INTEGRATION OF 3D TOOL WITH ENVIRONMENTAL IMPACT ASSESSMENT (3D EIA)

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Abstract. Environmental Impact Assessment (EIA) tools have been available for some years now and their function is predominantly to predict and identify the environmental impact of building projects. However EIA analysis is often done after the completion of the project or building and when it is too late to influence the design, materials or components to be used. Also, more than 80% of the design decisions that influence the whole life cycle of a building are made at the initial design phase. EIA does not receive the required attention. A new approach is suggested in this research to ensure that designers, clients and stakeholders have all of the relevant information needed at the outline design stage for the assessment of cost and environmental impact. The idea is that building owners and users will have the opportunity to minimise their operating costs from 'cradle to cradle'. As energy resources reduce over the next few decades, the value of this research will increase and it is possible to foresee government legislation which drives building construction in this direction. By making environmental impact analysis readily linked to 3D products at the very early stage of the design process, the value of 3D technology will be enhanced significantly resulting in more use of the technology in the construction process. In this context, the objective of this paper is to introduce and explore approaches for developing integrated 3D- EIA, LCA (Life Cycle Analysis) and LCCA (Life Cycle Cost Analysis) and VR (Virtual Reality) tools and develop trade-off analysis to assist in the decision making process. To demonstrate initial results, a pilot case study in the UK is being developed.

1. Introduction

Many environmental impact assessment tools are currently available but few of them are integrated in virtual reality (VR) (Parker, P., 2002) and may prove to be difficult to use by non-professional or untrained people. The existing BREEAM assessment (Refer to the BREEAM pre-assessment estimators: http://www.breeam.org/page.jsp?id=87) from BRE is major assessment tool in UK and used to measure the environmental impact from the development project, construction disposal plan, impact of construction material delivered to site, etc. The main gap in this tool is that it simulates individually and is not linked to any major 2D/3D software, it also requires complicated data input and can only used from professional analysers; a manual assessment means higher risk of errors. McCabe and Jinman (1999) have suggested that a good Environmental impact assessment (EIA) modelling has to have an accessible database, clear menu and ideally with object-oriented component that can reduce time consumption in modelling. To close the deficiency of BREEAM, 3D-EIA will therefore, create a database that refer to the elements in BREEAM and perform the EIA result in VR. In addition, the material input will trade off with the EIA-LCA-LCCA to compare the cost benefit of both sustainable and ordinary materials in 60 years. Consequently, 3D-EIA helps on decision making and enhance the communication significantly among project team compare with the conventional manual EIA.

To achieve a holistic analysis; there is a need to bridge the gap between EIA, Life Cycle analysis (LCA) and virtual reality technology. Therefore, LCA and LCCA will be used in this research along with the EIA to simulate the value of each proposed material and suggest a best option to be applied in a project. A product database is being created to be used to compare and analyse the different materials proposed for a design by considering its carbon emission, disposal, recycling and life cycle cost. The result will be used to support early design processes and evaluate the environmental impact and whole life cycle of a building. The paper discusses literature review in the subject area and the specification for the 3D-EIA. A case study of a school design is presented to demonstrate the proposed tools. The major issue for the tools is the lack of consistency of the existing data particularly for the LCCA (Thomas et al, 1996) that could be overcome by sharing data with industry partners and research groups.

Literature review also indicates that there is a lot of fragmentation for the conventional EIA and LCCA tools which cause inaccuracy. An Engineering and Physical Science Research Council (EPSRC) project clubbed sue-MoT, has identified 78 sustainable and social tools (sue-MoT report, 2004). These tools have been categorised into three main areas: monitoring, evaluation and monitor people perception. Whilst another 25 environmental tools that prepare on behalf of BRE (2004) and being divided into urban planning tool, design tools, rating systems, assessment tools and infrastructure tools. Both sue-MoT and BRE reports have comment on 103 tools in total provided their Pro and Cons, which will be taking as a useful reference for the development of 3D-EIA in tools comparison and bridging gaps. There are still some EIA base Building Information Model (BIM) software that have not been assessed in sue-MoT report. These software including DesignBuilder, DProfiler, Solibri Model Checker and Riuska (See Section 4 for a comparison and description of BIM software), will be reviewed in this paper. As a result, these BIM tools have not assessed the whole construction process to achieve a holistic appraisal. There is a potential to close the gap for these EIA tools by provide a more specific regional material data looking at the potential use of renewable energy and its life cycle cost.

