Automation in Construction 70 (2016) 26–37

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Green building assessment tool (GBAT) for integrated BIM-based design decisions

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ARTICLE INFO

Article history:
Received 6 February 2015
Received in revised form 12 February 2016
Accepted 1 May 2016
Available online 2 June 2016

Keywords:
BIM
BREEAM
Green building assessment
IFC
Integration
Sustainability

ABSTRACT

The benefits of BIM such as effective decision making, improved analysis, easier access to information and simpler green building certification provide an optimised solution for sustainable design and construction. This study proposes an IFC-based framework within an integrated BIM and sustainable data model for the design stage of the building project life cycle. We present the green building assessment tool (GBAT), which implements the proposed model and aids the design team in the generation of documentation necessary for obtaining green building certification. It extracts the necessary data from BIM models for calculating the green rating and provides feedback for further evaluation. A sample project is run and a green rating score table for the BREEAM materials category is obtained for validation of the model. This tool serves as a proof of concept that green data relevant for BREEAM certification can be automatically processed and used to inform the design.

1. Introduction

The necessity of integrated data approach has resulted in the "building modelling" concept, which is the development of a single model of the architectural project incorporating the 2D, 3D and material property information for both schematic and detailed design [12]. Building information modeling (BIM) facilitates integration, interoperability and collaboration in the construction industry [39], by providing a three-dimensional (3D) representation of a project including all the parameters of its components. BIM has become the centre of the building project life cycle for the requirements of performance analysis, planning, programming, cost and time data organisation, and the provision of construction documents, in addition to design and visualisation. Resource scarcity, sustainability challenges and stricter decrees for recycling and resource efficiency in buildings motivate the architecture, engineering and construction (AEC), facility management (FM) and deconstruction communities to manage resources more efficiently [41]. Policies, laws and regulations around the world now require the sector to adopt sustainable innovation in terms of products and processes to encourage more sustainable outcomes [17,20,36]. BIM is ideally suited to the delivery of information enabling improved design and building performance. Two major beneficial features of BIM in relation to sustainable building design are those of integrated project delivery (IPD) and design optimization [4,42]. Traditional CAD-based design requires a great deal of human intervention and the whole process is time consuming and costly. However, with BIM, designers can optimise the building design efficiently in the very early stages of the whole process and produce a better solution. Since the construction industry has become more interested in environmentally friendly buildings that can provide both high performance and monetary savings [24], the development of more sophisticated and robust platforms is now necessary to maintain the level of achievement reached so far. Accordingly, BIM must increase its capacity to integrate environmental analysis and improve interoperability. The advancement of technology will assist both the goal of sustainability and BIM itself in establishing standards of excellence in the future. Nevertheless, and most importantly, the AEC industry and owners must be willing to incorporate these tools as standard practice. Additionally, parties must be willing to cooperate with one another so that an optimal collaborative effort is provided for sustainable building projects [11]. Lack of interoperability of sustainable data has the effect of limiting the application of BIM in building design and needs to be addressed earlier in the planning stage. Throughout the ongoing development in this area, the overall practical effectiveness of BIM still needs to be analyzed and validated [16,29,32].

1.1. Problem statement

Since most sustainable decisions are made during the design stage, integrating the sustainable data into this process via BIM is critically important to solving decision-making dilemmas. The challenge then, as Brahme et al. [8] point out, is to find a way of using detailed tools even during the early stages of design when values for many of the variables for the building's technical sub-systems are not yet available, and

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http://dx.doi.org/10.1016/j.autcon.2016.05.001
0926-5805/

to provide the designer with quantitative predictions of the building's future performance [6]. Currently BIM software is still a long way from being fully integrated with the various databases required for sustainable building projects. In some cases, a team may need to import information to the BIM model from an outside source, such as a database of weather data or material properties. Better and more seamless integration between BIM and sustainable design will come with time as the industry continues to standardise file formats, as data sets are developed, and as owners, clients and designers begin to demand more from application developers [27]. The integration therefore requires considerable effort and time such that the evaluation of sustainable data ends up being performed after the design stage in most cases. This is a common and well-understood problem by many involved in sustainable projects.

Clearly, construction professionals would benefit from an integrated tool that helps optimise the process of material, equipment and systems selection at every stage of the construction project life cycle [7]. Material selection and use, site selection and management and systems analysis are the main areas of sustainable design with a direct relationship to BIM [19]. This paper presents a framework for such an integrated BIM platform, which would also facilitate the generation of documentation required for green building certification. The framework bridges the gap between the green building assessment processes and BIM, simplifying design stage decision making regarding sustainability.

1.2. Aim and objectives

The purpose of this study is to address the problem of BIM and sustainability integration through the development of an automated tool, which can process BIM models, generate a draft green building assessment and highlight potential sustainable design improvements for the user. To this end, the following points are addressed:

1- Extension of the data contained in the BIM model within the BIM software to enable a building assessment (e.g., storing in the BIM model extra material properties, whether materials are reused or responsibly sourced) and ensuring the data are encoded into the saved BIM model file
2- Creation of a database of materials with the necessary green properties and interfacing it with BIM software to reduce the user effort required to produce a suitable BIM model containing the extra green data
3- Processing the BIM model file to extract data relevant for the green building assessment (e.g., selected materials and their surface area)
4- Calculation of the green score from the extracted data and presentation of the results in a clear and intuitive manner to the user, highlighting potential areas for improvement.

The proposed model aims to provide guidelines for the design of a project's sustainable features at the design stage when they are most needed. It will allow timely decision making by offering an evaluation of the alternatives for sustainability performance and enable the utilisation of pertinent data stored in the BIM model for green building certification.

1.3. Methodology

Due to its flexibility in exchanging data between different types of software used in the AEC industry [14,28,46], an IFC-based framework is intended for the proposed model. The framework builds a relationship between the BIM and the green building rating processes. The main objective is to designate green properties to the BIM objects using the IFC model schema, which is an open, international and standardised specification for BIM data exchanged and shared among software applications used by the various participants in a building, construction or facilities management project. To create BIM designs with sustainable information, the property sets and green materials library should be embedded within the software. The user, then, can determine the necessary data for certification and evaluate the decisions. For an effective response to the aim and objectives, a two-step methodology is adopted in this study: (1) model development process and (2) user process (Fig. 1).

The model development process involves the following sub-processes:

- Developing the property sets in the IFC standard: The major green building assessment systems are first investigated and the list of possible categories for IFC schema is created according to the analysis. Following this, the property sets are developed.
- Producing the green materials database (GMDB) and the green materials library (GML). The GMDB consists of an Excel xls file and the GML is contained in an ArchiCAD® template file.

The tool addresses the Materials category of the BREEAM Europe Commercial 2009; in principle, it could be extended in the future to cover the remaining 9 categories. The materials database is produced manually for 68 out of the approximately 1500 materials in the Green Guide to Specification but could be produced automatically from the BREEAM materials database if a suitable application program interface existed. The GML is produced by manually entering the 68 selected materials into ArchiCAD® and translating the human readable textual description into a computer readable form (specifically the "Element Definition" field of the Green Guide to Specification is translated into ArchiCAD®'s building element and material property).

