A framework for integrating sustainability estimation with concepts of rules of building measurement

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Abstract— **BIM promises improvement in project delivery efficiencies such as reduction in costs and errors and timely completion. Benefits are also expected in sustainable construction aspect with research efforts being extended to sustainable design and assessment. These efforts are still been explored for the purposes of unifying quantification methodologies, the standardisation of system boundaries, terms of references and sustainability measures. Embodied energy and CO_2 are two common measures that have been widely used in the construction sector. Although a number calculation system exists, they are not useful to the iterations that occur at the early stages of the project life cycle. At the procurement stage, professionals often rely on schedules and bill of quantities with no reference to sustainability credentials. It is therefore important to integrate sustainability measure with concepts in standard measurement methods. As such, we propose a framework to integrate sustainability credential with the concepts in rule of building measurement. We conclude that this framework can be applicable to any rule of building measurement and it is implementable in a computer programmable environment.**

Keywords— BIM; embodied energy; rules of building measurement

I. Introduction

The use of BIM in the Architecture, Engineering and Construction (AEC) industry comes with the modifications of conventional working approaches. The BIM working approach promises improved efficiencies in project delivery such as reduction of costs and errors. There have also been efforts to demonstrate such efficiencies in accounting for sustainability measures in the aspects of building design and sustainability assessment. These efforts are still developing regarding quantification methodologies and timeliness of applications. Existing embodied energy and CO_2 calculation tools are of little use to the design iterations inherent at the early stages of projects. Sustainability credentials for project are hardly available at the early stages of planning and procurement, hence, professionals often rely only on schedules and bill of quantities to make decisions. This study therefore aims to demonstrate integrating sustainability measure with concepts in standard building measurement methods. To achieve this, we propose framework to automate the computation of the sustainability measures of embodied energy and CO_2 of buildings and align the results to rules of building measurement (in this case UK New Rules of Measurement).

The remainder of this paper is divided into 5 sections. Section II presents an overview of related works on embodied energy and CO_2 estimation before stating the methods in Section III. The proposed framework and its components are presented in Section IV. Future works on the implementation of the framework and the proposed illustration with a test case are discussed in Section V. Section VI concludes the paper.

II. Related works

Two forms of energy, embodied energy and operational energy are associated with sustainability assessment of buildings. The embodied energy of a building is the non-renewable energy required to extract and process its raw materials (indirect energy) and transport the finished product to the job site and install it (direct energy) [1, 2]. Embodied energy can also be considered to be recurring for of a building component where non-renewable energy is expended to maintain and replace it, as well as recycle it or disposing it at the end of its useful life [1, 2]. On the other hand the operational energy includes that required for maintaining comfort conditions and the day-to-day maintenance of the buildings through processes such as heating and cooling, lighting and use of appliances and air conditioning [3].

The focus of building performance assessment has been on the operational energy with the assumption that the impact of embodied energy is not substantial [4-6]. However, Pacheco-Torgal et al. [4] suggested embodied energy represents between 10-15% of operational energy. This compares well with Cabeza et al. [5] suggestion that embodied energy constitutes 10-20% of life cycle energy of a building. Also, Sartori and Hestnes [7] reported that embodied energy could account for 2-38% of total life cycle energy of a conventional building and 9-46% for a low-energy building. In a similar study of traditional buildings in Sweden, Thormark [8] suggested that embodied energy can be reduced by approximately 10-15% through proper selection of building materials with low environmental impacts. Up to 30% reduction in emissions can be achieved according to González and Navarro [9] from the right combination of selected low impact building materials. A more optimistic prediction by

Sturgis [10] stipulated the proportion of embodied carbon to increase from 30% to 95% while the operational carbon will reduce to 5% from 70% for a domestic dwelling over the coming 7-10 years with improved legislation. As the operational energy use decreases, embodied energy use will occupy a greater portion of the building life cycle carbon emissions. According to Cabeza at al [11], the proportion of embodied energy in buildings can increase to about 40% in the near future with the effective implementation of Energy Performance Building Directive policies. Hence, embodied energy and CO_2 are important in environmental building assessment.