Similar research in LCCA tool development is being developed in nD modelling (Fu, C., et al, 2007), which focus on the interoperability in 3D model and LCCA to deliver the building information across various CAD systems. The nD tool shows a potential to enhance of communication between stakeholders and clients via virtual reality. However, it has not looking at the energy consumption. Obviously the LCCA itself in the nD modelling is not enough to demonstrate an accurate analysis.

The objective of this paper is to define a conceptual framework and identify the research of 3D-EIA through a prototype. A comprehensive database is being developed to incorporate LCA, LCCA, carbon dioxide (CO2) emission, R-value, U-value, waste management, recycling potential, and assess the impact from the common used or likely to be used construction materials. Statistic information shows that 52% of the CO2 in UK is contributed from the construction products and materials and energy consumption of a building responsible to 40% of global carbon emission (Price, L., 2003). Therefore, the goal has been set by the UK government to reduce 60% of the carbon emission by year 2050, (DEFRA, 2004; Innes, S. and Grand, Z. L., 2006). The fact is, CO2 emission from construction is not only limited to the building itself but also responsible from the production or manufacturing process from the suppliers, transport to site, on-site installation, construction method, whole life CO2 emission of each materials, and deconstruction process. Other factors such as maintenance processes, human factors or lifestyle (Summerfield, A.J. et al, 2005), are also the key issues to control the CO2 emission. The carbon reduction in building (CaRB) project that is running by five UK universities has carried out a through investigation towards the energy efficiency and carbon used in a building. Past failure to reduce carbon emission has been caused by a lack of understanding for human energy consumption in buildings, poor strategy, and data shortage (Oreszczyn, T., 2005). The CaRB project will be a reference for the data development of 3D-EIA.

The rational and importance of the research work reported in this paper is that considering the existing scene in AEC industry, where clients often set a fairly low budget for design stage, an incomplete design planning and assessment can cause extra cost and time in changing the design in the construction stage. The crucial part is that the proposed materials are not normally analysed thoroughly and this can cause a serious environmental impact for the next 60 years or longer. By designing a holistic IT based 3D-EIA tool that appeals to different groups of professionals such as energy analyser, project manager, environment auditor, site surveyor, engineer, etc, will helps to overcome the issue of complicated data exchange processes and closing the gap of inaccurate or poor EIA tools that are currently used in the AEC industry.

2. Literature Review

To design the framework of 3D-EIA, three major factors have been suggested by the environmental professional groups: 1) to maximise the data quality. 2) make the tools available and easy-to-use by the professionals by using the ICT technology. 3) to maintain the elements in the data so that all the documents and information presenting are up-to-date. There is a gap in the current decision support LCA software where they are not compatible with other tools such as EIA, cost benefit analysis (CBA), risk assessment, etc, for best appraisal (Vigon, B.W., 1996). Therefore, the 3D-EIA will be design in conjunction with the EIA, LCA and LCCA.

LCA tools can be divided into three categories, which are strict LCA, product design LCA and engineering LCA (Vigon, B.W., 1996):

- The strict LCA is used to focus on the material input analysis consider factors including energy, transport, waste management, client's data and analysis data input through a centre calculation engine, followed by a report produced for exporting/ integrating with other tools.
- The product design-oriented LCA tool is an opposite of the strict LCA. It is performing a result in graphical based that can easily read by people who have little or no environmental assessment background. The product design LCA tool is also one of the major LCA software options for the CAD or solid modelling users. It has appeal to user's requirement as knowledge and decision support based software providing alternative material choices, manufacturing process options, etc.
- The engineering-oriented LCA tool is not a choice for the designer, since it has no direct linkage with the spreadsheets or databases.