The user process is the validation of the developed framework via a case study and includes two main sub-processes:

- Generating BIM model: Sustainable BIM model is generated based on the template file and exported to IFC format.
- Calculating the data for green documentation: The green building assessment tool (GBAT) extracts the related data, makes the calculations according to the green ratings and presents the available credits as the output. The tool was developed in Visual Studio 2013 integrated development environment (IDE) using C# programming language due to its being a modern and very high level programming language.

2. Related work

Green BIM, as an emerging trend, has been increasingly discussed for more sustainable outcomes. BIM is examined from the general sustainability aspect in various studies.

Initial studies focus on the state of the art of BIM for sustainable design and construction. An online survey designed by McGraw-Hill Construction for 2010 Green BIM Study [31] was conducted with a range of industry professionals who use BIM tools to assess the level and scope of BIM tools to help achieve sustainability and/or building performance objectives. The results of the study show that BIM is considered an essential tool for green construction and is expected to be in extensive use in the near future. Greater use of integrated design is highlighted in this study as one of the key areas of potential growth for Green BIM. Azhar [3] conducted a questionnaire survey to evaluate the state and benefits of BIM-based sustainability in design and construction firms who use BIM technology and/or sustainable design/construction practices in most of their projects.

On the other hand, Ilhan and Yaman [21] focused on the current state of BIM in sustainability by performing interviews with the Turkish architectural firms that participated in certificated sustainable projects in order to find out the key indicators for better BIM and sustainability integration solutions. The results show that BIM is not used thoroughly for sustainable projects, including all building production processes, due to lack of qualified staff and allocated budget. Moreover, the difficulty of developing sustainable material and an IFC database, along with the

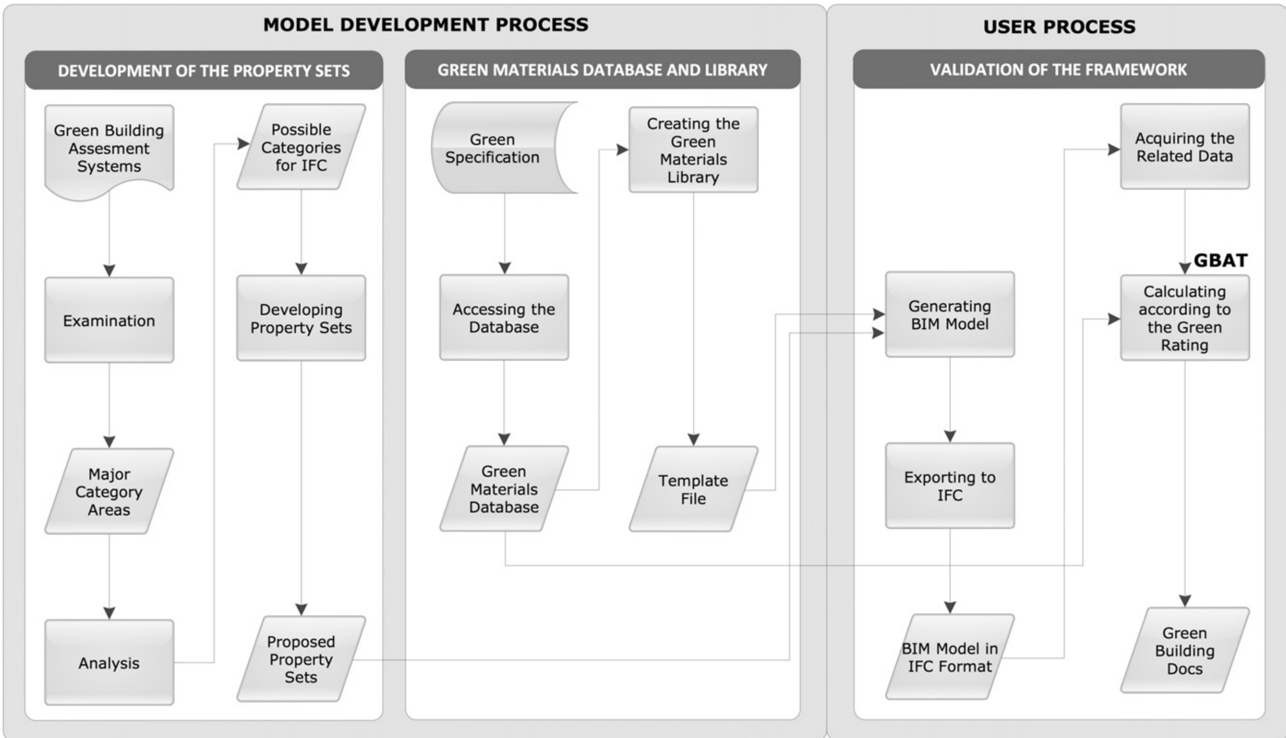

Fig. 1. Research methodology.

limitation of using current standards, can be mentioned as drawbacks of BIM and sustainability integration in Turkey.

As the main concern of green buildings, Ham and Golparvar-Fard [18], Kim and Anderson [25], Kim et al. [26] and Ma and Zhao [30] carried out studies on BIM-based energy analyses to improve the reliability of energy performance modelling. Advanced decision making for sustainable projects was a subsequent topic of discussion. Inyim et al. [23] introduced a simulation of environmental impact of construction (SimulEICon), which is an add-on to the Autodesk Revit Architecture software, designed specifically to aid in the decision-making process during the design stage of a construction project. Zanni et al. [47] discussed the need for a structured process for sustainable building design for BIM execution with the aim to develop a BIM-enabled sustainable design process model that identifies critical decision actions in the design process along with the information and level of detail that facilitates an informed and timely decision. Geyer [15] examined the use of systems modelling language (SysML) to model systems for sustainable building design and developed a method called parametric systems modelling (PSM) for integrating systems modelling into the CAD/BIM-based design process.

A number of studies have also been made with regard to sustainable building certification and BIM integration. For instance, Wong and Kuan [43] used a two-stage method (Delphi and case study) to explore the potential use of BIM in the case of a residential building project seeking BEAM Plus sustainable building certification in Hong Kong. Oti and Tizani [34] proposed a modelling framework combining the indicators of sustainability of buildings, which are life cycle costing, ecological footprint and carbon footprint for providing sustainability assessments of alternative structural design solutions, based on the economic and environmental sustainability pillars.

Studies regarding the relationship between BIM and LEED have also been carried out. Azhar et al. [5] presented the ways designers and planners may use BIM for various sustainability analyses specifically in pursuit of the leadership in energy and environmental design (LEED) certification. They develop a conceptual framework to establish the relationship between BIM-based sustainability analyses and the LEED certification process and then validate it with a case study. Wu and Issa [44] proposed a 3rd-party web service relying on BIM as the information backbone to facilitate the LEED documentation generation and management. Furthermore, Wu and Issa [45] developed an integrated green BIM process map for LEED projects. Alwan et al. [1] aimed to examine the feasibility of using 3D simulation transfer processes to streamline the environmental assessment of buildings that have been designed digitally using BIM. A case study for LEED evaluation within the BIM process is presented.