Decision support tools have tapped into emerging BIM and Semantic Web to address key issues such as facilitating automatic extraction of data and improving intelligence exist. Hou et al. [12] used ontology and Semantic Web rules to represent information about structural design and sustainability, and to facilitate decision-making in design process by recommending appropriate solutions for different use cases. A similar work on ontology was carried out by Zhang and Issa [13] and Zhiliang et al. [14] [15] to export and filter Industry Foundation Classes (IFC) data to align with specifications and other constraints for cost estimation in China. Also, Cheung et al. [16] developed a system for the representation of cost information in accordance to the Chinese and UK standard measurement methods. This study acknowledges the previous works and addresses alignment of embodied energy and embodied CO_2 measures to standard measurement methods, e.g. the UK New Rules of Measurement.

III. METHODS

The aim of this study is to investigate how to integrate sustainability measures with rules of building measurement. To achieve this we propose a system that can automate the computation of the sustainability measures (embodied energy and CO_2) of buildings and align the results to rules of building measurement (UK New Rules of Measurement). This will be achieved through a combination of methods including review of the literature, information modelling and test case illustration as aspects of further work. We carried out the review of the literature to streamline gaps in the computation of embodied carbon and CO_2 sustainability metrics for buildings vis-à-vis applications in rules of building measurement. The review covered aspects relating to the modelling and integration of building embodied energy and CO_2 estimation into BIM environments in accordance with a research framework to achieve the stated aim.

We will rely on earlier works [17] on ontology engineering to improve and modify concepts of building measurement standard, NRM1, develop in Protégé and the use of MS Excel to format information exported from a project management tool (Navisworks) to enable appropriate mapping with materials elements of digitized building model in a BIM environment. Further we will explore a Matrix-based mathematical model to account for the numerous materials making up the building and captured in the concept. These information will be transformed to object instantiations in a computer programming environment to develop a system that will perform the proposed assessment. Figure 1 captures a high level illustration of the information flow of the system. The IDEF0 (Icam (*Integrated Computer Aided Manufacturing*) DEFinition for Function Modelling 0) representation of key parts of the implementation has the Input as the project information obtained from developed building models. The Mechanism is the material database storing established material information such as of density and embodied energy intensities. The rule of building measure serves as the control for the system which influences how the Output, in this case, sustainability measures of embodied carbon and CO_2 computed for items and how they are mapped for display. A case-illustration is proposed to demonstrate the operation of the system. The research framework proposed for this study is discussed in the next section.