From the above review, the LCA features inside the developing 3D-EIA tool of this research project, which falls on the product design-oriented LCA category. As per suggested linkage process from Vigon (1996), the data format and elements is crucial for data input simulation. These elements including database classification associate with general data, purpose, source of products, etc; also detail descriptions for the model; system structure and data input-output. In fact, this is one of the biggest challenges for the research institutions and software developers to collect accurate LCA data. Data for actual frequencies and failure factors, cost of reactive maintenance, whole life estimation for the construction materials and its effects are major shortage in the existing sources of LCA data (Horner, M., 2002).

There are various methods applied for the LCA in different industries. The existing ‘Well to Wheel’ is applied for the transportation, whilst ‘cradle to grave’, ‘cradle to gate’ and ‘cradle to cradle’ are mainly used for material and product assessment. The difference between these methodologies is that ‘cradle to grave’ is looking at the input at the beginning stage of the raw product including processing, manufacturing, transport to site, installing, etc to the end of life of the product; ‘cradle to gate’ is about the same as the above example but only considers the first part appraisal and end at the delivering stage; the last approach, ‘cradle to cradle’, which is also the prefer methodology in this 3D-EIA research that it looks at the renewable potential of the products.

‘Cradle to grave’ has been used as an alternative name for LCA but it is not the case for the current situation, where environmental bodies now focus on the development of zero carbon building instead of low carbon building in the past. In other word, renewable resources are a mainstream to achieve a target green building that set by the Kyoto Protocol (Browne, J., 2004) and ISO14000 environmental management standard. The benefit can be proved by comparing both ‘cradle to grave’ and ‘cradle to cradle’ methodology. The ‘cradle to grave’ evaluation for conventional floor board will drive through the raw material that is being used in the manufacturing process, the impact of fuel used to deliver it to site, impact of the on-site installation, the whole life maintenance of the floor board and the impact of the disposal process. Finally, the product will end up with landfill and causes another impact in the graving stage by producing greenhouse gas - methane back to the atmosphere. On the other hand, ‘cradle to cradle’ emphasis the concept of recycling disposal products and reuse them as a raw material for another new product, which, obviously will reduce the impact of dumping a disposal product.

Different format of data interpretation from different industry is a major problem in LCCA tool development that exist for years, which is also the major factor that causing data inaccuracy. Problem for conventional manual LCCA or EIA is to recalculating or reanalyse the building if there is a change on building design or product selection (Fu, C. et al, 2007). Therefore, it is time consuming for manual EIA template compare with the IT based EIA; 3D-EIA. However, there is also a potential of data loss in the input-output process that has to carefully deal with in developing the 3D-EIA. To avoid this happen, a compatible file format is the key solution.

A leading global consultancy- Atkins have worked on bridging the capital expenses (Capex) and Operation expenses (Opex) in order to optimising the total cost in a whole life cost and get the best value out of a constructed building (Bartlett, E., 2002). The vision of developing a holistic EIA tools exist for long in the AEC industry, however, it is still a long way to go. Hence, the concept of developing 3D-EIA is carrying on the vision of holistic EIA by trade off EIA-LCA-LCCA.

3. Development of the Framework

In this research project, 3D-EIA will use AutoCAD as simulation platform by refer to the methodology of 4D Spa, where the 3D-EIA will add-in with Visual Basic (Dawood, N., et al, 2004). Figure 1 shows the concept of 3D-EIA where, a 3D model prepared in BIM software that supports the Information Foundation Classes (IFC) format. The idea is to add the energy information for the product attributes. These attributes will then allow the EIA information in corresponding with the building components in a 3D model. It also means that the process of EIA will be quicker, easier and more accurate compare with conventional tools. This is obviously technology advancement in the EIA tools.