BIM is expected to become a fundamental tool for sustainable design and construction due to the potential benefits it offers. Since BIM provides an opportunity for superposing the multidisciplinary information within one powerful model, its growing importance is commensurate with the increased demand for green certification. However, the number and the content of studies related to sustainability concept indicate that there is still a gap for integrated solutions, especially where the whole certification process is concerned. Even though the importance of using BIM technology for sustainability is discussed in the literature, there are some barriers to full integration, such as lack of functional tools and the complex structure of existing tools [24]. It is, therefore, important to propose a supporting method that facilitates the sustainable project decisions generated by BIM software for an integrated BIM and sustainable data model.

3. Integrated BIM—sustainable data model

The proposed model provides a guideline for the design team to address the sustainable features of the project during the design stage. The model is based on the green building assessment tool (GBAT) sustained by three main modules (Fig. 2).

The first module develops the property sets that represent the initial data for green certification. The property sets for designating sustainable properties to the BIM projects are incorporated within the IFC structure. To effectively determine the property sets, the process includes three main steps, which are examining the green building

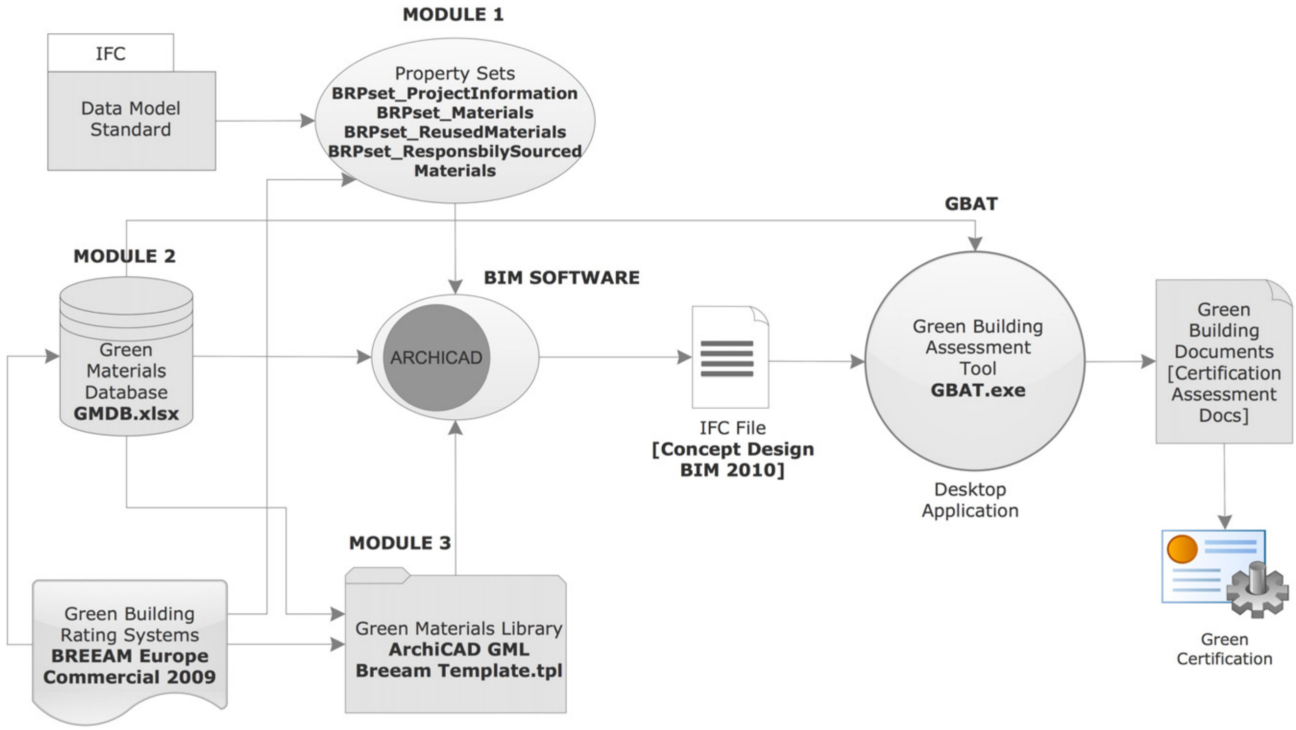

Fig. 2. Proposed integrated BIM—sustainable data model.

assessment system, analysis of the major category areas of this assessment system and determining the property sets for IFC model schema.

The second module of the proposed framework creates the green materials database, which depends on the related green building rating system, such that the stored green data in the database is used for calculation. The last module, on the other hand, generates the library based on the green materials data. The green materials database consists of the environmental information relating to building materials and components, whereas the green materials library is set up to use that information within the BIM software. The specified modules are the inputs for the BIM software. The output of the related BIM software, which is the IFC file of the completed project, forms the input for the next step of the proposed model.

In order to generate the green building certification assessment documents, the developed desktop application (GBAT) is run, making a calculation depending on data obtained from the previous steps. An evaluation can then be made according to the targeted certification level (such as a reconsideration of construction materials to increase the credit rating of the building).

There are some restraints and assumptions concerning the proposed model and its implementation.

- The model focuses on Building Research Establishment Environmental Assessment Methodology [9] and uses BREEAM Europe Commercial 2009.
- The BREEAM scheme is approached from the point of view of materials due to being the most computable category. The scope of the proposed property sets for the first module of the framework is limited to materials.
- Accessing the green materials database manually is the other limitation of the model due to the requirement to log into the Green Guide to Specification.
- Graphisoft ArchiCAD® is used for generating the BIM model since ArchiCAD®'s IFC interface provides the possibility to define, export and import these data types.
- Developing a desktop application and the necessity of MS Access Database Engine® and IFC File Analyzer (IFA) [37] installation are the constraints regarding GBAT.

The parameters of the proposed model are derived from the property sets, green materials, IFC file of the BIM project and the input from the user into the assessment tool. While the property sets are based on the categories of the green building assessment system, the materials and components are designated according to the related specification of that assessment system. The user should enter the values of the property sets, such that the data of the generated project, including the property sets, building elements and materials, can be stored as in the IFC file.

3.1. Proposed property sets

The proposed property sets are BRPset_Materials, BRPset_ProjectInformation, BRPset_ReusedMaterials and BRPset_Responsibly SourcedMaterials. The property sets are generated for schema IfcArchitectureDomain in the domain layer of the general IFC architecture. BRPset_Materials has Mat 1_Materials Specification, Mat 2a_Natural Boundary, Mat 2b_Hard Landscaping and Boundary Protection, Mat 3_Façade Reuse, Mat 4_Structure Reuse, Mat 5_Responsibly Sourced Materials, Mat 6a_Insulation, Mat 6b_Responsibly Sourced Insulation and Mat 7_ Designing for Robustness properties, respectively. All data types for each criterion are set as IfcBoolean, which means the data type can have value TRUE or FALSE.

