Developing an Integrated BIM Process for Real-time Environmental Impact Assessment as per LEED v4 and COBie Requirements

تطوير خطّة عمل متكاملة باستخدام إدارة معلومات البناء لتقييم التّأثيرات البيئيّة

بشكل آنيّ وفقاً لمتطلّبات **LEED v4** و **COBie**

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List of Abbreviations

AEC: Architecture, Engineering and Construction

AIA: American Institute of Architects

AP: Acidification Potential

BEP: BIM Execution Plan

BIM: Building Information Modeling/Management

BREEAM: Building Research Establishment Environmental Assessment Methodology

CAFM: Computer Aided Facility Management

Capex: Capital Expenditure

CDE: Common Data Environment

CIC: Computational Integrated Construction

CMMS: Computer Maintenance Management Systems

COBie: Construction Operation Building Information Exchange

CSI: Construction Specifications Institute

DB: Design Builder

DRM: Design Responsibility Matrix

EIR: Employer's Information Requirements

EP: Eutrophication Potential

eQUEST: Quick Energy Simulation Tool

FM: Facility Management

GBS: Green Building Studio

gbXML: green building eXtensible Markup Language

GHG: Green House Gas

GWP: Global Warming Potential

IDM: Information Delivery Manual

IES: Integrated Environmental Solutions

IFC: Industry Foundation Class

IFD: International Framework for Dictionaries

IPCC: Intergovernmental Panel on Climate Change

IPD: Integrated Project Delivery

ISO: International Standards Organization

LCA: Life Cycle Assessment

LCI: Life Cycle Inventory

LEED: Leadership in Energy & Environmental Design

MIDP: Master Information Delivery Plan

nPE: Non-renewable Primer Energy

NRMCA: National Ready Mix Concrete Association

ODP: Ozone Depletion Potential

Opex: Operation Expenditure

PAS: Publically Available Standard

PCR: Product Category Rules

PDT: Production and Delivery Table

PEPG: Project Execution Planning Guide

PIM: Project information model

POCP: Photochemical Ozone Creation Potential

PRT: Project Roles Table

RIBA: Royal Institute of British Architects

Abstract

Building Information Modeling (BIM) has emerged as an effective integration model for designing and constructing sustainable buildings. It is a process model that improves total project quality, provides quantity take-offs, ensures accurate schedules and reduces time and cost of projects. BIM has become extremely popular in the Architecture, Engineering and Construction (AEC) industry where it is extensively used because of its capacity to support collaborative and distributed work processes that make project delivery less costly and much efficient. Even though a majority of those in the AEC industry emphasize the importance of BIM practices, most of them still argue that technology and software applications are the essence of Building Information Modeling implementation. Nevertheless, there has not been any empirical investigation focusing on the impact of BIM as an integrated process on sustainable design and construction practices. The main objective of this study is to investigate the current market trends regarding BIM application in architecture, engineering and construction (AEC) industries, and explore how it can support decision-making for achieving sustainability targets.

This paper has focused on developing an integrated BIM process that is capable of maximizing the utilization of the Integrated Project Delivery (IPD) method and managing the information exchange procedures throughout all project stages. In particular, this process has involved the creation of informative digital models and the generation of BIM-based mechanisms for assessing building life-cycle environmental impacts. These mechanisms can provide a real-time evaluation of project’s elements within the Autodesk Revit modeling context as per the LEED V4 reference standard and the COBie guidelines.

خلاصة البحث

لقد ظهرت إدارة معلومات البناء كنموذج فعّال لدمج عمليات تصميم و تشييد الأبنية المستدامة. إنّها نموذج عمليّ يحسّن نوعيّة المشروع بأكمله, يساعد في حساب الكميّات, يضمن دقّة الجداول و يقلّل مدّة تنفيذ المشاريع و تكلفتها. لقد ازداد انتشار إدارة معلومات البناء بشكل كبير في أوساط الهندسة و البناء حيث أنّها أصبحت تستخدم على نطاق واسع و ذلك لقدرتها على تعزيز التّعاون و توزيع المسؤوليّات ممّا يساهم في جعل عمليّات إنجاز المشروع أقل تكلفة و أكثر كفاءة. على الرّغم من أنّ أغلبيّة العاملين في مجالات الهندسة و الانشاء يؤكّدون على أهميّة ممارسات إدارة معلومات البناء,إلّا أنّ قسماً كبيراً منهم لا زال يجادل بأنّ التّطبيقات البرمجيّة والتّكنولوجيّة هي الأساس لتنفيذها. بالإضافة الى ذلك فإنّه لم يكن هنالك أية دراسة تجريبيّة تتمحور حول تأثير إدارة معلومات البناء كعمليّة متكاملة على ممارسات تصميم و تشييد الأبنية المستدامة.

الغاية الأساسيّة من هذه الدّراسة هي بحث توجّهات سوق العمل في الوقت الرّاهن والمتعلّقة بتطبيق إدارة معلومات البناء في مجالات الهندسة و الإنشاء و استكشاف كيفيّة تسخيرها للمساعدة في اتّخاذ قرارات حاسمة من أجل التوصّل الى أهداف الاستدامة المنشودة. التّركيز في هذه الأطروحة كان على تطوير عمليّة متكاملة لادارة معلومات البناء قادرة على رفع مستوى استخدام مبدأ التعاون المشترك في إنجاز المشاريع إلى درجة عالية و إدارة الاجراءات المتعلّقة بتبادل المعلومات خلال كافّة مراحل المشروع. إنّ هذه العمليّة وبشكل خاص شملت تكوين نماذج رقميّة غنيّة بالمعلومات و تطوير منظومات تعتمد على إدارة معلومات البناء لتقييم التأثيرات البيئيّة للأبنية خلال دورة حياتها. هذه المنظومات قادرة على تأمين تقييم فوريّ لعناصر المشروع ضمن سياق عمليّة النّمذجة باستخدام برنامج Autodesk Revit وذلك وفقاً للمعايير المرجعيّة المحدّدة بحسب LEED V4 و مبادئ COBie التّوجيهيّة.

Chapter 1: Introduction and background

1.1 Introduction

The need for sustainable design and construction has led to an emerging trend in the adoption of Green BIM practices that utilize the BIM tools to achieve more sustainable outcomes. As per the architecture, engineering and construction (AEC) industry the term “green” refers to a construction project that meets the standards set by a green building rating system. Thus, the AEC industry has started to incorporate BIM in green buildings delivery with the primary objective of capitalizing on synergies between the two. However, the application of such Green BIM approach has yet to be efficiently utilized in most use-cases due to insufficient connection between BIM execution and sustainable design procedures within most of the firms in the AEC industry (Dowsett and Harty, 2013).

Furthermore, the majority of the firms lack experience in BIM and are focused on hard project data and observed evidence before they fully commit to the project. The market adoption of BIM currently faces the usual obstacles created by uncertainty and reluctance in the adoption of new technologies. It means that there is a fundamental need for more awareness of BIM’s benefits among the project’s stakeholders including owners, contractors, designers and facility managers in order to become a part of standard practice in design, construction and facility management activities. Firms which are reluctant to use BIM point to the limited functionality and the fact that it is an evolving technology. Industry players argue that BIM tools and concepts have usage complexities and it is better to rely on other traditional tools which they are more familiar with, e.g. AutoCAD. Consequently, building owners are hesitant to incorporate BIM so as to avoid cost inflation associated with an unfamiliar BIM workflow.

Moreover, there is tendency for industry actors to pay attention to the technology implementation dimensions and overlook its comprehensive process aspects. They conceptualize BIM as a technology add-on and fail to observe the importance of also adapting their business operations to absorb the cultural and organizational transitions required to successfully adopt BIM. It is this attitude and half-measures that have fundamentally weakened or undercut the synergies between BIM and green building standards. Consequently, the current Green BIM practices are improvised, immature and unsystematic. Thus, the success of a single Green BIM project has been dependent on the improvisations by experts and not on a well understood BIM integration process that can be repeated in other projects. In essence, there are too many elements which are left to chance in using improvisation, because there is no standard and reliable BIM integration model. The transient nature of project team composition in construction projects makes such success very difficult for other peer project teams to replicate. Another issue is that there are missed opportunities in knowledge acquisition and knowledge transfer from previous projects.

This study is directed towards the importance of a better integrated process for implementing BIM in green buildings which can be reliably used to leverage the synergies between green building standards and BIM Execution Planning.

1.2 Aims and objectives of this study

In recent times, project teams have found it very challenging to fully capitalize on the synergies that exist between BIM and green building requirements due to the fact that there have been immature, improvised and unsystematic methods used which has been very frustrating, however, this can be avoided with the production of more efficient and comprehensive guidelines. In addition, in order for industry professionals to successfully implement BIM, they must execute detailed and comprehensive planning and information management procedures since the early design stage of construction projects.

In the meantime, there is a major concern in relation to BIM contracting and the absence of a proper understanding of the Integrated Project Delivery (IPD) method. It is important for industry players to understand the procedure for any project in order to achieve the desired outcomes while implementing an integrated BIM Process. Therefore, it is critical to focus on establishing relationships among stakeholders and the application of collaborative management practices. However, current industry practices regarding BIM project execution give a basis upon which this research seeks to take a step further so as to develop an Integrated BIM Process.

Therefore, the aim of this study is to develop an integrated BIM Process that can improve the efficiency of design, construction and facility management activities. The proposed integrated BIM Process should be able to combine and organize all the required project information within one information management and tracking tool which will be further utilized to manage the information flow throughout all project stages. In addition, this will support in developing an evaluation mechanism within the software modeling context in order to check the compliance of project’s data against the required project targets and evaluate the possible actions for a better real-time decision making.

This study attempts to systematize the use of BIM in construction projects with a focus on utilizing BIM for sustainability analysis and reporting. In this context, it will examine the critical issue of implementing BIM practices in the AEC industry with a fundamental emphasis on the need for an integrated process that increases efficiency and reduces costs while ensuring the compliance with specific sustainability goals.

The research will be based upon recent industry best practices and BIM standards and protocols which were provided by the buildingSMART alliance (buildingSMART, 2015) and the U.K. BIM Task Group (BIM Task Group, 2015) along with the Royal Institute of British Architects (RIBA, 2013) and some other attested regulatory bodies. However, it must be noted that most of the current market efforts regarding BIM implementation are providing generic frameworks that can be applied in any building project and do not give specificity regarding the incorporation of BIM in green buildings. Therefore, this study will be looking into analyzing, combining and adapting those standards and protocols in order to be suitable for the purpose of this research and contribute to the regulation and development of the intended BIM Process with a particular emphasis on achieving project’s sustainability goals.