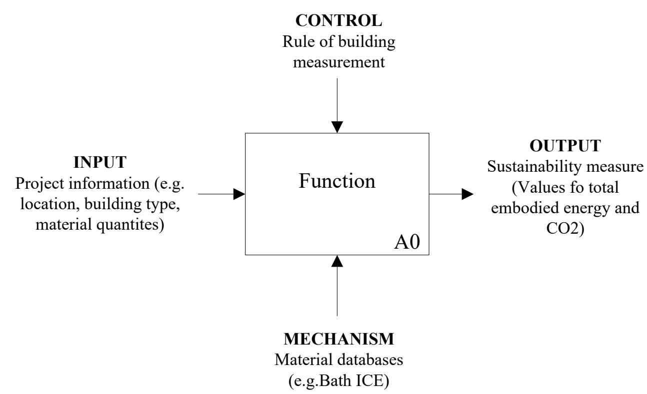

Fig. 1. Proposed system information flow

IV. A FRAMEWORK FOR THE INTEGRATION OF SUSTAINABILITY MEASURES WITH RULES OF BUILDING MEASUREMENT (RBM) IN BIM

The research is comprised of three main aspects (See Fig. 1): (1) The preliminaries which comprises of developing a building model in BIM, exploring representation and mapping of sustainability measures, identifying cost information associated with materials, Looking at option to use mathematical models to aid the quantification sustainability measures concerned. (2) Digitization of the RBM, (3) System implementation and testing. The first two aspects are expansions from previous research works in line with directions identified from literature. The utilization of existing databases, such as the Bath Inventory of Embodied Carbon and Energy (Bath ICE), for construction materials embodied energy and CO_2 intensities values are captured in the third aspect. It also includes the process of developing (modelling) the building model in a BIM-enabled environment. This process of digitizing the building model is very important for the purpose of mapping building elements, work break down structure (WBS) items and material database entries. Besides serving as the data repository from where quantities of building elements can be extracted, it informs how the Embodied

Energy and CO_2 intensity values are represented in a database and also how items in WBS of the NRM are segregated and represented in the digitized form for the system implementation.

A. Preliminaries

The approach in modelling building structures using BIM technology guided this preliminaries aspect. Since objects are represented distinctly in a building model which can be associated with options of materials embedded in a BIM programme database, it is thus possible to link such options of materials with sustainability figures from existing material property databases. In this, the advantage offered by BIM is the possibility of updating material information in the software database with their respective established energy performance data. Such information can be accessed programmatically through tools such as application programming interface (API) if made available in the BIM programme. Provided the information to be added to the digitized building objects has been determined, the building model can be developed and modified accordingly. However, the challenge is accounting for every element in the building and automatically computing the measure of sustainability for each element and analysing these information to arrive at a total figure. The key aspects involved are proposed to be carried out concurrently and background discussions are presented here.

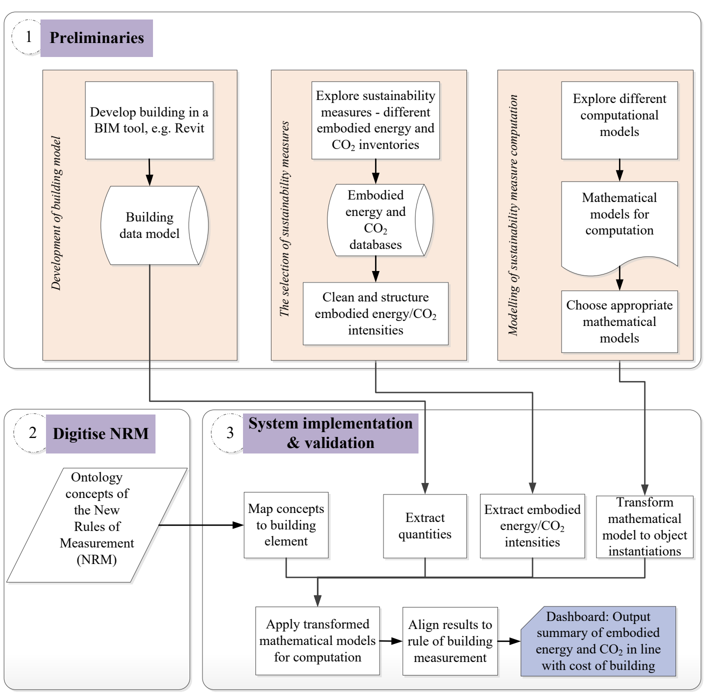

Fig. 2. Framework for the integration of sustainability measures (embodied energy and CO2) with rules of building measurement

1) Development of the building model:

Building models developed with BIM software are embedded with objects to which information are attached. These objects are defined by geometry, attributes, rules and relationships that bring their behaviours and appearances close to the associated physical counterparts. BIM technology allows input of new information and it is also able to output information in other formats such as MS Excel to ease interoperability challenges. Further, computer programmers can build systems for interacting with developed building models. A good awareness of this premise is important for developing the building model in a BIM environment. One important check that needs to be done is to verify how the BIM software aggregates materials when generating schedules or quantity take-offs of developed models. The challenge is BIM software systems such as Revit used in this study lumps similar material types together irrespective of the phase or group item it should belong. For example, a schedule of a building model generated by a BIM software system aggregates all similar wall materials together despite the fact that walls are elements found in the foundation, ground floor and upper floors. These three categories feature at different sections in schedule items of RBM and as such should be quantified separately. To achieve the required separation to the appropriate RBM sections, the designer needs to alter the name of similar materials according to where they should feature in the group elements. This alteration is expected to be done for composite materials such as wall layers, floor layers and structural elements made of concrete and steel that need to be separated into different groups.