Moreover, property sets are developed in gathering data related to the project, the reused materials and the responsibly sourced materials. BRPset_ProjectInformation has ProjectType and BuildingType properties, which are enumerated. BRPset_ReusedMaterials concerns reused façade and structure materials for BREEAM certification. Therefore, FacadeReused and StructureReused properties identify whether the existing façade and structure materials are reused. The properties of responsibly sourced materials are derived from BRPset_Responsibly

SourcedMaterials. This first checks whether the material is responsibly sourced and then gives a tier level to those that are. Thus, ResponsiblySourced is IfcBoolean and TierLevel has an EnumList. While BRPset_ProjectInformation and BRPset_Materials are applicable to IfcProject entity, BRPset_ReusedMaterials and BRPset_ResponsiblySourcedMaterials are applicable to IfcBuildingElement entity.

Additionally, a classification reference is created for obtaining the green guide rating of each building element, with the reference name Green Guide to Specification and the item reference set as the element number.

3.2. Minimum model view definition (MVD)

A model view definition, MVD, defines a subset of the IFC schema that is needed to satisfy one or many exchange requirements of the AEC industry [10]. As a rich external and internal software schema and mapping between the two, IFC offers multiple ways to define objects, relations and attributes [40]. Data exchanges, however, are often unreliable due to inconsistencies in the assumptions different implementers of exchange functions make about how information should be expressed [35]. There are often unpredictable differences in the ways in which export and import functions treat the same data, posing a barrier to the advancement of BIM [13,33]. There is a need for clear definition of MVD since the IFC itself does not address a number of semantic issues comprehensively.

The minimal set of IFC properties must be exported to the IFC file for it to be a valid input into the GBAT. The project entity and main building elements that are necessarily discussed for BREEAM certification are included. These elements are beam, column, curtain wall, slab, stair flight, wall and window. The minimum model view definitions for each entity are developed for the proposed integrated BIM and sustainable data model.

3.3. Green materials database (GMDB)

Green materials database (GMDB) is based on the requirements of the related green building assessment system. For the proposed model, the database is created according to the Green Guide to Specification, which is an environmental profiling system depending on life cycle assessment (LCA) for building materials and components used for BREEAM certification.

The Green Guide specifications have been arranged into tabular form for common building elemental categories: ground floors, upper floors, separating floors, roofs, external walls, windows and curtain walling, internal walls, separating walls, insulation and landscaping [2]. The building elements and materials taken into consideration are specified according to the building type. For each building type, the building elements included for the calculation vary. For each building element, the Green Guide ratings are given by building type. The rating values range from A+ to E. The summary rating takes account of the performance of the specification for each of the environmental impacts, where those with A+ ratings will have lower overall environmental impact than those with A or B ratings, and E ratings have the most environmental impact. It should also be noted that a building element might have a different summary rating depending upon the building type that is used. For instance, screeded beam and aircrete block flooring as an upper floor construction has the summary rating of A+ for health and commercial buildings, but B value for domestic and retail. On the other hand, it would have an A summary rating if used in an education building. The database proposed for the model is built by setting up the relationships between the building elements and building types. Since the element number of each building element is unique, it can be used to link up the components of the model.

3.4. Green materials library (GML)

Green materials library (GML), as the third module of the framework, is important for providing the practicable sustainable data. The library is composed of the building elements addressed in the green materials database. The building elemental categories specified by Green Guide to Specification are addressed separately and all components for each building element are generated for the BIM software library. The building elements created for green materials library are upper floor, ground floor, internal wall, domestic windows, commercial windows, external wall, insulation, separating floor, separating wall, roof, landscaping—boundary protection wall and landscaping—floor and floor finishes. Table 1 shows the classification of the created elements within ArchiCAD® 17 structure.

In addition to the element attributes, each material in the ArchiCAD® GML has also a set of building element layers, derived from the Green Guide to Specification element definition, and an element name that contains the Green Guide to Specification element number.

Where floors, walls and roof are classified as composites, insulation and floor finishes are defined in building materials as part of those composites. Windows are approached separately as in the other BIM supported software.

An external wall composite structure is presented in Fig. 3, as an example of the created elements. The definition of the composite includes the element number specified in the green guide to specification. The insulation layer of the external wall composite is expressed in the building materials (Fig. 4).

The file including the green materials is then saved as a template file (Breeam Template.tpl) and inserted into the ArchiCAD®. This template is used for generating the sustainable project.

3.5. Green building assessment tool (GBAT)

The green building assessment tool, GBAT generates the green rating score table of the project by extracting the related data from IFC file and making a calculation according to the required criteria. Fig. 5 shows the use case diagram for GBAT.

After creating and uploading the IFC file into the GBAT, the tool saves the IFC file and makes the calculation according to the project, building and element type as necessitated by the green guide specifications obtained through interrelation of web server and database. The available points for BREEAM material issues, which are Mat 1-Materials specification, Mat 2-Hard landscaping and boundary protection, Mat 3-Re-use of façade, Mat 4-Re-use of structure, Mat 5-Responsible sourcing of materials, Mat 6-Insulation and Mat 7-Designing for robustness, are presented.

For Mat 1 issue, initially the BRPset_Materials property set within the IFC file is checked to find out which specification to use. In case of

Table 1
Building elements and their corresponding element attributes in the ArchiCAD® library.

Building elements (Green Guide to Specification)	Element Attribute (ArchiCAD® GML)
Ground floor	Slab
Upper floor	
Separating floor	
Landscaping—floor	
Internal wall	Wall
External wall	
Separating wall	
Landscaping—boundary protection wall	
Domestic windows	Window
Commercial windows	
Roof	Roof, slab
Insulation	Building material
Floor finishes	Building material

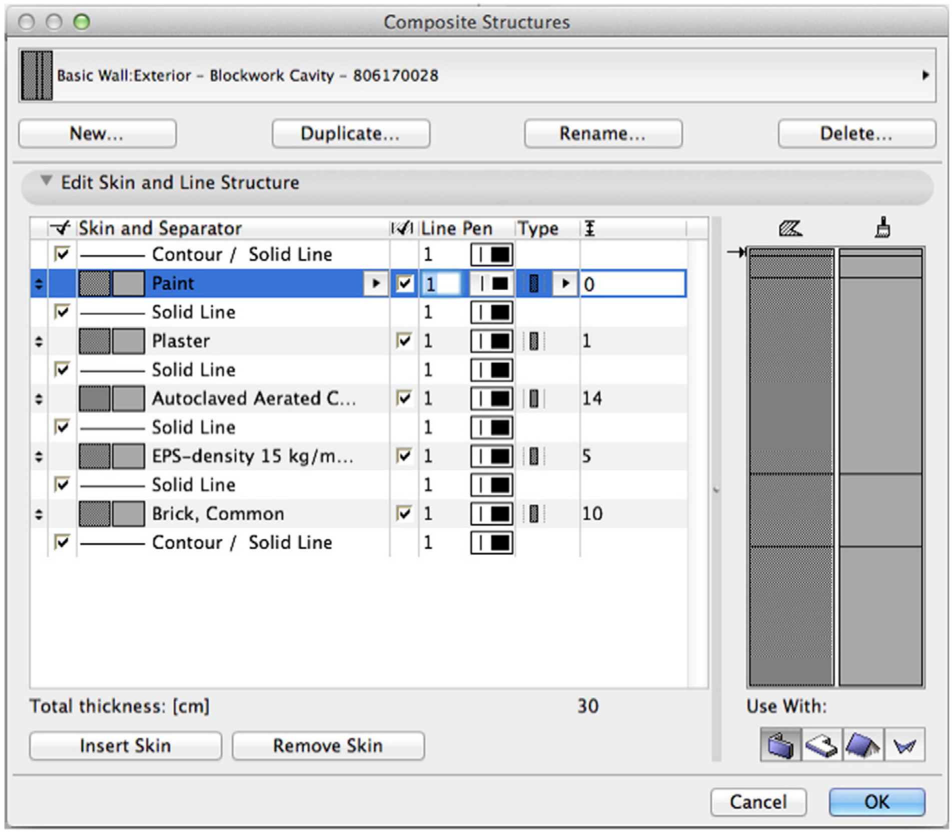

Fig. 3. Example of composite within ArchiCAD®.

its being true, the related data are acquired from the IFC file, and required calculations are made depending on the BREEAM guide. Finally, the green guide points and available credits are awarded. The requirements, workflow diagrams and IFC algorithms of each issue (Mat 1–Mat 7) for materials category are discussed (though not presented here due to space limitation, for further details see [22].