The objectives of this research are:

1) To perform a broad literature review of current research findings and industry best practices regarding sustainable design and BIM implementation in the AEC industry and analyze the current trends and future developments regarding between the two.
2) Proposing and developing an Integrated BIM Process in order to generate one source of information that would be used for managing the information flow throughout all project stages.
3) Adopt the Leadership in Energy and Environmental Design (LEED) version 4 as a use case in order to identify specific sustainability requirements and develop a particular evaluation mechanism as a sample of the proposed BIM Process.
4) To apply the proposed integrated BIM Process to a case study in order to verify its execution and check the possibilities for any further modifications and improvements.

The expected outcomes of developing an Integrated BIM Process will be:

- Produce a roadmap that will be critical for the planning of integrated BIM practices at the formative stages of project delivery. This step will eradicate uncertainty and add value to the project.
- Provide lucid identification of sustainability goals, matching BIM utilizations and the relevant stakeholders which promote more organization.
- Come up with a sequential operational guide with a detailed execution of green building information management practices identifying the right tools, competent personnel and required resources. It will also guarantee that the process outcomes are comprehensible to all stakeholders.
- Improve productivity and reduce the overall project duration and cost while ensuring the successful compliance with specific project targets.

The Integrated BIM Process will be extremely valuable to the industry because it will symbolize a holistic and systematic approach to the efficient utilization of BIM resources so as to conquer the complexities and challenges to the successful delivery of projects while at the same time allowing the team members to fully capitalize on BIM for achieving the overall project goals and the sustainably targets in particular.

Finally, the Integrated BIM Process will be structured in a way that allows flexibility which makes it an effective model that can be successfully applied to any project and facilitate the green building certification in particular.

Chapter 2: Literature Review

2.1 Sustainability in the architecture, engineering and construction (AEC) industry

It is no longer acceptable for architects, engineers and professionals in the construction industry to design and build assets that are just aesthetically appealing and functional. In the past, all that really mattered was that the building had integrity to withstand daily use and the occasional natural disasters as well as outstanding design that allowed aesthetic value (Sadler, 2005, 17). Today, the industry presents additional requirements, given the nature of the planet and the environmental pressure to create for the future. Sustainability has grown from a fringe aspect of the building industry to a core property that any building coming up today would like to have (Fewings, 2013, 46). Sustainability has almost become an absolute mark of quality that the AEC professionals deliberately seek. However, there are several reasons why sustainability is important in the AEC industry.

The first of these reasons is because of the need to protect public health. The rapid increment of the built-up area in the world will have a huge impact on human living in the future as there will be lesser open spaces especially in cities, for example. Thus, people will have lesser interaction with the green environment such as parks or gardens on the ground since the spaces are likely to have been taken up by buildings (Charlesworth and Adams, 2011, 37). Consequently, many of the benefits that people derive from a natural environment will be lost. An example is the calming effect that people experience when they have beach and park views from their houses. In order for the future population to have an experience that is close to what people have today, the industry will have to come up with ways through which the building practices of today do not alter the natural set up aggressively. The AEC community is therefore charged with finding ways, for example, to ensure that natural lighting gets into buildings as well as fresh air circulates naturally.

Another issue that the AEC industry needs to be aware of as far as the importance of sustainability goes is food security. The relationship between construction and availability of food is a complicated one for several reasons. One is because where buildings come up in stable agricultural areas, the food production goes down. As a result, food has to be bought and people who cannot afford the rising cost are forced to go hungry more often than not. According to Nersesian (2007, 99) the construction of roads also takes away land that could have been used for growing crops, especially when the roads have to go through productive areas. However, it is the construction of large projects like dams which poses the biggest threat to food production. Dams result in the blocking-off of a river, meaning that land that was being used for agriculture upstream gets flooded as the water level rises behind the dam to form the reservoir while the farmers downstream are denied water to irrigate their crops (Desai, 2008).

Environmental equity and justice is another reason why sustainability is important (Borden, 2009). The situation as it is today is such that the developed world is hurting the rest of the world through pollution which is directly linked to the AEC industry. As a result, the developing world is left to suffer environmental consequences of practices that they were not part of (Khare and Beckman, 2013, 78). Additionally, when the weight of buildings causes instability in the tectonic plates and accelerates the incidence of shifting plates causing earthquakes and tsunamis, countries which played no part in such construction fall victim of the damages visited on the whole fault area (Khare and Beckman, 2013, 80). Effectively, there is an injustice that is visited on the countries which played no part in the factors that accelerated the quake or tsunami.

The same happens for the damaged ozone layer. When the developed world's construction activities result in gases which damage the layer, the whole world suffers, even when the whole world is not part and parcel of those activities. Another area of concern as far as environmental equity and justice goes is the unequal use of water resources. Considering that most of the buildings and construction happens in the first world countries, and that fresh water is a dwindling resource in the world, there is a need to establish measures to ensure that there is equity in the drawing of fresh water.

2.2 Global Warming and the AEC industry impact

Perhaps one of the most serious reasons why sustainability is important in the AEC industry is to reduce the greenhouse effect which is the main cause of the global warming phenomenon. Buildings consume approximately 70% of electricity, 40% of raw materials and total energy, and 12% of fresh water in the US. Additionally, they account for 30% of greenhouse emissions (Nguyen, Shehab, and Gao, 2010). Therefore, there is a need to ensure that the buildings that are coming up have a lesser impact on the environmental pollution front (Forbes and Ahmed, 2010, 56) by reducing their dependency on the dwindling fossil fuels. Buildings rely on fossil fuels-directly or indirectly- when under construction and for regulating temperatures when completed (Khare and Beckman, 2013, 39). In order to reduce the dependency on oil, there have been builders who incorporate solar energy usage and other alternative fuels within the buildings structure. Scientific evidence shows that concrete poses the highest negative environmental impact among all construction materials even more than that of bitumen (Khare and Beckman, 2013, 70). This is because the process of mining cement is very polluting. In addition, the process of drying concrete is polluting as well because it is accompanied by a release of greenhouse gases.

Carbon Dioxide (CO_2) has been recognized as the biggest direct contributor to the greenhouse effect. There are many instances in the AEC industry when CO_2 emissions are produced. The first opportunity for the production is when the raw materials to be used in the building process are being mined (Nersesian, 2007, 35). A common building material that results in relatively high emissions of CO_2 is the mining of limestone which is then crushed to manufacture cement (Stegemann, 2014). The machines used in the mining process burns fossil fuels. The machines used in the crashing process use heavy fossil fuel as well, in addition, more emissions occur during transportation of the materials. However, it is the actual making of the concrete that results in huge emissions (Nersesian, 2007, 40). After the construction is completed and people have moved in, emissions continue through energy use by residents. The eventual carbon footprint of a building is therefore potentially high, relative to the size of the facility and the number of occupants and visitors (Nersesian, 2007, 40). Having identified carbon dioxide emission as a major concern, there is a need for AEC professionals to find ways for reducing its impact to the environment.

One of the ways is by the introduction of more plants in a building. Plants use carbon dioxide in their processing of food and output oxygen. Therefore, when buildings are designed in such a way that there are terraces and other spaces such as roof tops open for planting green plants then there is a reduction in CO_2 emissions (Levy, 2013, 39). However, Hensley and Aguilar (2011) cautions that one or two plants make no significant difference; there needs to be a reasonably sufficient plant population in a building.

AEC professionals should also design buildings which are energy efficient. Energy efficiency can be achieved by incorporating well insulated envelope and using appliances which are rated for their power saving (Levy, 2013, 60). However, achieving such an energy efficient and sustainable building would require the involvement and commitment of all team members since the early design stage through an Integrated Project Delivery (IPD) approach.

2.3 Integrated Project Delivery (IPD) as the main method for achieving sustainability

According to Charlesworth and Adams (2011, 29) the building of a sustainable project is not a function of the individual efforts of the architect, engineer and builders, rather it is a function of the combined effort applied. The need for everyone involved to be on the same page becomes clear when the principles of IPD are considered. These principles include mutual respect and mutual trust. The importance of mutual respect is that it allows the whole team to move past the suspicion that one player, may let the whole team down. When an architect trusts that the builder will implement the project as designed then he will be able to concentrate on making a sustainable design without worry. The presence of a good team spirit fostered on mutual trusts and respect with full faith that everyone is fully interested allows for ideas that might not be agreed upon in a disjointed team to be accepted. This is because when team dynamics are aligned, there is ease in reaching decisions on typically divisive matters.

IPD principles also include mutual benefit and reward. According to AIA (2007, 5) there needs to be a system of benefit and reward that is tied to the goals of the project. Considering that the goal in this case is sustainability, the project needs to reward early involvement because that then allows for the identification of a mutual benefits and reward program. Benefit, as noted by (Howes, 2001, 83), is not so much about individual benefits but rather about the provision of convenience for each stage of the project. This will allow all team members to reap the benefit of convenience as well as time saved.

The other principle of IPD of interest is collaborative innovation and decision making. The value of this in the creation of sustainable projects is that it allows for the development of ground breaking solutions and innovations. When there is a will for everyone involved in the conception, design and building of a project then the chance that new ideas will come from the synergistic environment are high (Yates et al., 2015, 113). Allowing brainstorming through regular meetings can be the difference between a ground breaking innovation, such as a new way to save energy, and unrealized potential. Collaborative innovation and decision making should be promoted to the highest possible practical extent in order to allow for any ideas that might reside with the AEC professionals and others involved to be deliberated upon and accepted, improved upon or discarded. Hence, there is value in encouraging collaborative innovation in sustainable design activities because ideas are then refined when they get debated upon vigorously and resultant decisions reached through a collaborative process (Gransberg and Shane, 2010, 36).

Open communication is another principle of IPD which has importance as far as sustainability is concerned. Open communication is defined as the provision of clear channels through which all key actors in a project can communicate without unnecessary restrictions (AIA, 2007, 7). The value of open communication in the pursuit of sustainability is that it allows for the people involved to exchange ideas in a timely manner. Kaptein (2013, 53) says that the value of an idea can be adversely affected by the time of its presentation. If the architect has an idea that the engineer needs to ratify as structurally viable but fails to get a response from the engineer owing to poor communication, the value of that idea is lost, regardless how outstanding it was. The communication is also important because it determines whether instructions are executed as they were supposed to be. When an engineer, for example, designs a central cooling/heating system in such a way that it is able to benefit from natural conditions during the day, the constructor is expected to execute the building of the system to the letter, as instructed by the engineer. However, in a construction site things that were not anticipated are bound to happen. The constructors might therefore require to consult the engineer as to whether some changes can be made in line with the new things that come up. In such a situation open communication becomes invaluable.

In order to understand the other ways through which IPD helps in achieving sustainability, one should consider how the process is related to the creation of projects that can be said to be sustainable. In particular, one can compare the three main reasons for the pursuit of sustainability and the IPD process. The first goal for sustainability is environmental protection. IPD allows for the achievement of environmental protection by ensuring that the people working on a project understand how their individual efforts are related to the whole project sustainability goals.

