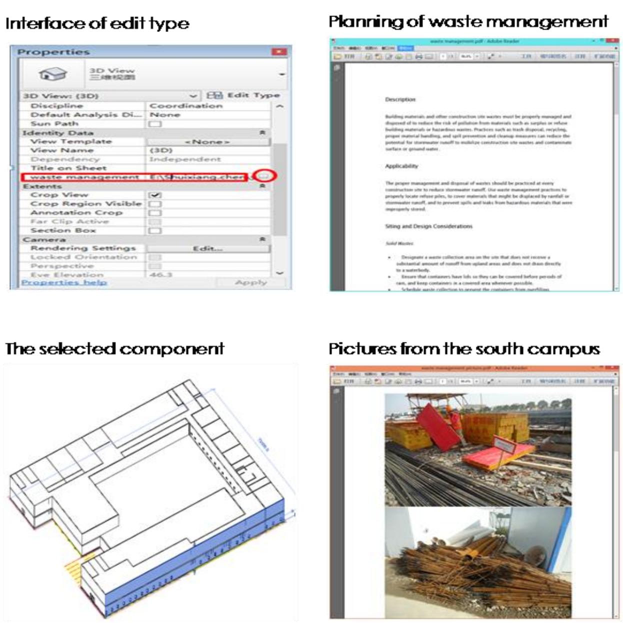

Fig. 10 Waste Management integrated in the BIM model

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