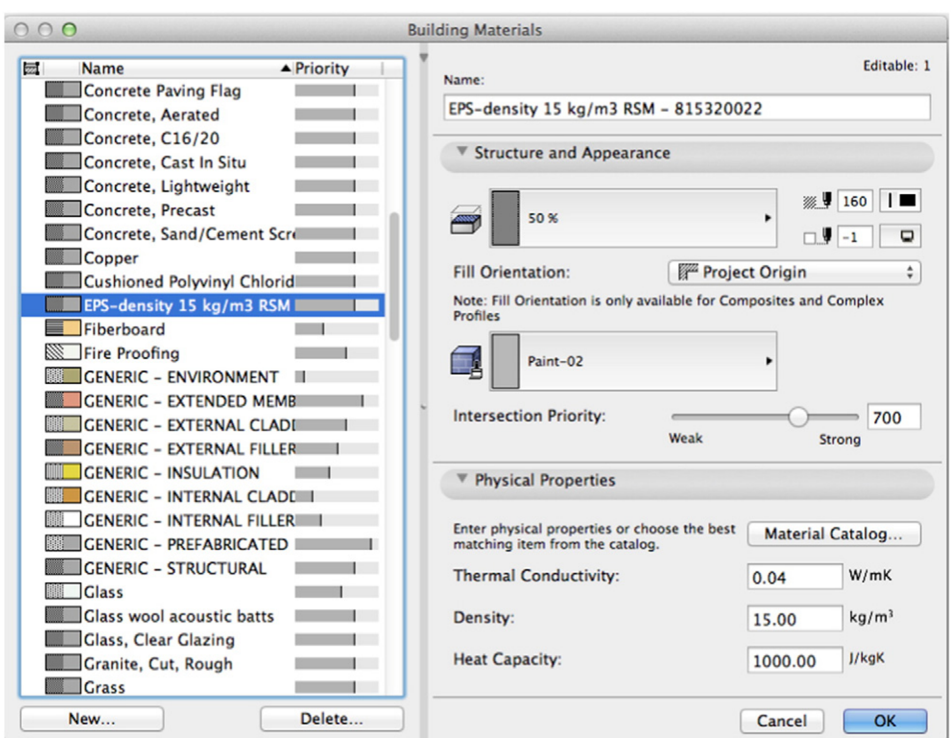

Fig. 4. Example of building material within ArchiCAD®.

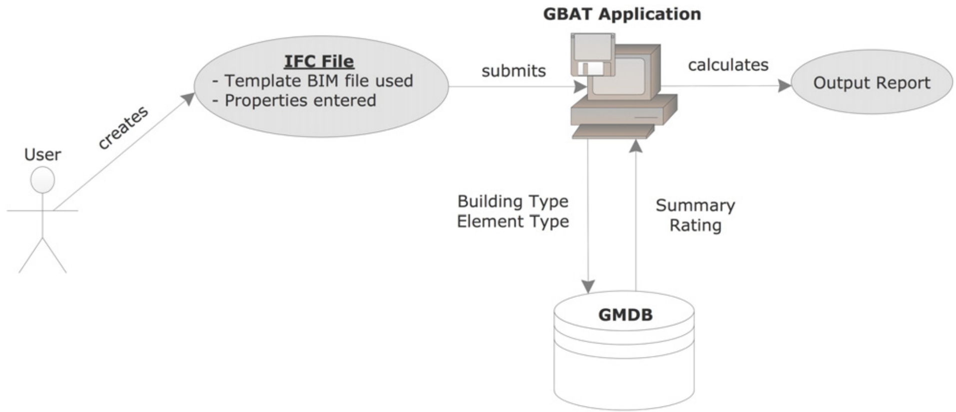

Fig. 5. Use case diagram for GBAT.

Fig. 6 presents the architecture and components of GBAT and describes how the system behaves.

The input of the application is the IFC file exported from BIM software. Within the GBAT, an independent program, IFC File Analyzer (IFA) developed by NIST [37], is used to obtain all the required data. IFA generates a spreadsheet from the IFC file. In the spreadsheet, a worksheet is created for each type of IFC entity in the file. Every row in the worksheet contains the attributes for an instance of an IFC entity.

Fig. 7 illustrates the spreadsheet produced from an IFC file. It is able to parse and analyze all of the entities and their attributes easily from the corresponding worksheet. Calculation implements the GBAT algorithms by reading the spreadsheet and retrieving data from the database. The algorithm specifies the steps that compute the green score for each BREEAM material issue. Each step of the algorithm consists of true/false conditions and formulas for the necessary quantity (e.g., area or volume) of the related building elements and green guide points of each issue. The achieved credits from Mat 1 to Mat 7 are displayed on the results screen and a detailed report about the main building elements, the materials and green ratings is provided.

The relevant property of BRPset_Materials from the IfcPropertySet of the IfcProject worksheet is checked first for each material issue. The required quantities such as areas and volumes of the major building elements are acquired from IfcQuantityArea and IfcQuantityVolume, which are accessed through the IfcElementQuantity. IfcProperty SingleValue of the IfcPropertySet entity gives the information for the building elements that should be checked according to their common properties such as IsExternal or LoadBearing. The PredefinedType of the IfcSlab worksheet should be obtained for all slab and roof types. Reuse of façade and structure data is enabled via the IfcPropertySingleValue of the BRPset_ReusedMaterials of each building element. Similarly, the information of responsibly sourced materials is derived from the IfcPropertySingleValue and IfcProperty EnumeratedValue of the BRPset_ResponsiblySourcedMaterials, which is accessed through the IfcPropertySet. The information regarding a material such as insulation is obtained from IfcMaterial worksheet, which is accessed through IfcMaterialLayer, IfcMaterialLayerSet and IfcMaterialLayerSetUsage of the relevant building element entity. The BREEAM element number of each building element is retrieved from IfcClassificationReference via ItemReference. The corresponding green guide rating and points to the element number should be matched from the database. The project and building type information necessary for awarding the credit, is obtained from BRPset_ProjectInformation accessed through the IfcPropertySet of the IfcProject.

The open source code can be accessed from an online repository for examination and further developments [48].