The need to safeguard public health is another reason why sustainability is sought. IPD as a process allows for the involvement of categories of people who in typical construction do not get involved. A project can for example enlist the input of potential occupants in order to determine the viability of some living ideas that the technical team has.

Moreover, IPD allows for the technical people to step out of the formally defined roles and play other roles that might be beneficial to the sustainability of the project. An example is when an engineer goes out of his way and shows the architect various cutting edge materials that can be used to make a building more sustainable.

However, applying the IPD approach to the AEC practices needs a well-defined framework that allows for smooth and efficient information exchange among all project stakeholders. Therefore, Building Information Management (BIM) has been introduced to the industry as a comprehensive process for achieving such an IPD framework.

2.4 Building Information Management/Modeling (BIM) as a comprehensive approach for IPD and Sustainability achievement

Although the Integrated Project Delivery (IPD) principle has been used for a while in multiple areas of the economy (Mannix, Neale, and Goncalo, 2009, 47), its application to the AEC industry was not fully recognized until the introduction of Building Information Modeling (BIM) which has adopted the IPD approach as the key driver of all the related project activities. The synergy between the two has been mainly represented by the information sharing method that forms the basis of any BIM usage and regulates data exchange among all the team members at a highly dynamic level. This process is usually supported by the utilization of intelligent software applications that facilitate the creation of such informative models containing all relevant project data.

Hence, IPD is considered as the fundamental approach for both BIM implementation and sustainability practices. Subsequently, the IPD principle enables BIM to embrace a huge potential and capability to support the achievement of project's sustainability targets using IPD as a tool to accomplish that integrated process.

This BIM-based sustainability assessment approach has attracted considerable attention by many scholars and industry professionals in the market those have all agreed that for sustainability to be achieved, the broad collective evaluation of design information required during a building's design stage can be done using Building Information Modeling (BIM) (Cidik and Hill, 2014). BIM can help designers in various fields to negotiate, make concessions regarding conflicting aspects of design, and optimize a building's performance. For example, while aesthetics considerations are important, they can affect a building's energy and resource consumption negatively during construction and use. BIM allows specialists such as architects, engineers, electricians, and constructors to collaborate in the design stage to enhance optimization. Consequently, it can be used to ensure that a building is in line with a particular standard such as Building Research Establishment Environmental Assessment Methodology (BREEAM) or Leadership in Energy & Environmental Design (LEED). BIM utilizes digital illustration of a building process such that design decisions can be made cooperatively by various specialists. Consequently, BIM presents a useful tool for improving the sustainability of buildings through judicious decision-making from the design stage upwards. The application of BIM is still in its infancy. Therefore, it is useful to explore how the construction market is currently utilizing the process to identify developments and opportunities.

Following recent concerns about the environment, computer aided design (CAD) has emerged as a solution for improving the sustainability of buildings. Advances in computing and information technology have made it possible to manipulate and transfer large amounts of data cost-effectively and with ease. Out of these advances, computer aided design (CAD) has evolved into BIM, which "provides the data needed for building performance analysis and evaluation" (Nguyen, Shehab, and Gao, 2010). BIM technology provides a model that can produce information on sustainability that can then be assessed using sustainability standards.

Sustainability assessment when BIM is utilized in the design process goes through several stages. Zanni, Soetanto, and Ruikar (2013) presented a list of useful software that can be used in the energy simulation of a design and in sustainability assessment. The list included Green Building Studio (GBS), Quick Energy Simulation Tool (eQUEST), and Design Builder (DB) among others. Further, they present a list of software for enabling collaborative design between various specialists. However, they emphasize the need for specialists to be trained on using the software. This will improve their ability to use the software collaboratively as well as document their work for ease of keeping an audit trail. Then, they would overcome creative isolation, which limits the effectiveness of design sustainability efforts (Zanni, Soetanto, and Ruikar, 2013). Further, the researchers point to the need for the clarification of sub-processes involved in the design process. This would enable stakeholders involved to coordinate efficiently by specifying workflow and interactions between various parties.

Nguyen, Shehab, and Gao (2010) used a model of a hotel building made using BIM to investigate the viability of sustainability assessment using such models. Using the LEED rating system – which requires that buildings satisfy criteria in areas such as water efficiency, energy and atmosphere, and materials and resources – the researchers assessed the building's sustainability. First, they used a framework to translate the building's features as they were represented in the model into sustainability indicators. Then, they assessed the sustainability indicators against LEED criteria and reported the results. Nguyen, Shehab, and Gao (2010) were successful in calculating the maximum points the building satisfied for LEED; they found that it had a rating of "Platinum". They demonstrated the ease of evaluating a building's sustainability from data drawn from a BIM representation.

BIM applications yield data that can be used during the design process to ensure accreditation is received. In their paper, Harding, et al. (2014) point out that there are methods for linking BIM applications to BREEAM criteria. However, they argue that it is necessary to create standards that would help guide designers as they proceed with a design. With such standards, it would be possible to input data in a BIM model with the express goal of achieving BREEAM accreditation. Additionally, they argue that the inclusion of best practices that accommodate cultural and behavioral factors could help ensure design teams are motivated to use BIM with the aim of achieving BREEAM (Harding, et al., 2014). BIM application data can also be used to achieve other popular certifications such as LEED as pointed out by Azhar, et al. (2011). However, there is still no one-to-one application that links LEED criteria to BIM application data. Azhar, et al. (2011) use a case to validate the method they develop for linking BIM application data to LEED certification. In their case study, they found discrepancies between the software-produced results and the manual results due to modelling inaccuracies. With better integration of certification criteria to BIM applications, it will be possible to evaluate and improve a building's sustainability in the conceptual design stage.

Raffee, Hassan, and Karim (2015) argue that it is possible to automate the sustainability evaluation process. This would make it easy to include sustainability considerations early in the design process. The researchers propose the use of the software Autodesk Revit as a BIM tool and Microsoft Visual Studio (MVS) as a tool for automating the evaluation of a building's sustainability. The researchers propose the use of Industry Foundation Class (IFC), a standard data model, to overcome interoperability problems. In their theoretical paper, Raffee, Hassan, and Karim (2015) propose the use of automated assessment software to enhance design. They demonstrate that it is possible to improve a building in the design stage by responding to sustainability assessment outputs. Consequently, designers would be able to produce buildings that meet or exceed particular sustainability criteria.

While early sustainability assessment is useful, it remains problematic because of a lack of applicable software for analysis and the disjointed nature of data available before a design is completed. Cidik and Hill (2014) present an example of early sustainability assessment for an ongoing case. They argue that sustainability efforts after the design has been created are limited since they do not include architectural aspects. To improve assessment efforts, they use a data categorization system that was developed using available literature and industry professional interviews. Such a system would overcome the problem of differences in data representation inherent in different fields involved in a design. The data categorization system would also minimize complexity for stakeholders such as the clients. Cidik and Hill (2014) propose the use of an information categorization system such as Uniclass to improve data organization, and overcome problems such as "overlap, confusion, and misinterpretation". Consequently, designers and stakeholders involved can evaluate designs early and thereby cooperate in enhancing a building's sustainability qualities.

Moreover, Xu, Ma, and Ding (2014) point to the potential for BIM to be deployed throughout the life cycle of building's construction. They present a framework that emphasizes the need for components and information flow to be well defined. This would enable various parties to coordinate their efforts and respond to changes. The researchers divide the design phase into three departments that should coordinate to enhance sustainability efforts; these are the structural design, architectural design, and facility engineering. Through collaboration, it would be possible to manage risk and sustainability. Each department is able to "create value through its participation" (Xu, Ma, and Ding, 2014). The researchers highlight the usefulness of BIM as a tool for managing information that may be mined for use in other projects. Consequently, users of BIM would benefit from increased efficiency on sustainability as they tackle different projects.

BIM applications can produce data on specific design outcomes such as the amount of daylight a building will receive and use. The most efficient building designs utilize solar radiation to regulate the indoor temperature and for lighting during daytime. Some designs that incorporate solar panels can generate enough energy to use for nighttime cooling/heating and lighting as well. Therefore, the ability to analyze the amount of radiation received by a particular design is a useful design requirement. Moakher and Pimplikar (2012) highlight the usefulness of BIM for analyzing the efficiency of a building. They list software that can be used depending on the designer's needs. The software can address the lost opportunities in the design phase for optimizing energy use because features such as lifecycle energy efficiency are not always considered key design criteria (Moakher and Pimplikar, 2012). The researchers offer a theoretical analysis of the quality and applicability of various programs for use in analyzing the impact of sunlight on a design.

In addition, Lim (2015) points out that improved computing speed and storage space has made possible to carry out complicated modelling processes such as daylight modelling. The researcher compares several programs that are used and he examines their design parameters and performance outputs. Their application allows designers to develop a design while studying its sustainability characteristics thereby improving workflow. Welle, Rogers, and Fischer (2012) examine the difficulties involved in integrating daylight simulation into design processes. They propose decomposition and re-composition of a model as a solution for fast analysis of "climate-based daylighting simulation". Using an extant building, the authors validate their methodology and demonstrate its effectiveness. Their method yielded high accuracies and reduced simulation times of as much as 69%, 76%, and 60% compared to an industry case study. Welle, Rogers, and Fischer (2012) argue that automated decomposition and re-composition will be useful in the integration of sustainability characteristics such as solar radiation analysis into BIM applications.

Furthermore, BIM applications can also be used to analyze the energy consumption of a building during and after its construction stage. Energy consumption in a building's life is an essential consideration given the heightened concerns regarding greenhouse emissions in the world today. Using an example one-family home, Antonopoulos and Sandidge (n. d.) demonstrate how a BIM application (Autodesk Revit) can be used in tandem with IES Virtual Environment software to "perform a simple total energy and carbon analysis of the model" (Antonopoulos and Sandidge, n. d.). The analysis allowed the researchers to obtain ideas on how to make their design more sustainable. Therefore, using data sourced from BIM applications, designers can create buildings that are sustainable and cheap to maintain.

In addition to determining the energy a building would consume during operation, BIM software can be coupled with other software to determine the lifecycle costs and carbon dioxide emissions of materials used for the construction. Chen and Li (2014) combined the BIM application Autodesk Revit, eQUEST (an energy simulation program), and the spreadsheet program MS Excel to examine the costs and emission of construction materials for an extant building. To determine the amount of carbon dioxide produced, they determined the materials' production, transportation, and operation. Results from the study indicated that a change of roofing materials could minimize carbon emissions. The researchers demonstrated the usefulness of BIM to analyze a building's sustainability with regard to energy consumption.