2) The selection of sustainability measures:

The definition of sustainability in the built environment is varied but generally built on the sustainable development principles of achieving social, economic and environment dimensions for the present and future generations [18]. At the moment, it is difficult to find systems that account for these three pillars in the assessment of sustainability. One key reason is that the processes of accounting for social sustainability are not yet fully matured. Hence, many systems dwell on the economic and environmental aspects. Elements such as total cost and life cycle costing have been used to measure economic sustainability. On the other hand, sustainability measures used in the environmental aspects usually differ. Thus sustainability metrics such as ecological footprint, carbon footprint, embodied energy, operational energy have been used depending on assessment objectives [19, 20]. In this research work, one of our objectives is to achieve aligning appropriate material sustainability measures with work break down items of building measurement standards side by side cost estimations as obtainable in bills of quantities. Such proposal can add to informing early decisions made at tendering and procurement stages. For this we found primary/embodied energy and CO_2 emission appropriate. The advantage is that these sustainability measures can be calculated for each material used in the building and aggregated to obtain a total value for a project. This will provide valuable information about the primary energy consumption figures of a project which can become part of the energy labelling process of buildings. Given the total number of different materials used in the construction of a building, the challenge is not only accounting for each and every material but also the process of modelling the automatic computation of these sustainability measures to align the work breakdown structure of RBM. We have relied on mathematical modelling to achieve this.

3) Modelling of sustainability measure computation: A mathematical model of a real object is a totality of logical connections, formalised dependencies and formulas, which enables the studying of real world objects without its experimental analysis [21, 22]. Real world objects include process, phenomenon, object, element, system, etc. Mathematical models typically offer convenience and cost advantages over other means of obtaining the required information about real world objects [22]. Most recently, mathematical models have been used in decision-making about environmental impacts from waste [23]. In construction projects the focus has been on the derivation of mathematical models for the computation of environmental emissions from the building life cycle [24, 25]. The leading approaches that have employed mathematical models in computing sustainability measures such as embodied energy and carbon are process, input-output (I-O) and hybrid analyses. The matrix-based models, based on the I-O system examined in the British Standards (BS 2010) were adapted for embodied energy and CO2 assessments in this study.

B. *The digitization of the rules of building measurement*

The complete developed electronic NRM 1 [17] was integrated into the proposed system and used for the computation of quantities, and hence embodied energy and CO_2. A total of 942 concepts from the NRM1 were captured in Protégé-OWL. Producing an XML format of the ontology made it possible to load the generated XML based NRM1 work break down structure into Navisworks Manage 2015 from where it was exported to MS Excel spreadsheet. The choice of Navisworks is based on our experience and the fact that it contains similar catalogues to NRM such as Uniformat and is likely to preserve the structure of the developed NRM l XML-based ontology. Reading the developed NRM 1 – XML based ontology with Excel from Protégé-OWL without Navisworks as intermediary led to a huge loss in the structure and number of concepts. When Navisworks is used as an intermediary the loss of structure and number of concepts is minimised.