The database will basically divide into two sets, which are EIA and LCCA databases. The first data set in the EIA database is all about the thermal and external energy information of the building material including source of energy input from materials, the cost of CO2 emission, building orientation and the impact from material delivery to site; potential use of smart materials; thermal efficiency and the U-value and R-value of a product. After completed the data input, it will then lead to analysis process that formula will work out the total energy input of the building, solar gain, and heat gain from human and equipment.

Second set in LCCA database is mainly a material properties information and directory of building material mirror from the EIA product database. The idea for this LCCA database is to adjust the material life cycle cost according to the original material cost, material recycle capability and embodied energy. For example, a non-recyclable boiler with x cost and expected to last for 10 years will have a higher life cycle cost and lower product value than a solar panel with y cost but last for 60 years and lower energy consumption. Formula for whole life cost (WLC) or life cycle cost as suggested below from Horner (2002) will be used as a reference to developing the LCCA database in 3D-EIA:

$$\boxed{\text{WLC (project)} = Ccp + Ocp + Mcp + Rcp \pm Dcp}$$

Ccp = capital/construction cost
Ocp = operation cost
Mcp = maintenance cost
Rcp = recycling cost
Dcp = disposal cost

The ratio of 1:5:200 has been set as the golden fraction of a building life cycle cost, 1: represents construction cost, 5: represents maintenance and building operation cost and 200: as the business operation cost (Barlett, E., 2002). In other words, construction cost is only a very small portion in a building whole life cycle. Apart from the formula and fraction that mention above, building depreciation is another factor that can influence the building value, therefore, net present value (NPV), discount factor, etc, will utilised to determine the cost impact. This will definitely increase the value of the 3D-EIA and bring it a step forward towards achieving a holistic assessment tool.

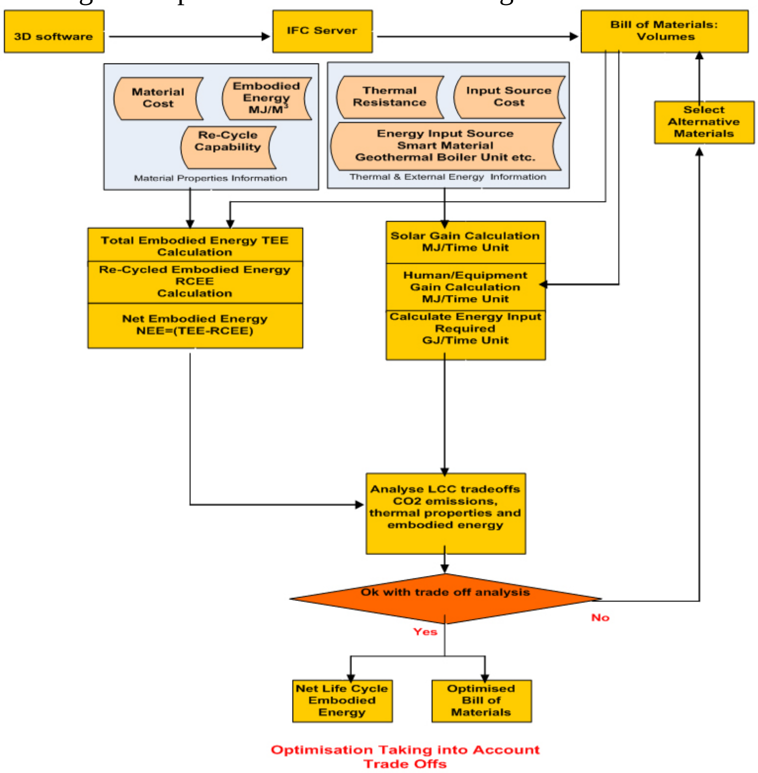

Figure 1. Flow chart for the EIA, LCA and LCCA simulation

Final stage of the assessment is a trade-off analysis for EIA, LCA and LCCA associated with energy input, material selection, human and solar gain, recycling capability, material cost, maintenance, etc. This trade-off analysis will follow after the material input. EIA will optimise with the

LCCA considering that people often find it difficult to decide for either select a green material with higher cost or a cheaper material with higher environmental impact. In fact, this will help architects and engineers making decision for either selecting an alternative material or accepting the proposed material. If the EIA result is acceptable, then the EIA is reach to the end. Else, if the result for both original selected material and propose sustainable material are not satisfied, then users have to go through the process of data input again to achieve a desire assessment result.