Jalaei and Jrade (2014) highlight the capability of BIM applications to assess design alternatives early especially with regard to energy usage. They propose a method for integrating BIM applications with applications for evaluating day lighting and energy consumption. Their proposed system features five modules; these include (a) a database for sustainable building components, (b) an application for analyzing lighting and energy, (c) a module for assessing a building's life cycle, (d) a LEED accreditation assessment application, and (e) an application for assessing cost. Using a test case, the researchers demonstrate it is possible to integrate several programs that offer substantial information in the early stages of a design. Nasyrov et al. (2014) offer a similar analysis of integrated applications. They contend that the challenge for achieving seamless integration is the presence of "space boundaries and the spatial limits and interrelations of room objects" (Nasyrov et al., 2014). However, they argue that continued testing and refinement of the import and export processes involved between applications will improve the functionality of BIM applications thereby making them valuable tools for sustainability evaluations.

Similar, in a study by Aksamija (2012), the integration of BIM applications with energy simulation tools is examined. The researcher examines the level of detail required in the design state to enable smooth analysis of energy requirements using simulation tools. Using a case study, she demonstrates that data on rooms, analytical surfaces, openings such as windows and shading surfaces, which can be generated by BIM applications, are necessary for the effective analysis of energy requirements. To improve integration between BIM software and energy analysis applications, standards can be utilized. Laine and Karola (2010) demonstrate the effectiveness of the open IFC standard to manage transfers of architectural BIM data into energy analysis software. They demonstrate the need for better transfers of data on spatial requirements, energy analysis mapping, and space boundaries in designs. To enhance energy optimization for sustainability, they argue for the development of applications that consider the effect of lighting control on a building's energy consumption.

Chen et al. (2010) highlighted the ability of BIM software and other related suits to evaluate energy consumption by taking into consideration factors such as geography, environmental conditions, the types of materials used and the technology employed in construction. Using several energy analysis programs, they produced a more precise prediction of energy consumption. To optimize energy usage, the researchers proposed a method that incorporates three models: the design model, a construction-planning model, and a model for energy performance analysis (Chen, et al., 2010). Using a case study, they showed that the model improved estimation results substantially.

Azhar, Brown, and Farooqui (2009) analyze three performance analysis programs, Green Building Studio (GBS), IES Virtual Environment, and Autodesk Ecotect to determine their ability to inform designers of the usefulness of their designs' sustainability. The researchers developed a weighted scoring system to tally the performance of the analysis programs. They obtained information from literature, software manuals, and interviews with professionals to gain insights into the programs' usage. Using Emory University's Psychology Building to test the analysis programs, the researchers experimented with various surfaces and building orientations to determine how precise the programs' results were. They found that the programs could produce highly informed results on sustainability problems such as daylighting and solar access. Of the three programs, IES Virtual Environment was found to be the most powerful and flexible while GBS was the least useful although it was more flexible than Ecotect. Such analysis could help establish the best products in the market while helping to shape future products for analyzing sustainability features in buildings.

Additionally, Chen, Cho, and Woo (2011) investigated the efficacy of two leading analysis programs for building performance; these are Energy Plus and IES Virtual Environment. They highlighted their use as energy simulation applications that can be coupled with BIM applications. Using a case study of a single story building, they calculated the building's performance and compared the usefulness of the two programs. They found IES to be the more user friendly of the two programs in addition to its ability to compute fluid dynamics and life-cycle cost analysis. They found Energy Plus to be the more powerful simulation tool since it had great capabilities for defining heating, ventilating, and air conditioning (HVAC) systems. Nonetheless, the complicated program required that the designer have substantial knowledge of HVAC systems for it to be effective (Chen, Cho and Woo, 2011).

As shown by Chen, Cho, and Woo (2011), some BIM applications require substantial expertise in the manipulation of data. This may limit their applicability since designers are often not trained to use complicated programming languages and procedures. Asl et al. (2014) investigated the use of graphical applications for sustainability design and analysis.

They contend that designers with minimal knowledge of parametric modelling and programming can use such applications without loss of effectiveness. The method offers faster analysis of "BIM-based simulation and representation of solution spaces and trade-offs" (Asl et al., 2014). Using a case study, they demonstrate that it is possible to modify a design using graphical-based applications to achieve a particular LEED Indoor Environmental Quality (IEQ) credit rating for daylighting. Because architects are often nonprogrammers or novice programmers, the creation of such graphics-based software could vastly improve its adoption and usage by designers.

The design of a building substantially affects how much energy is used in construction and during its use. Yuan and Yuan (2011) highlight this synergy between design and construction and they offer a theoretical examination of the function theory of energy saving design. They examined the problems of Chinese traditional building energy-saving designs especially the lack of information sharing between the design process and the analysis of energy consumption.

The data generated by BIM software offers substantial opportunities for improving a building's sustainability features when it is integrated with other sustainability analysis software. It can allow buildings to achieve certification or a particular standard, reduce energy use during construction and use, and save time during the design process (Azhar, Brown, and Sattineni, 2010). According to Motawa and Carter (2013), BIM software can even improve the post-occupancy analysis process of a building's sustainability features. Although Salmon (2013) has noted some variations between actual data and software calculated results for energy consumption, it is possible to improve the sustainability credentials of a building using the programs in the design phase given their convenience. Additionally, the programs can be used to share data regarding a building's performance after it has been occupied. This would help create better evaluation programs that could in turn produce better designs.

Azhar, Khalfan, and Maqsood (2012) offer a highly inclusive analysis of BIM concepts and benefits. Using case studies, they demonstrate the effectiveness of the software for sustainability analysis. They note that the main problems affecting BIM adoption and usefulness is interoperability problems and the integration of useful data into building models. Interoperability can be improved by establishing standards for data transfer.
In addition, Adamus (2013) made a comparison between green building XML (gbXML) and

Industry Foundation Class (IFC) data exchange schemas. He found that it was easier to use the gbXML open schema which is meant to facilitate the exchange of specific building data from CAD software to specialized sustainability analysis applications (energy analysis in particular). However, he stated that the IFC open schema was more inclusive despite its complexity as it carries all building specifications when exchanging the data among all related AEC software applications containing detailed information about building geometry, systems, materials…etc. By solving these interoperability problems, the applications will be more useful in the achievement of particular certification goals such as BREEAM (Zanni, Soetanto, and Ruikar, 2013). Through the effective integration of BIM tools and Life Cycle Assessment tools, the capability for designing sustainable buildings will be substantially improved (Antón and Díaz, 2014). As Zhang et al. (2014) demonstrate using a rule-based system that examines a building's LEED credit achievements, it is possible to integrate BIM with other tools so that real-time results are produced regarding the building's sustainability.

On the other hand, Dowsett and Harty (2013) and Gandhi and Jupp (n. d.) reviewed literature regarding the use of BIM applications for sustainable designs. Dowsett and Harty (2013) concluded that BIM software will help to reduce the bureaucracy involved in traditional design teams. This is because they eliminate the constrictive conditions that discourage collaboration in the traditional design environments. However, they contend that improvements to BIM software should be made to improve their diagnostic qualities for the production of sustainable designs. Gandhi and Jupp (n. d.) used a qualitative approach that utilized interviews which revealed that there was need for new management techniques for BIM applications to be effective. By establishing effective management techniques, it will be possible to use BIM applications as drivers of sustainability rather than validation tools.

2.5 Conclusion

Because of growing concerns regarding the environment, demand for environmentally friendly buildings has grown substantially. The construction industry takes up large fractions of the world's energy consumption, with the industry taking up as much as 40% of the energy used in Europe (Harding et al. 2014). The design stage (pre-construction stage) is the best time for designers to put in place environmentally friendly features in a structure (Lim, 2015).

However, owing to the high degree of complexity of modern buildings and the large number of specialists involved, coordination and collaboration is often difficult during the design stage. Better coordination and collaboration would enhance the efficiency of designs, preservation of the construction site, and the effective sourcing and use materials. Additionally, it would enhance life cycle management of the building such that it remains efficient while in use and its end-of-life managed effectively.

It can be determined that BIM, while being a relatively new concept in the AEC industry, is a goal whose pursuit brings with it other benefits to the stakeholders in a project. The interrelationship between the various disciplines as exhibited by the IPD method and the ability to take professionals from different backgrounds and bring them together in a project would contribute significantly to reducing time, cost and inefficiencies in the implementation of any type of projects especially the large ones such as infrastructure projects. In addition, sustainability assessment has been made easier by the existence of processes such as BIM and approaches like IPD.

Chapter 3: Methodology

3.1 Overview

As demonstrated in the comprehensive literature review, there is a tendency in the AEC market to focus on the technological aspect of BIM without considering the full implementation and capability of it as an integrated process. That technology-driven approach can be clearly recognized within the majority of the reviewed research papers which have focused on the usage of advanced simulation software as a BIM application for evaluating building's energy consumption and exposure to solar radiation considering them as the main aspects for assessing the sustainability performance of construction projects. On the other hand, only few of the recent studies have proposed a framework for utilizing BIM for sustainability assessment, however, the suggested guidelines were more theoretical than practical and were not sufficient to detail an integrated BIM process through all project stages.

Therefore, the main methodology of this study is to pursuit a comprehensive process-driven BIM approach. In order to achieve that, the study will look into the details of BIM principles and go through its implementation procedures. In addition, the study will discuss possible BIM integration with the AEC practices and explore its utilization for saving time and cost while ensuring the achievement of project's goals in general and sustainability targets in particular through the development of an Integrated BIM Process.

3.2 BIM definition

BIM is an emerging and ever-evolving industry with different areas of development and application, therefore there has been no totally accepted definition of it.

The first dilemma of defining BIM is caused by the term 'Building' which was used by many industry professionals like Eastman et al. (2011) who defined BIM as a promising development that enables the generation of one or more precise virtual digitally-constructed models of a 'building' to regulate the related activities. However, some other professionals have focused on the differentiation between 'building' as a verb and 'building' as a noun by using the term 'facility' which was mentioned by the U.S. National BIM Standards

Committee who described BIM as a digital illustration of physical and functional properties of a ‘facility’ generating a common information recourse (NBIMS, 2007).

In addition, the terms ‘asset’ and ‘project’ were used to replace ‘building’ in many BIM definitions. The U.K. BIM Task Group has stated that BIM is basically value-adding collaboration across the whole life-cycle of an ‘asset’ (BIM Task Group, 2015), while, on the other hand, the U.S. Department of Veteran Affairs has explained how sharing a model can impact the successful utilization of BIM for achieving targeted ‘project’ results (VABG, 2010).

The second debate when defining BIM is whether “M” should refer to “Modelling” or to “Management”. The misconception that happens when using “Modelling” is that people tend to think essentially in terms of a Computer Aided Design (CAD) model (RICS, 2014). Though this definition would favor the software vendors it is actually more accurate to relate the “M” in BIM to ‘Managing’ a system or a process that would lead to an ‘Informative Model’.