C. *Future works: system implementation and validation*

The key future works on this research will cover aspect implementation and the validation of the proposed system through a test case of a building design project. The system implementation will involve the process of extraction of data from the digitized building model, digitized rule of measurement, materials database vis-a-vis the mathematical transformation of the Embodied Energy and CO2 equation. It is illustrated in the flowchart presented in Fig 3. The processes are divided into two blocks: user initiated process and the system executed processes. Actions and processes carried out by the user fall under user initiated processes while the corresponding responses of the system and subsequent system triggers in completing required processes are captured under system executed process. Three key parameters need to be considered before commencing the embodied energy and CO_2 assessment process. The project location, type of building and the rule of measurement needs to be provided by the user. The latter determines the work break down items which therefore makes apparent the matching material type to choose from the provided database. Once this can be done for all interested items on the work break down structure, the alignment of embodied energy and CO_2 can be achieved with corresponding values calculated as proposed in the matrix-based mathematical model equation.

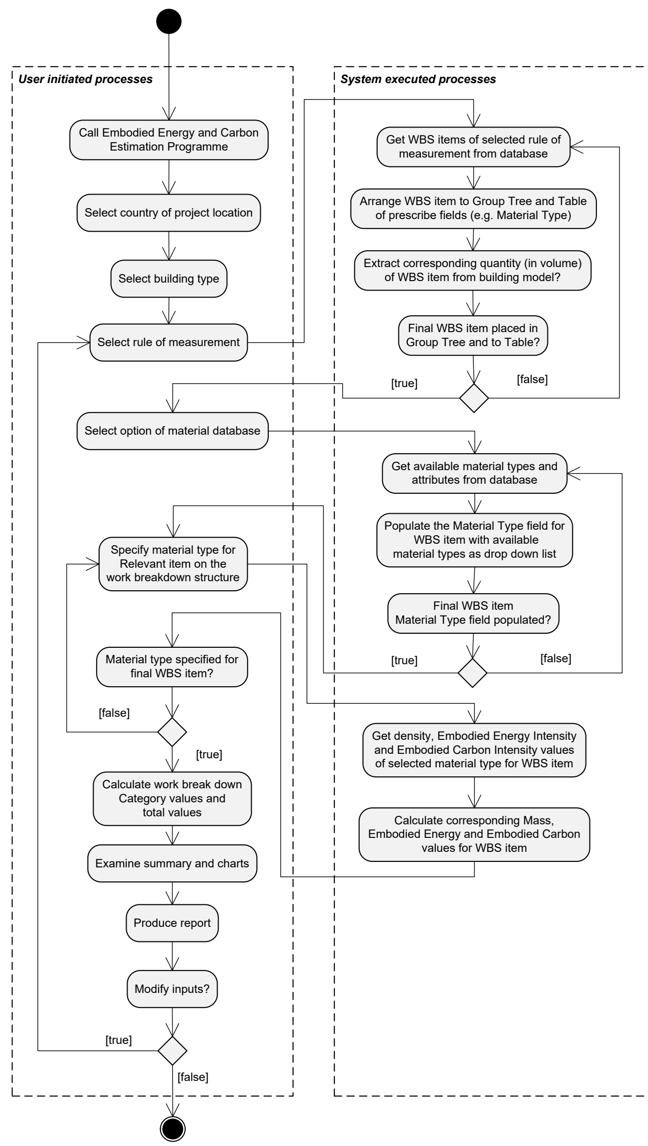

Fig. 3: Flow chart for embodied energy and CO2 measure assessment in rules of building measurement

V. CONCLUSIONS

The overall aim of this study is to integrate sustainability measures with concepts of standard methods of building measurement. This will be accomplished through the implementation of the research framework and the development and testing of an associated system. The system will automate the computation of embodied energy and CO_2 sustainability measures of buildings and aligns the results according to the UK standard rules of measurement (NRM). We conclude that the framework can be used with any rule building measurement and implementable in a computer programming environment.

The premise of work stemmed out of a literature to identify knowledge gaps in the area of embodied carbon and CO2 estimation in the procurement and construction of building projects. The goal is to contribute to providing additional guide for decision makers to base their opinions not only on costs but also environmental impacts. Thus, the knowledge of environmental impacts of a given building component in connection to the total in a work break down structure can guide end users to change the material type in a virtual building model so as to achieve a minimum level of environmental impacts of the whole building.

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