4. Validation of the model

For validation of the model, a sample project is created, and the IFC file of the project is then processed in GBAT to obtain the results for green certification.

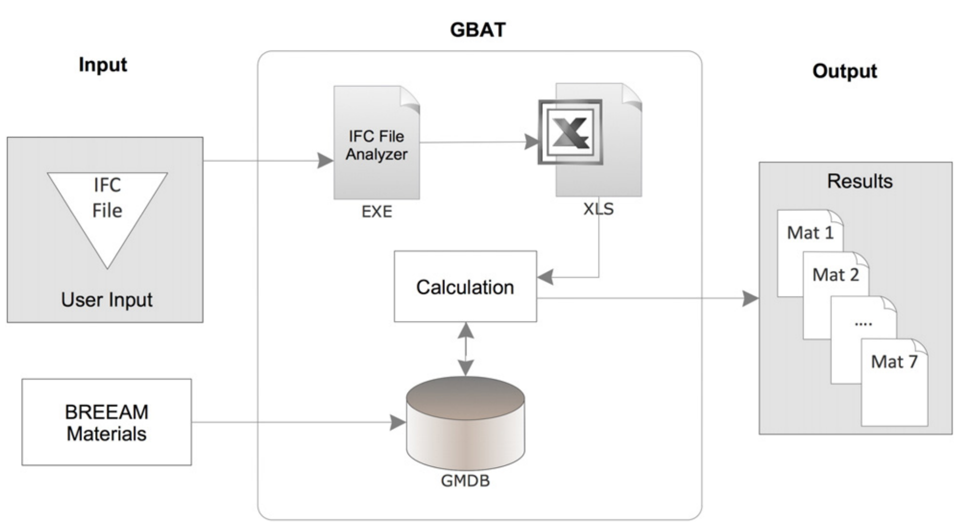

Fig. 6. Software IO diagram.

	A	B
1	IFC File	Sample Project.ifc
2	IFC Directory	\\psf\Home\Desktop
3	Excel File	\\psf\Home\Desktop\Sample Project_ifc.xlsx
4	Application	IFC file generated by Graphisoft ArchiCAD-64 17.0.0 INT FULL Macintosh version (IFC2x3 add-on version: 4005 INT FULL).
5	Timestamp	2014-03-21T11:03:51
6	Total Entities	57550

8	Entity	Count	Name	Description	ObjectType	Tag	ProfileName	IFC2x3	IFC4	CV-Arch	CV-Struct	CV-BldgSrv
9	IfcBeam	1	1	0	1	1		Doc	Doc	X	X	
10	IfcBeamType	1	1	0		1		Doc	Doc	X	X	
11	IfcBuildingElementProxy	4	4	0	0	4		Doc	Doc	X	X	X
12	IfcBuildingElementProxyType	2	2	0		2		Doc	Doc	X	X	X
13	IfcColumn	3	3	0	3	3		Doc	Doc	X	X	
14	IfcColumnType	1	1	0		1		Doc	Doc	X	X	
15	IfcCurtainWall	4	4	0	0	4		Doc	Doc	X		
16	IfcDoor	6	6	0	0	6		Doc	Doc	X		
17	IfcMember	240	240	0	0	240		Doc	Doc	X	X	
18	IfcMemberType	3	3	0		3		Doc	Doc	X	X	
19	IfcOpeningElement	17	17	0	0	17		Doc	Doc	X	X	X
20	IfcPlate	102	102	0	0	102		Doc	Doc	X	X	
21	IfcPlateType	47	47	0		47		Doc	Doc	X	X	
22	IfcSlab	16	16	0	0	16		Doc	Doc	X	X	
23	IfcSlabType	7	7	0		7		Doc	Doc	X	X	
24	IfcSpace	7	7	0	0			Doc	Doc	X	X	X
25	IfcSpaceType	1	1	0		1		Doc	Doc	X	X	X
26	IfcStairFlight	1	1	0	0	1		Doc	Doc	X	X	
27	IfcStairFlightType	1	1	0		1		Doc	Doc	X	X	
28	IfcWallStandardCase	19	19	0	0	19		Doc	Doc	X	X	
29	IfcWallType	4	4	0		4		Doc	Doc	X	X	
30	IfcWindow	11	11	0	0	11		Doc	Doc	X		
31	IfcArbitraryClosedProfileDef	383					19	Doc	Doc	X	X	X
32	IfcExtrudedAreaSolid	416						Doc	Doc	X	X	X
33	IfcRectangleProfileDef	33					0	Doc	Doc	X	X	X
34	IfcMaterial	33	33					Doc	Doc	X	X	X
35	IfcMaterialLayer	34						Doc	Doc	X	X	X
36	IfcMaterialLayerSet	10						Doc	Doc	X	X	X
37	IfcMaterialLayerSetUsage	34						Doc	Doc	X	X	X
38	IfcMaterialList	2						Doc	Doc	X	X	X

Summary | Header | IfcBeam | IfcBeamType | IfcBuildingElementProxy | IfcBuildingElementProxyType | IfcColumn | IfcColumnType | IfcCurtainWall | IfcDoor | IfcMember | IfcMemberType | IfcOpen

Normal View Ready Sum=0

Fig. 7. Spreadsheet generated by IFA.

4.1. Sample project

The project is generated using the BREEAM template, which includes the GML in ArchiCAD®. It is considered as a two-story new retail project. The steps taken in creating the IFC file with the minimal MVD that includes the extended property sets and classification references of the green materials are shown in Fig. 8.

Each property of the proposed property sets is assigned using the IFC Manager menu. The property sets are applicable to the relevant IFC entities. BRPset_Materials and BRPset_ProjectInformation are applicable to the project entity. BRPset_ReusedMaterials and BRPset_Responsibly SourcedMaterials are valid for the relevant building element. For instance, where the roof is examined in terms of responsible sourcing, reuse of façade is assigned for the elements composing the façade of the building and reuse of structure is discussed for structural building elements. On the other hand, classification reference should be specified for each building element. It should also be noted that in an ArchiCAD® project an ArchiCAD® Curtain Wall is an IfcCurtainWall IFC Container entity with its Frame (IfcMember) and Panel (IfcPlate) components; IfcStair, IfcRamp and IfcRoof entities can also be IFC Containers if they originate from an IFC model that was exported by another application and merged into the ArchiCAD® project earlier. Thus, the following changes were made to make the IFC file compatible with MVD.

- IfcStair was converted to IfcStairFlight manually since the concept MVD requires tread number property for this type but ArchiCAD® combines IfcStairFlight into IfcStair and does not export this property. The subtype of the IfcStair object was changed into IFC2x_StairFlight, which converted the IfcStair to an IfcStairFlight.
- IfcSlab was converted to IfcSlab in an IfcRoof container object if the slab corresponded to a roof, by default ArchiCAD® does not create IfcRoof container objects but it was necessary to manually introduce them.

4.2. Results and discussion

The exported IFC file is used as the input of the program (Fig. 9).

After uploading the IFC file into the program, the BREEAM Mat 1–Mat 7 material issues to be calculated, from Mat 1 to Mat 7, are selected and the program is executed via Process button. While the program is processing, IFA runs within the GBAT and generates a spreadsheet from the IFC file. Then, GBAT accesses the quantity take off of the building elements and performs the necessary calculations.