Furthermore, in addition to “Information Management” and “Geometrical Simulations”, “Information Communication Technology” is a fundamental part of BIM as it controls the flow and sharing of structured information (Figure 3.1). This information exchange is the central philosophy of BIM by which the resulting model would contain the actual information of the building products. Furthermore, it would enable project teams to simulate various aspects of the design, construction and operation of an asset.

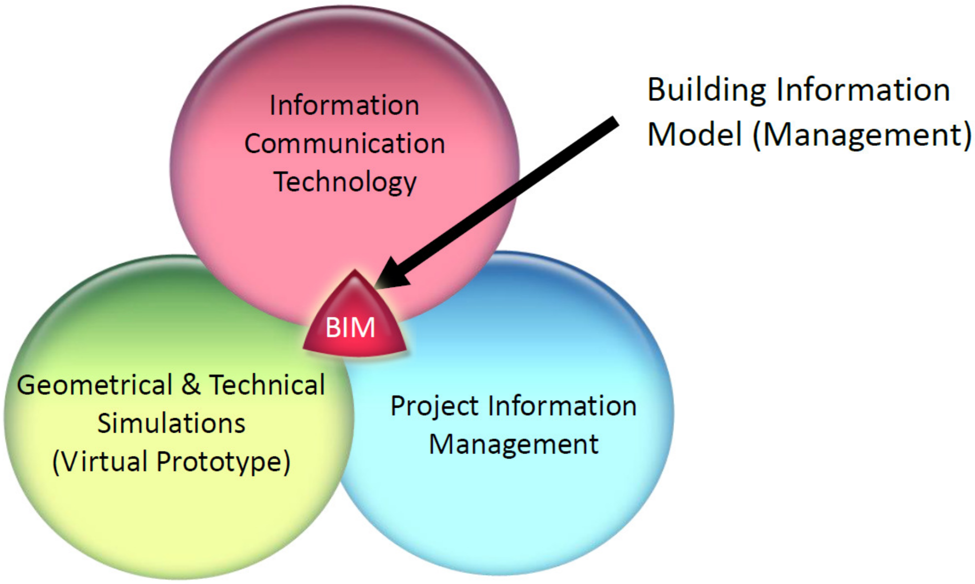


Figure 3.1: BIM as the union of Simulation, Information Management and Information Communication Technology (Isurv, 2014)

However, despite all the dilemmas and debates, almost all the definitions of BIM have addressed three related characteristics which are the model itself, the process of developing the model and the use of the model. These aspects form the basis of any comprehensive BIM definition.

3.3 BIM maturity levels

According to CIC (2013) the BIM maturity model defines the development of BIM from traditional CAD to entirely integrated and interoperable BIM (Figure 3.2). It explains the maturity levels regarding the capability of the supply chain to exchange information (BIM Task Group, 2015). However, the timeline for BIM maturity at any organization will depend on multiple factors (CIC, 2013).

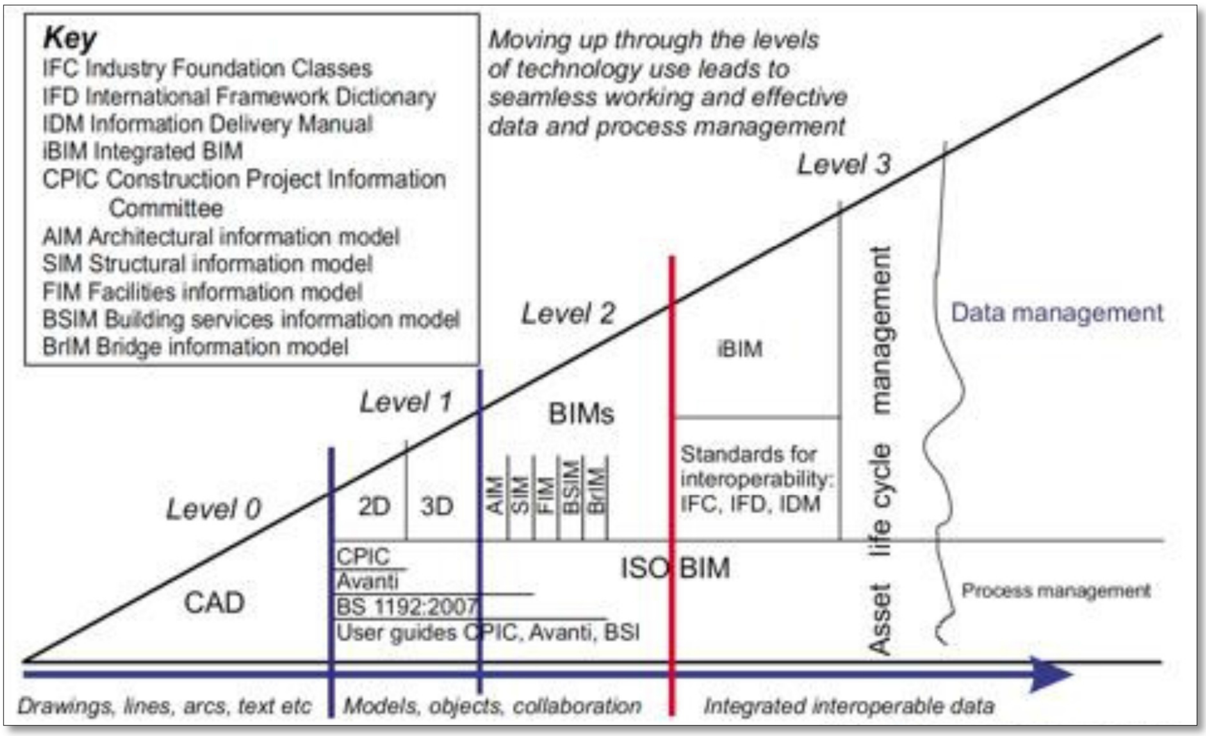


Figure 3.2: The BIM Maturity Model (CIC, 2013)

Level 0: This level represents the conventional design process that has been applied by most of the firms for many years using 2 dimensional (2D) CAD production files. This level is also defined as an unmanaged CAD according to the fact that common CAD standards were not able to get the required consideration during the development of CAD usage (RIBA, 2012).

Level 1: This maturity level represents the business-as-usual process at most of the companies nowadays. It is generally described as lonely BIM due to the fact that the 3 dimensional (3D) model is mostly created and used by architects for visualization purposes during the concept design stage or for final presentations without the collaboration of the remaining project teams in generating and utilizing the resulting model (RIBA, 2012).

Level 2: At this level of BIM the collaboration of all key team members is required in order to develop multiple 3D informative models that will guaranty rational design development without generating a single model (PAS, 2013).

In addition, BIM level 2 obligates the utilization of COBie (Construction Operation Building Information Exchange). COBie is a standard for managing the data provided by the BIM model and sharing it with the client at specific stages of the project especially the handover where the as-built information form the basis for the operations and maintenance activities of the asset (BIM Task Group, 2015).

Level 3: This is the level where a fully integrated BIM (iBIM) is achieved with a single project model which requires not only the complete collaboration by project team members but also a high level of software interoperability in order to collect all the information within the generated model as one source of accurate data.

3.4 Building Information Management (BIM) Process

The main principle of BIM is to use informative building elements for creating an information model which goes through several stages during the asset lifecycle (Figure 3.3).

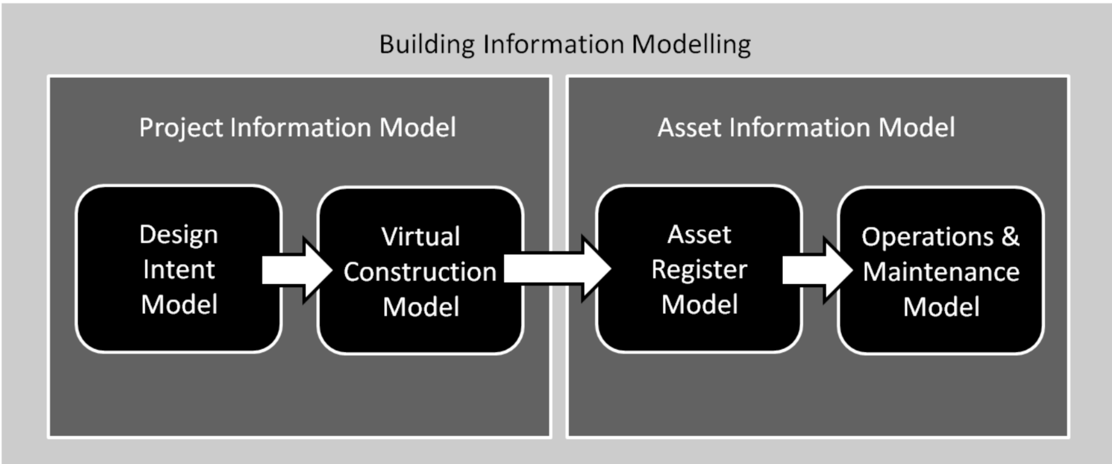


Figure 3.3: BIM Process (PAS, 2013)

In addition, Teicholz (2013) has demonstrated the progression of the modeling data through the main project stages starting with generic graphical data at the conceptual design stage and developing into the as-built information at the handover stage where more non-graphical data are provided to support the Facility Management (FM) systems (Figure 3.4).

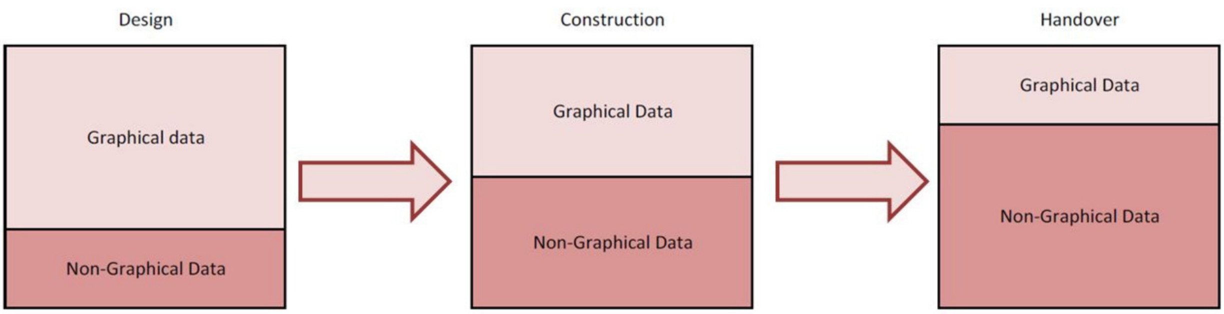


Figure 3.4: BIM model processing (Teicholz, 2013)

Moreover, the British Standards Institute (BSI) has released several Publically Available Standards (PAS) which have provided guidelines for standardizing and specifying BIM implementation across all disciplines in the AEC industry. However, PAS 1192-2:2013 (PAS, 2013) is the most reliable document so far and it has been adopted widely in the market. This Publically Available Standard has specified and detailed the usage of BIM process for the information management regarding the capital/delivery stage of construction projects (Figure 3.5). The standard's main focus is on developing a Project Information Model (PIM) that contains all the graphical and non-graphical data along with the project documents from both design and construction stages, thus, the model will support in transferring accurate as-built information from the Capital Expenditure (Capex) phase to the Operation Expenditure (Opex) phase for lifecycle facility management assessment.