4. Review the existing EIA and LCCA IT system in Architecture Engineering and Construction (AEC) industry

The existing IT system has a major problem in data inaccuracy. It means that software that are developed and developing are actually data hunger and in need of data sharing across industries partner and research team to share or standardise the data. To assess this problem, four majors Building Information Modelling (BIM) software for environmental and building life cycle simulation in the market have been review and compared. Table 1 shows the software description, their feature, and gaps among all.

Existing software such as Revit, ArchiCAD are simulating based on the design modelling, then only move to the costing and construction scheduling simulation. It is quite common that the drawing will changed or altered until the end of the project, this could cause a problem and it may be necessary to reanalyse the EIA again and again. This design methodology is also known as ‘micro model’. To close this gap, the new rise D-Profiler used the method known as ‘macro model’ to add-in the feature of cost estimation and construction scheduling running across the design modelling stage by using the RS Means cost data.

From a test drive of DProfiler internally by Beck group, it was found that the cost estimations were within 5% of the final construction cost, which is also 35% lower than earlier project testing (Khemlani, L., 2006). As a result of comparing above software, D-Profiler has been concluded has the most potential assessment tools to be refer as in 3D-EIA development due to its technology advancement and adoptable concept. However, the D-Profiler has the same weakness of data inaccuracy as mention above, where the product database is RS Means. It is a cost data based on the US suppliers that, obviously, could not be used to achieve precise assessment in UK or the rest of the world. This will be an opportunity for the 3D-EIA to close the gap for the regional UK market.

Another software - DesignBuilder is indeed a powerful tool that support the energy simulation (heating, cooling) by integrating with the Energy Plus. The value for this tool is that it has an in depth energy analysis that considering the type of building, construction condition, human activity, indoor equipment, HVAC, lighting, etc; that has not been achieve in other BIM software. Similar as the DProfiler, the design method for DesignBuilder is macro model. In addition, an accessible data input is available for the users to add in new product data accordingly. It is however, has various constraints in data transfer: 1) only DesignBuilder file (.dgb) and drawing exchange format (.dxf) file is supported. 2) Imported .dxf file is only available for 2D drawing. 3) The energy simulation is only limited to Energy plus, which means it cannot work on a wider simulation aspect such as LCCA.

TABLE 1. Comparing the major BIM software

BIM Software	Developer	Feature
DesignBuilder (www.designbuilder.co.uk)	DesignBuilder Software LTD	Feature: • Integrated with Energy plus • detail simulation for energy consumption, heating, cooling • 3D modelling tools • Customise product data
D-Profiler (www.dpearth.com/)	Beck Technology (US)	Feature: • Integrated with RSMeans cost data • Export to Google earth • 3D modelling tools • Starting templates for 46 types of building • Reports • Output model views
Solibri Model Checker (www.solibri.com)	Solibri (Finland)	Feature: • Proposed design alternative by looking at potential flaws in the design, clashing components. • Costing and energy budget • Model comparison analysis • Report layout in RTF and PDF • Multi selection to view several issues at the same time • Walk-through • Model checked to comply with the building codes.
Riuska (http://www.dds-bsp.co.uk/PDF/RIUSKA_english.pdf)	Granlund (Finland)	Feature: • Simulation of energy con-sumption for building services. • temperature simulation • heat loss calculation

To perform the EIA result visually, it is necessary to take the Building information modelling (BIM) technology as a baseline, where BIM will be used for generating graphics and information about building components in order to demonstrate the entire construction planning, project costing, lifecycle costing, etc (Autodesk Building Solution, 2003). This enables the users to overview the potential problems during early stages of a project; reduce the design errors; save cost and time and predict the lifecycle of the building.