The results of the available credits of the selected issues form the output of the program (Fig. 10).

On the result screen, the corresponding credit for each material issue is displayed following the project information including project name, project type, building type and project phase. A detailed report on the building elements under consideration can also be achieved.

The names, element numbers, quantities and the green guide ratings of the building elements and materials are provided so that the users can evaluate their project with a view to green certification.

This facilitates the decision as to whether the selected building elements and materials should be reviewed. A comparison of the elements according to their quantities and green ratings is made and in the case of lacking credits, alternatives are considered.

The sample report for Mat 1 of the examined IFC file is given in Fig. 11. GBAT provides a green rating score table including relevant quantity for each material issue. To validate the program, the values for the area of each element were obtained from ArchiCAD®, and the green guide ratings that were read from the Green Guide to Specification from this the score were calculated by hand according to the BREEAM guideline. For example, the Green Guide points for the Curtain Wall can be computed as follows: total area × green guide rating. This process must be repeated for each building element and, depending on the size of the project, can become very time consuming and error

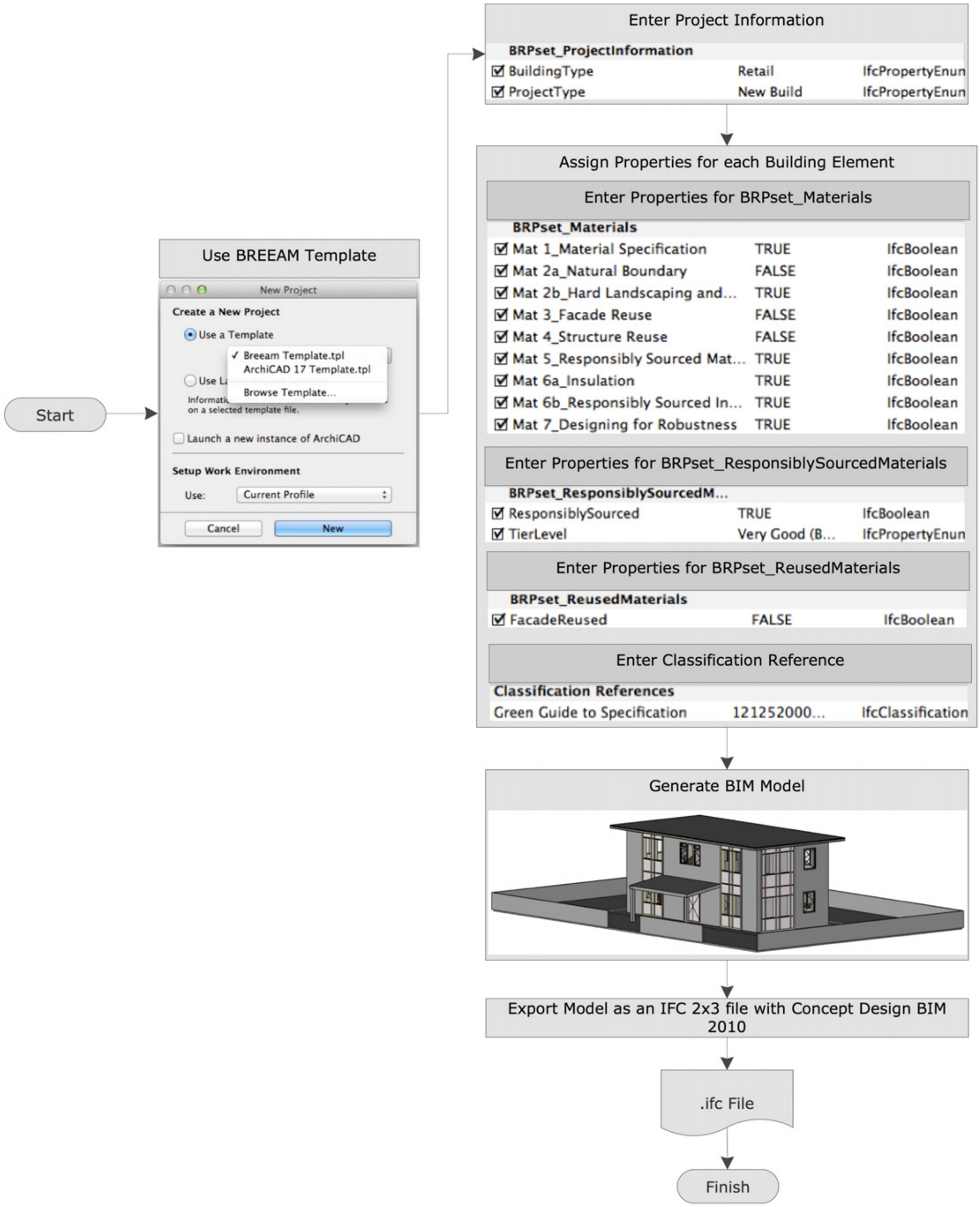

Fig. 8. Workflow diagram for users to create IFC file.

prone. The GBAT program determines the area of each building element automatically from the input IFC file and performs all calculations automatically, typically in just a few minutes (the slowest step is running the IFA software).

After the generation of the project, the IFC form, including all the data of the BIM model regarding the property set, classification reference, quantity and building element and material information, is evaluated for BREEAM certification in terms of materials category through GBAT. The developed assessment tool makes the calculation by accessing the rating points of the green materials used in the project from the database and depending on the green building assessment criteria. It provides the possible credits of each material issue as the output data. Then a detailed report of the results is obtained for consideration. In order to evaluate and make a comparison between the different materials usage options, GBAT can be used for further possibilities. The sample project generated by using ArchiCAD® BREEAM template file demonstrates the validation of the proposed model successfully.

The effective model validation of the limited area covered proves that the extension and adaptation of the model to the other categories, green building assessment systems or BIM software is achievable. The integrated model assures efficiency and accurate data in the generation of sustainable construction projects, which also results in effective decision making for the green building certification process.

Even though web applications provide some advantages (such as the ubiquity of web browsers, easier dissemination than traditional programs and ability of update and maintenance without disrupting