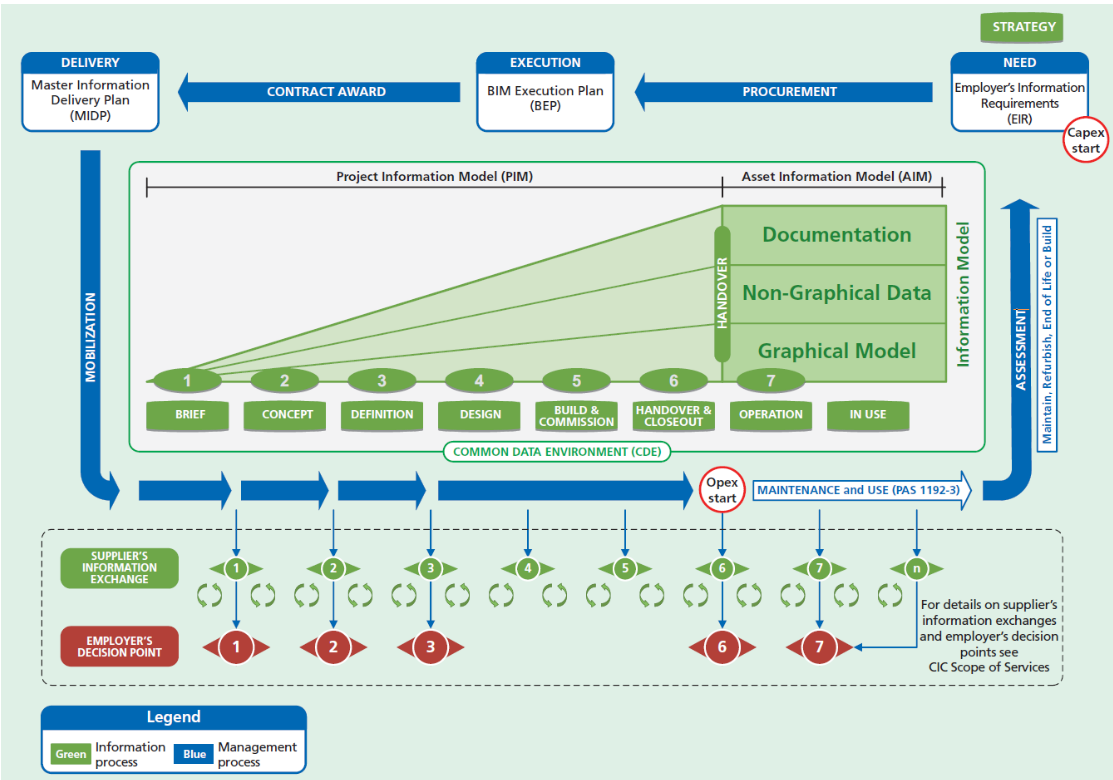


Figure 3.5: The Information delivery cycle (PAS, 2013)

In addition, the diagram in (Figure 3.5) illustrates how the Information delivery cycle starts by identifying the project's need and the Employers Information Requirements (EIR) which will then be developed into a BIM Execution Plan (BEP) and a Master Information Delivery Plan (MIDP) following procurement and contract award management. Subsequently, the mobilization and Common Data Environment (CDE) will be in progress representing the generation and production of asset information. However, the main processes of this information delivery cycle are discussed in detail in the following sections.

3.5 Employers Information Requirements (EIR)

According to PAS (2013) the Employer's Information Requirements (EIR) is a pre-tender document that forms the basis of any BIM process. However, the owner of any construction project will mainly require improvements in seven key areas including decision making, contract documentation, pre-construction estimation, procurement and scheduling, coordination, cost efficiency and close out documentation.

In addition, the BIM Task Group (2015) sets out comprehensive guidelines for generating a document that addresses the Employer's Information Requirements (EIR) which are divided into three main categories covering technical, management and commercial requirements (Table 3.1).

Table 3.1: Employer's Information Requirements (BIM Task Group, 2015)

Technical	Management	Commercial
• Software Platforms • Data Exchange Format • Co-ordinates • Level of Detail (general) • Level of Detail (components) • Training	• Standards • Stakeholder Roles and Responsibilities • Planning the Work and Data Segregation • Security • Coordination and Clash Detection Process • Collaboration Process • Model review meetings • Health and Safety and Construction Design Management • System Performance Constraints • Compliance Plan • Delivery Strategy for Asset Information	• Timing of data drops • Clients Strategic Purpose • Defined BIM/Project Deliverables • BIM-specific competence assessment

Furthermore, the PAS 1192-2:2013 standard (PAS, 2013) proposes the main features that should be included in the EIR document as follows:

6.5.1 Information Management

This part of the process is considered to be the basis of any BIM project as it defines the data segregation and work plans including the management of the model and naming conventions.

In addition, the required levels of information detailing (LOD) to be submitted at specified stages of the project are outlined by this process along with the training, coordination and clash detection requirements.

Moreover, the information management aspect embraces the client's requirements for bidders' proposals regarding the management of the coordination, collaboration and health and safety processes.

On the other hand, several schedules are also mandated to manage the information models like security and integrity, exclusions & inclusions, limitations of the model file size and software formats with the formats of any outputs.

6.5.2 **Commercial management:**

In this category a breakdown of all the work stages is required with the arrangement of data exchange points and expected outcomes. In order to achieve that, a responsibility matrix should be generated to define the responsible parties for providing and producing the required information according to the specified project stages.

In addition, schedules of the applied BIM standards and protocols should be provided as well as any modifications to the typical responsibilities, capabilities, authorities and positions as per the contract.

6.5.3 **Competence Assessment**

This third group of requirements mainly defines the capability assessment of bidders and the BIM tendering assessment with any amendments to the related tender documents.

In addition to all the above and according to PSU (2013), there will be a huge reduction in the time and cost of generating the facilities management system and an improvement in model maintenance when specifying the required information and the submission format by the employer.

3.6 BIM Execution Planning (BEP)

According to CIC (2013), a BIM Execution Plan (BEP) is believed to be the essential coordinating document that outlines the process of implementing BIM within a company or an organization by providing a solid BIM adoption approach starting from the early design stage of projects.

As soon as the BIM Implementation Plan is defined, the Execution Plan should be generated in order to control the project. This plan will mainly reflect the responses to the Employer's Information Requirements such as detailing the exchange of information between the team members and the required data drops at the defined project stages, thus, the plan will differ from one project to another as per its specific methodology and targets. However, BIM execution needs a lot of planning and key modifications to the traditional business-as-usual processes with continuous tracking in order to ensure that the project is achieving its targets and check for any opportunity to improve the efficiency of the process to maximize the value of the information model.

As proposed by CIC (2010), the development of a project BIM Execution Plan can be divided into four main steps starting with the identification of the BIM goals and uses then designing the process of BIM execution and specifying the deliverables followed by addressing the required resources for implementing the plan (Figure 3.6).

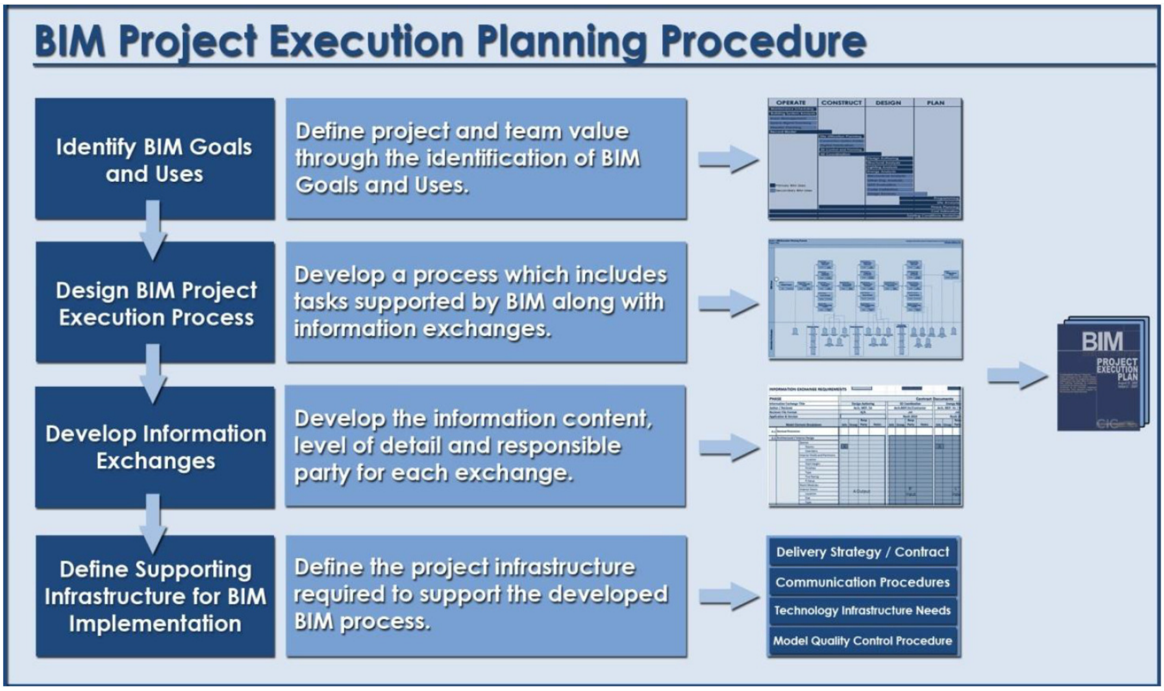


Figure 3.6: BIM Project Execution Planning Procedure (CIC, 2010)

However, a BIM execution plan can be developed using specific process mapping starting with a high level map that defines the structure and relations between the main BIM uses like site analysis, energy simulation and cost estimate (Figure 3.7). This can give the team members a clear idea about their tasks and the interaction between processes performed by them and other downstream and upstream parties identifying high level information exchanges during the project lifecycle.