Even though the BIM brings a massive of benefit for the AEC industry, it is not been fully adopted in many organisation due to the constraints in certain aspects. The barrier for the BIM including:

- There is a risk of losing data and drawings information in the middle of an exchange process even in a compatible format. Take the DesignBuilder as an example, it is supporting .dxf file but a 3D model is not transferable (Philip, G.B., and Jon H.P., 2004).
- Incomputable data cause the new value in the added to the database cannot be recognized. Philip and Jon (2004) have taken the Ms Word and Ms Excel as an example to reflect this problem: imagine a set of numerical numbers stored into Ms Excel, and the total figure and formula set will automatically change when a number is modified. If the same step applied to the Ms Word, the total figure will remain the same after one number has been changed. This is simply because the numerical value of the data in Ms Excel is computable and Ms Word is incomputable.
- Skill needed to produce the drawing by using a BIM tools. This is why there are still many contractors that prefer to use hand drawing rather than an IT tool (Chittenden, J. et al, 2007).
- Current 3D software users unwilling to change to unfamiliar BIM software (Chittenden, J. et al, 2007)**.**

The API (Application Programming Interface), ODBC, XML format has been suggested as an alternative option for data integration (Khemlani, L., 2004). However, the potential of BIM cannot be denied and it is the major solution to improve the efficiency of the AEC industry.

5. Development of 3D-EIA

From recent research, a complete EIA assessment result has seen a potential to link to the Industry Foundation Classes (IFC) 3D model. The idea of using the IFC 3D model in 3D-EIA is to share the IFC standard in the CAD platform with other design and construction team members, also fast track the environmental impact from a project in an easier way by adding attributes in the building components to enable design and analysis of the project in one shot. For instance, an IFC wall and IFC door with attribute input of CO2 emission can be calculate easily without doing a separate set of material input for CO2 emission as in usual 3D system. The advantage are obvious for not only saving time and cost to make decision at the early stage, IFC model also close the gap of poor communication in a project team.

Figure 2 shows the conceptual framework of IFC integration with the 3D-EIA. Two sets of database-EIA and LCCA as suggest in the above framework will be created and put together in the central database. The information in the IFC building component (data input) will then be transfer into the EIA analysis with output in a graph and table format. To link the analysis result to each building component, the IFC is used to model the building whilst the IFC viewer will act as the reader to translate the IFC detail in the BIM CAD interface.