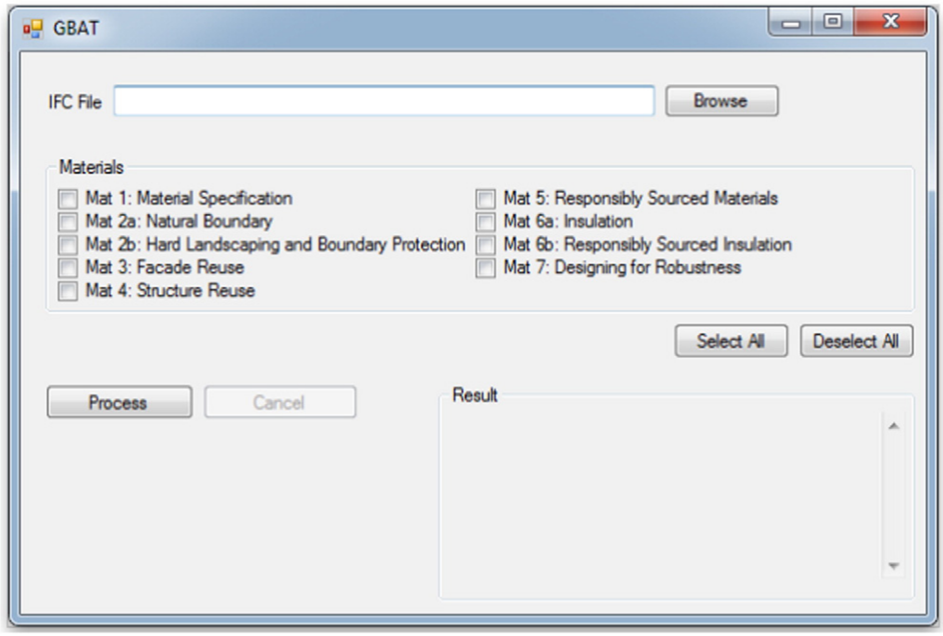

Fig. 9. Input screen (GBAT).

users), due to the security reasons and requirement of hosting, the tool is designed and developed as a desktop application. Since the IFC file of the project needs to be uploaded by the user, it may not be preferred for privacy and security reasons.

5. Conclusion

This study summarises the importance and justification for the integration of BIM and sustainable data pertinent to construction projects aiming at green certification, and presents an IFC-based integration solution. The changing approach to the design, construction and maintenance of buildings in the construction industry necessitates an integrated collaboration and BIM for sustainable projects. Integrated design process with sustainable properties simplifies the certification process in terms of time and cost due to early stage interactions and improved outputs.

Within the scope of this study, a calculating and documenting tool (GBAT) is proposed for attaining the goal, which was developing a model that allows the design team to address the sustainable properties of the project at the early stages and aids in the decision-making process for green building certification.

The proposed model provides obvious and accessible solutions for sustainable construction projects. As incorporating the sustainable data in the early stages of the building project life cycle is important,

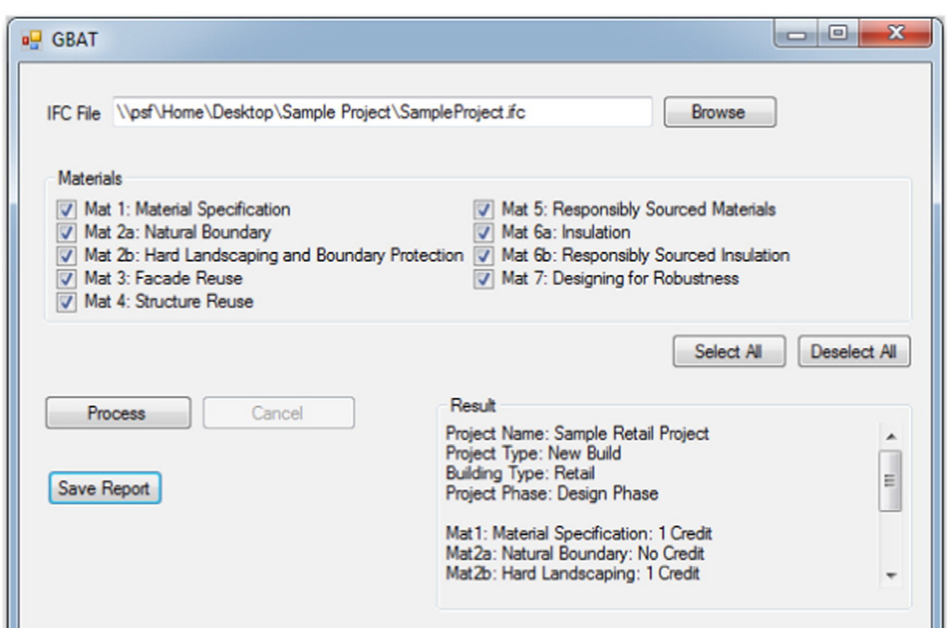

Fig. 10. Output screen (GBAT).

Mat 1

External Wall	Name	Element Number	Area	Green Guide Rating
1	Basic Wall:Exterior - Blockwork Cavity	806170028	143.44	A+
Curtain Wall	**Name**	**Element Number**	**Area**	**Green Guide Rating**
1	Curtain Wall: Laminated timber curtain walling system	1231500003	59.15	B
Window	**Name**	**Element Number**	**Area**	**Green Guide Rating**
1	Powder coated aluminium window	1231500011	15.00	A+
2	Aluminium window, (profile mass <1.25kg/m), double glazed	1231500007	8.70	A
Upper Floor	**Name**	**Element Number**	**Area**	**Green Guide Rating**
1	Floor:Screeded beam and aircrete block	807280031	28.08	B
Roof	**Name**	**Element Number**	**Area**	**Green Guide Rating**
1	Flat Roof: Cold Deck	1212520004	98.17	A+
			Score	1 Credit

Fig. 11. Green rating score table for Mat 1 (sample report).

the integrated solution has a beneficial effect on sustainable decisions. During the design stage, the users provide the related data for BREEAM certification by specifying the project, building element and material information. This is achieved via property sets, which are developed using IFC data model standard, green materials library depending on the green specification of the green building rating system and classification references of each building element and material. All of these are embedded in the BIM software so that the user can be easily guided through green documentation.

At this time, the model implementation is limited to only a subset of the available BREEAM materials (68/1500). The material library (GML) is only available within ArchiCAD® software and is distributed via a template file which must be loaded by the user. The material database (GMDB) cannot be automatically updated from the BREEAM database and there is manual effort (on behalf of the author) to convert from the material database (GMDB) to the material library (GML). Further, it would perhaps be beneficial to investigate ways of more intuitively visualising the output of the GBAT (eg. providing pie charts of the surface area of each material and a chart displaying their weighted contribution to the green score).

Adaptation of the proposed model to the BREEAM International New Construction 2013 as the current scheme to assess the sustainability of new buildings over their life cycle, at the design and construction stages of a project, is the starting point for future studies. When considered in terms of the materials category, focusing on the life cycle impacts of the materials rather than the green rating points is the key issue of the new scheme. An appropriate life cycle assessment tool should be used to calculate the number of credits achieved. In this way, IMPACT [38], which is a BIM integrated material profile and costing tool, could be operated for measuring the embodied environmental impact and the results then assessed for this BREEAM issue. As IFC is the major enabler of BIM when it comes to sharing and collaborating across platforms and applications, the IFC file of projects is used in IMPACT. IMPACTs based on the IFC standard also show that the proposed model is indeed developing along the right lines. Finally, the implementation of the proposed model can be considered as an add-on that enhances BIM-based applications. Although this will inevitably channel users to specific BIM software, it may increase uptake of this assessment tool due to its ease of use. Worldwide, there are various international BIM developments and legislative regulations that encourage BIM adoption, interoperability and coordination among the stakeholders of AEC/FM industry. As more participants embrace the advantages of BIM, it will grow to play a significant role in building performance throughout its whole life cycle.

Acknowledgements

This research was supported by the ITU Graduate Theses Supporting Program (project no. 36529). The authors wish to thank Timothy Davis who assisted in the proofreading of the manuscript.

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