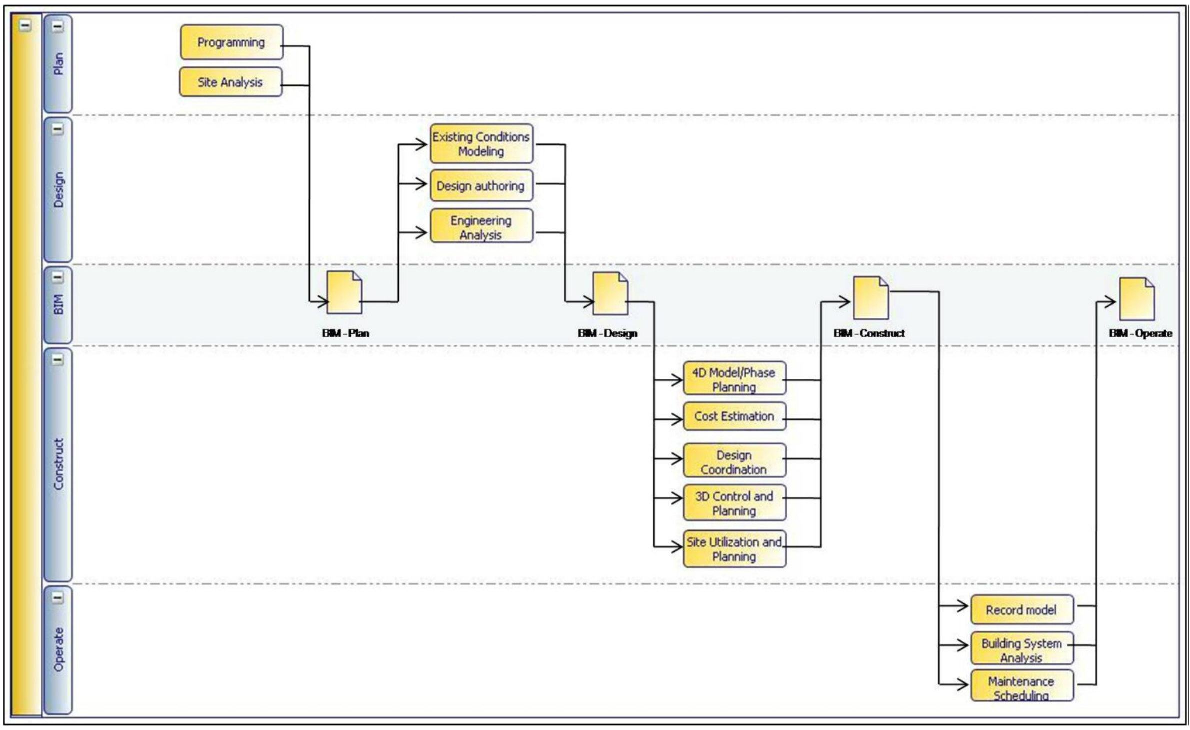


Figure 3.7: An example of high level BIM Process Map (RICS, 2014)

As soon as the main workflows are specified by the high level maps, the next step would be defining the second level processes (Figure 3.8) which will add further details regarding BIM uses and the roles and responsibilities of each involved party alongside standards and protocols of information exchange.

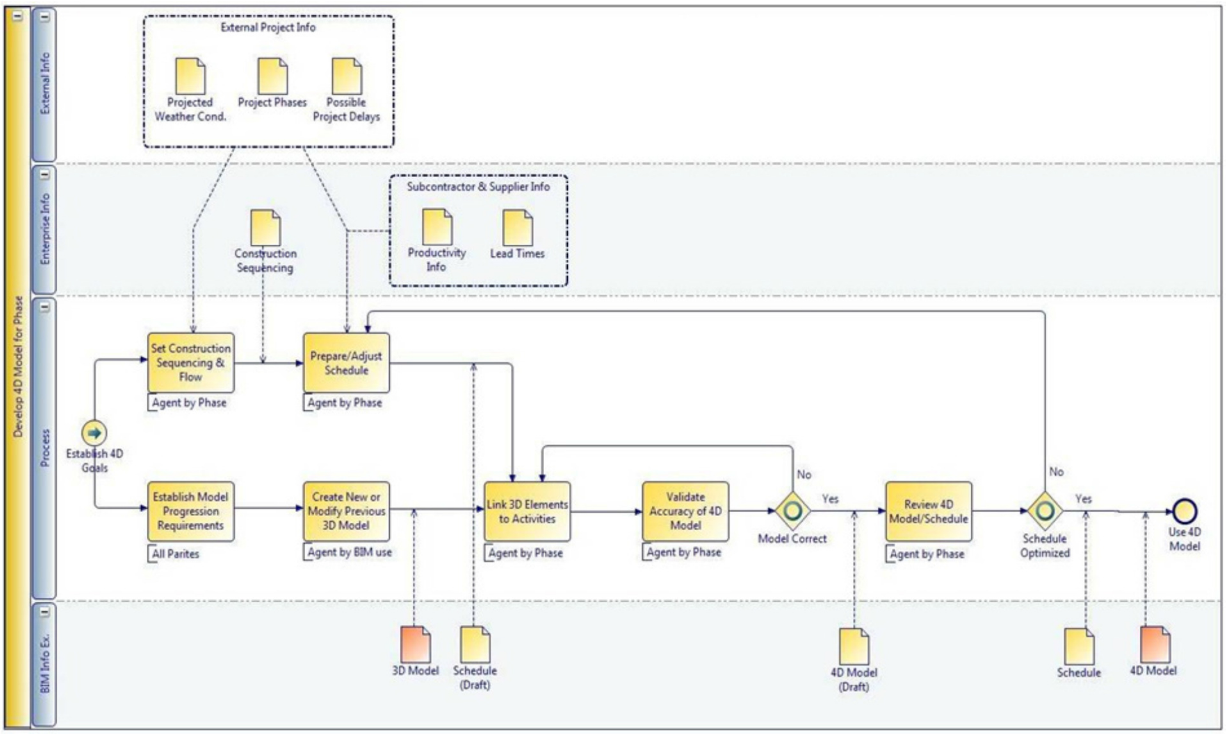


Figure 3.8: 4D model development – process map (RICS, 2014)

In addition, this type of process mapping would improve the quality of the BIM execution process by enabling project teams to reduce functions overlaps and rework by organizing the information exchange in the most efficient workflows.

Furthermore, Teicholz (2013) emphasizes that a BIM Execution Plan should address the transfer of key data of spaces, equipment, systems, finishes and zones from the information model to the Facility Management (FM) systems like Computer Maintenance Management Systems (CMMS) and Computer Aided FM (CAFM) systems (Figure 3.9). This will support in obtaining more accurate asset information in less time and effort, which will optimize the performance and reduce the operations and maintenance cost of an asset (BIM Task Group, 2015).

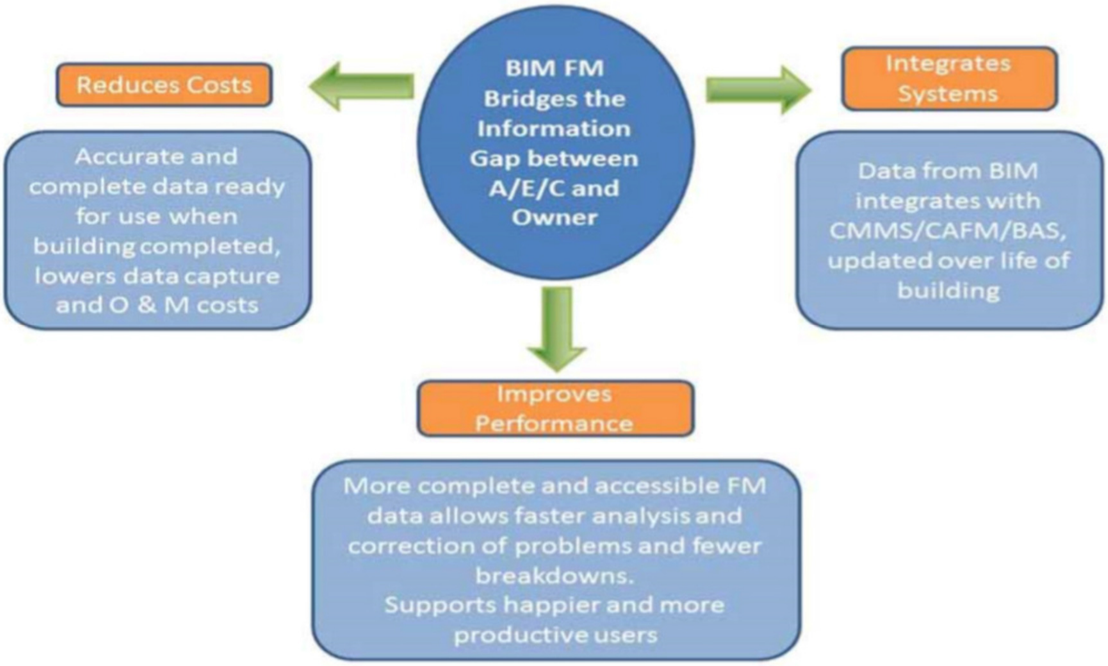


Figure 3.9: Benefits of BIM & FM Integration (Teicholz, 2013)

3.7 Construction Operations Building Information Exchange (COBie)

Construction Operations Building Information Exchange (COBie) is a global standard for managing and exchanging asset information during the different project stages especially the handover deliverables that support the operation and maintenance activities during the asset lifecycle (NBIMS, 2007). It mainly defines structured and unified non-graphical data (Figure 3.10) based on a specific spread sheet that can be easily utilized by any facility owner or operator for the post-occupancy asset management without the need for advanced IT capabilities.

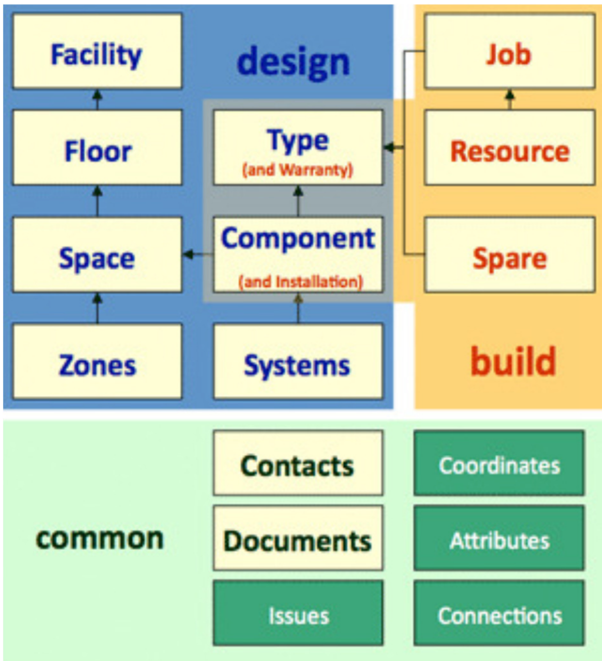


Figure 3.10: COBie Structure (www.wbdg.org)

The COBie approach requires the involvement of all the project parties in collecting the asset information progressively at specific project stages called the data drops (Figure 3.11) and then sharing the data through an open format database throughout the entire facility lifecycle.