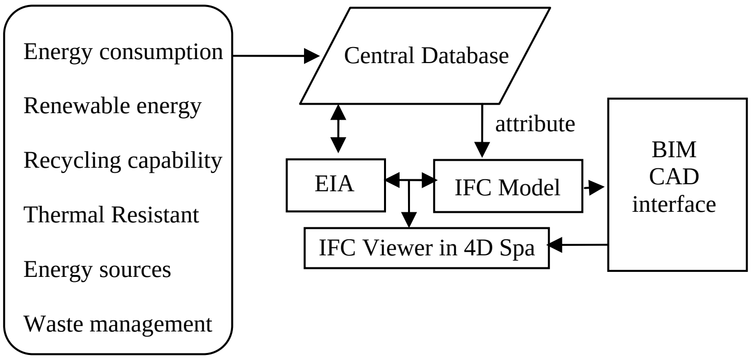

Figure 2. Conceptual IT framework for the 3D-EIA

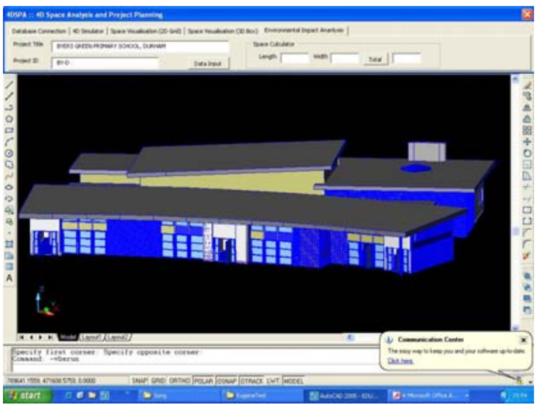

Figure 3. Main AutoCAD interface for 3D-EIA

Basic template of the 3D-EIA has been created where product database in CO2 emission developed referred to the approved environmental profile certified by BRE (Refer to Environmental Profile URL: http://cig.bre.co.uk/envprofiles/document.jsp). Main menu (figure 4) is design for the purpose of key-in project detail including the general information of the project, preferred legislation, project region, building orientation, etc. By selecting the project location (county), the database will automatically input the English, Welsh, Scottish or Northern Ireland legislation. The legislation and property orientation will decide the product available for data input and assessment result.

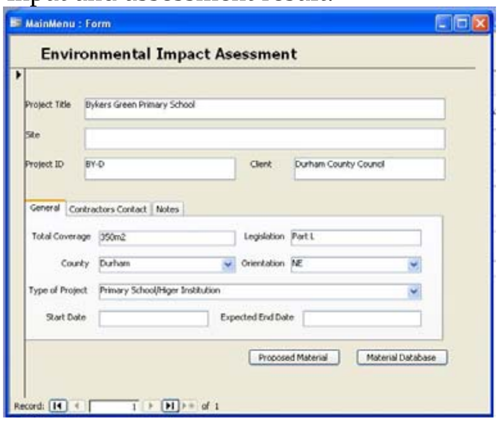

Figure 4. Main menu for the database

The proposed material button in general data input will then lead to the product selection as shown in figure 5. Products can be selected for different building part based on either available products or product suppliers. In addition, there is an option for the users to add new data into the product directories to update the existing database. This will then followed by assessing the environmental impact of products delivery to site and the waste management with regards to the nearest disposal or recycle site plant. With the objective of developing a hybrid tools, the database will be further develop by grouping formula of product thermal resistant, solar heat gain, in door human factors, renewable energy, etc.

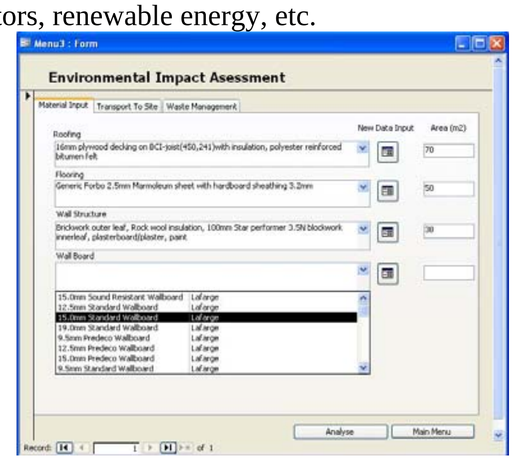

Figure 5. Product selection based on the proposed material or preferred suppliers. These products are filter to appeal to each region contractors/designers

Figure 6 shows CO2 emission of same product range from different suppliers. Building material can also be compared within products available from a supplier. Obviously, the graph creates a better view of products impact in the existing market, which helps architects and engineers in material selection.

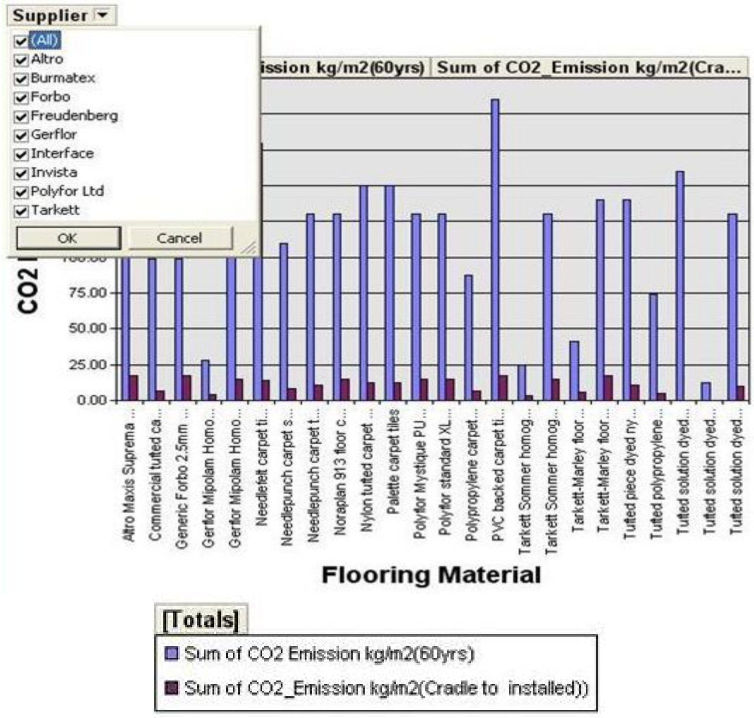

Figure 6. Comparing the CO2 emission in 60 years for same product range from different suppliers

A conceptual thought for the future development of 3D-EIA is to optimise EIA and LCCA by proposing an alternative material for a more sustainable perspective. The idea is to show two sets of assessment results for the original material selection and the alternative smart material that recommended from the 3D-EIA system. Both ordinary and smart materials will be trade-off with the EIA-LCCA to compare the cost benefit of the building material in the next 60 years. This idea will helps on decision making as budget constraint is the major reason for developers to select cost effective building materials rather than sustainable materials. Therefore, product optimisation is crucial in the future 3D-EIA development to enable developers or designers to visualise and compare the long term benefit that they can get from two different building materials.

6. Conclusion

Through the review on literature and existing IT system in this paper, a conceptual framework of the 3D-EIA has been set and gaps also have been found from the current EIA tools:

1) There is no holistic tools created so far where, stand alone EIA tools or templates have been used for a long time in the AEC without taking into account the LCA, LCCA. This is definitely not enough to demonstrate a high accuracy EIA result. Therefore, after the development of product database in CO^2 emission, the research on trade off the EIA-LCA-LCCA will carried out; potentially develop toward the cost benefit analysis (CBA) in the future. The hybrid assessment methodology will cease the inefficiency of current EIA tools.
2) Second gap is a rarely seen VR based EIA in current AEC market (Fu, C., 2007) and there is a potential for utilising the 3D-EIA to enhance the communication weaknesses among project members.
3) Third gap is the inaccessible EIA tools where most of them are too complicated or can only be read from the professional. Often there will be change of design or material due to the physical factors such as out of budget, insufficient materials, etc. Every small change requires a new set of assessment. This is time consuming for ordinary EIA tools and therefore 3D-EIA will looking at the potential use of IFC building components associate with attributes.

Sustainable and zero carbon housing has become a global vision and UK government which has set a target of reduce 60% of carbon emission in 2050 (DEFRA, 2004). In other words, there is a huge opportunity for the 3D-EIA to introduce a holistic appraisal by trade off EIA-LCA-LCCA in consider of thermal efficient, use of renewable energy, solar gain and human gain, product recycle capability, waste management, material cost, etc. However, there is still problem that exist in both IT and manual EIA development, where current AEC industry is fragmented that everyone using different standards. This has caused a high data inaccuracy (Thomas et al, 1996) and data hunger (Horner, M., 2002) in the present situation. A data sharing through partnership and collaboration suggested as the solution to overcome this problems.

The key for the developing 3D-EIA is to ensure that the designers have all of the relevant information needed for the assessment of cost and environmental impact. The concept is that the building users and owners will have the opportunity to minimise their operating costs from ‘cradle to cradle’. As energy resources reduce over the next few decades, the value of this research will increase and it is possible to foresee government legislation which drives building construction in this direction (Price, L., 2003). By making environmental impact analysis and life cycle cost control readily linked to 3D, the value of 3D technology will be enhanced significantly and it will likely result in more use of the technology in the construction process.

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