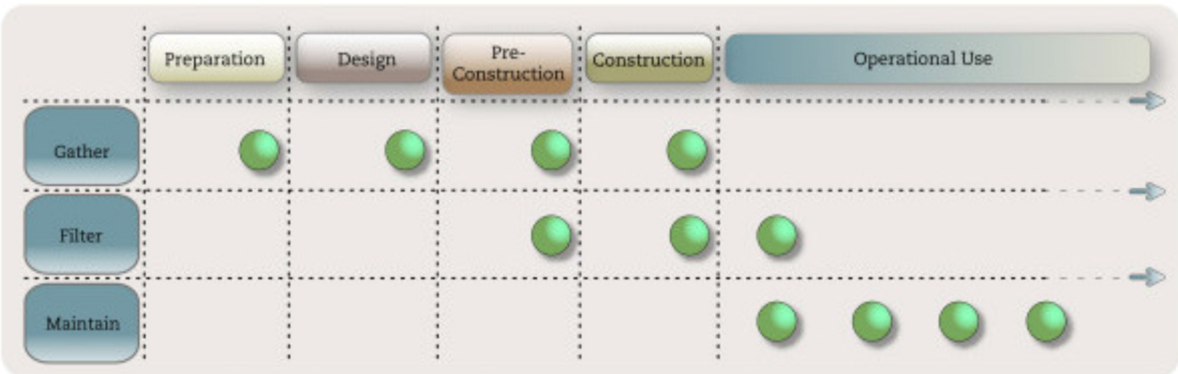


Figure 3.11: COBie data drops throughout a projects lifecycle (Fmmagazine 2013)

Generating and developing COBie for a project can be a time consuming process if applied by manually inserting the data within the spreadsheet. However, there are more efficient approaches to achieving this by either extracting the data directly from the BIM file to a COBie compatible file or using an Industry Foundation Class (IFC) file to export the well-structured data sets. Using a special COBie compatible software can be the most user friendly method but it has the negative aspect of adding extra cost to the process and tie it to a specific software vendor (Kasprzak and Dubler, 2012). Besides, although some particular software applications are offering a high level of interoperability, a significant amount of time and effort is still needed to manually adjust, import and export the data to the facility management systems.

3.8 Industry Foundation Class (IFC)

Industry Foundation Class (IFC) is an open data schema that is developed by the buildingSMART alliance in order to improve interoperability and support the information exchange among different software applications those are used by multiple parties throughout an asset lifecycle (buildingSMART, 2015). In addition, IFC is considered as a neutral non-exclusive data model which is independent of any particular software vendor, therefore, it is being used as a standardize specification for BIM model maintenance.

3.9 International Framework for Dictionaries (IFD)

According to Eastman et al. (2011), International Framework for Dictionaries (IFD) is a mean to standardize the BIM data and unify the terms internationally which allows for a global utilization of any BIM project. IFD generates a dictionary or a directory of items that represent comprehensive asset lifecycle information and manage them in a multilingual classification that provides consistent definitions for all building terminologies allowing every user to understand and utilize the content of the model during the lifecycle of the facility.

3.10 BIM and Interoperability

According to Fallon and Palmer (2004), interoperability is the capability to manage and exchange project's electronic data across all the systems between cooperating companies and within individual firms, thus, the value addition of BIM can only be recognized when using a technology that enables that level of collaboration. This can be achieved through two methods, the first is to use a single software package provided by the same vendor, e.g. Autodesk and Bentley. The second method is to utilize a standard data model like the IFC (Industry Foundation Class) which is a neutral open file format specification that is not controlled by a single vendor or group of vendors. However, the first scenario is preferable as it is less complicated and it minimizes the required time and potential errors while transferring the data (Eastman et al., 2011)

Inadequate Interoperability contributes to almost two-thirds of a lifecycle cost of an asset (Jordani, 2010) with more than 50% of that additional cost coming from the inefficient operations and maintenance due to poor quality and insufficient data exchange (Teicholz, 2013). Therefore, innovative BIM process workflow is needed to facilitate a sustainable lifecycle management that achieves sustainability and environmental targets while reducing the cost of energy and FM activities through the exchange of well-structured high-quality asset data.

In order to avoid the interoperability issues, the buildingSMART alliance has initiated a standard called the Information Delivery Manual (IDM) which specifies in detail the required lifecycle information exchange process and defines what and when each piece of that information need to be exchanged and the stakeholder who should be providing it (buildingSMART, 2015). In addition, if the IDM approach is applied properly it will significantly increase the efficiency of design and construction activities and support in achieving the targeted benefits of BIM while enabling data reuse and configuration for meeting national, local and asset requirements.

As illustrated in (Figure 3.12), the IDM process architecture consists of multiple layers of elements including the reference processes and process mapping at the top layers, data progression and exchange requirements in the middle, and software applications at the bottom layers.

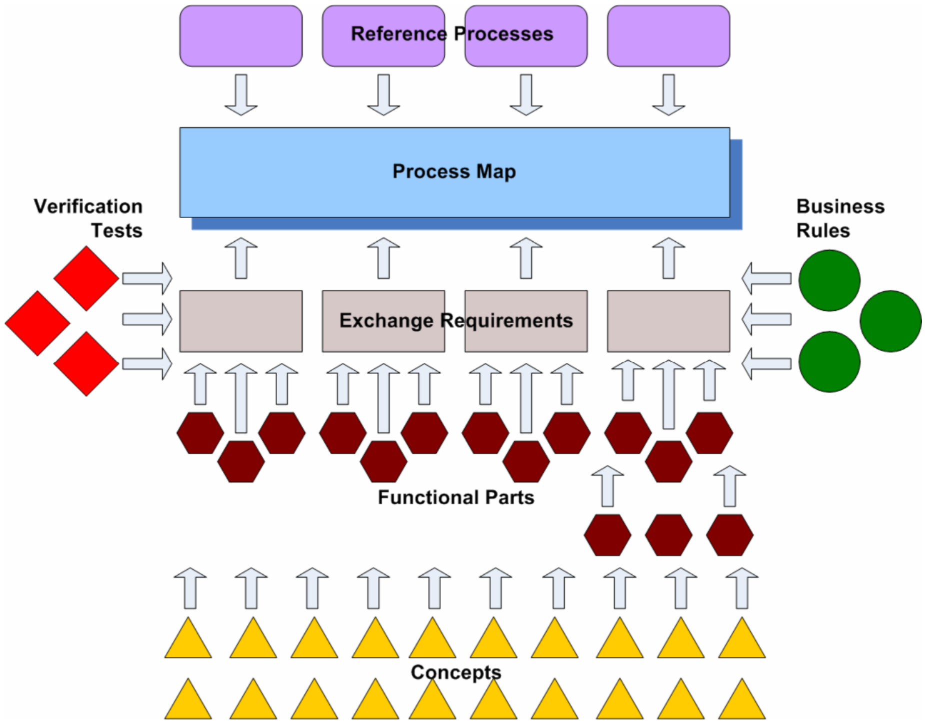


Figure 3.12: IDM technical architecture (buildingSMART, 2013)

However, technological support is needed in order to utilize an IDM without facing any interoperability issues while sharing the data (Berard and Karlshoj, 2011). This can be achieved through the integration of IFC as a data exchange format, IFD as a general directory of asset components and IDM as an integrated delivery process standard (Figure 3.13)

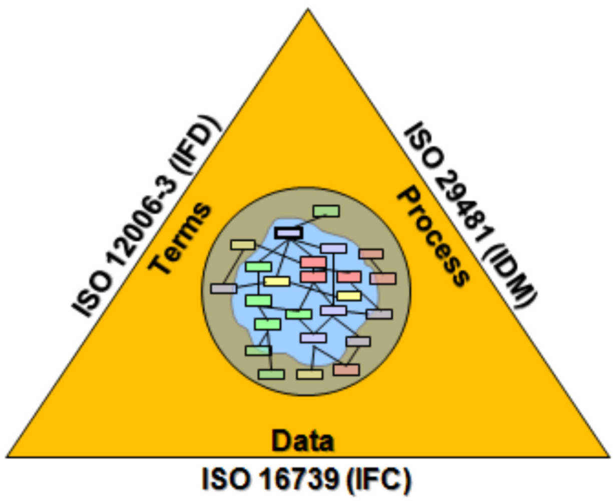


Figure 3.13: Interoperability solutions (buildingSMART, 2013)

As a result, improving the interoperability through the application of COBie, IFC, IFD and IDM will support in BIM implementation through the project stages and significantly reduce the lifecycle cost of the process especially at the operations and maintenance phase (Figure 3.14).

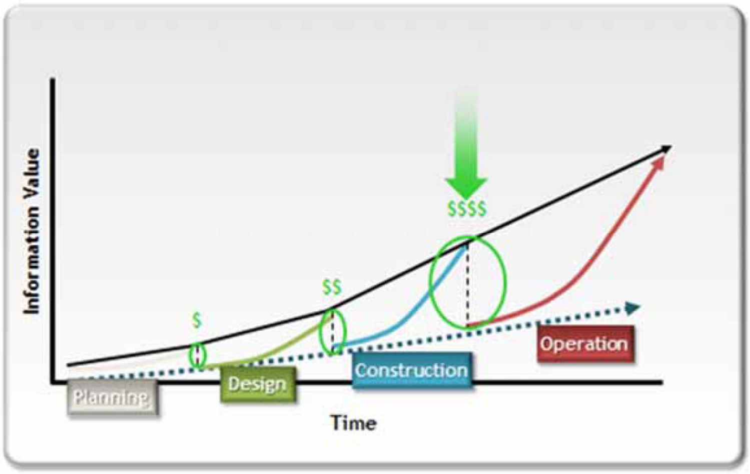


Figure 3.14: Interoperability impact of lifecycle costing (Teicholz, 2013)

3.11 Methodology of developing an Integrated BIM Process

Developing an Integrated BIM process requires a detailed information management procedure which involves the identification of important project stages, participants, project goals and how BIM will be used to achieve these goals.

The vital steps of creating an Integrated BIM Process are defined as follows:

- Identifying every phase of the proposed process per project delivery stage and Level of Development (LOD);
- The allocation of possible BIM utilization in each phase;
- The designation of responsibilities to the involved parties;
- Identifying specific process inputs and outputs as per the project information requirements in order to generate a detailed process map.

As illustrated in (Figure 3.15), this process should start by addressing all the project targets including the client's requirements, governmental regulations and any other specific standards or protocols. However, the best strategy to control these requirements would be to generate a comprehensive information management tool for organizing and tracking the required activities during the project progress.

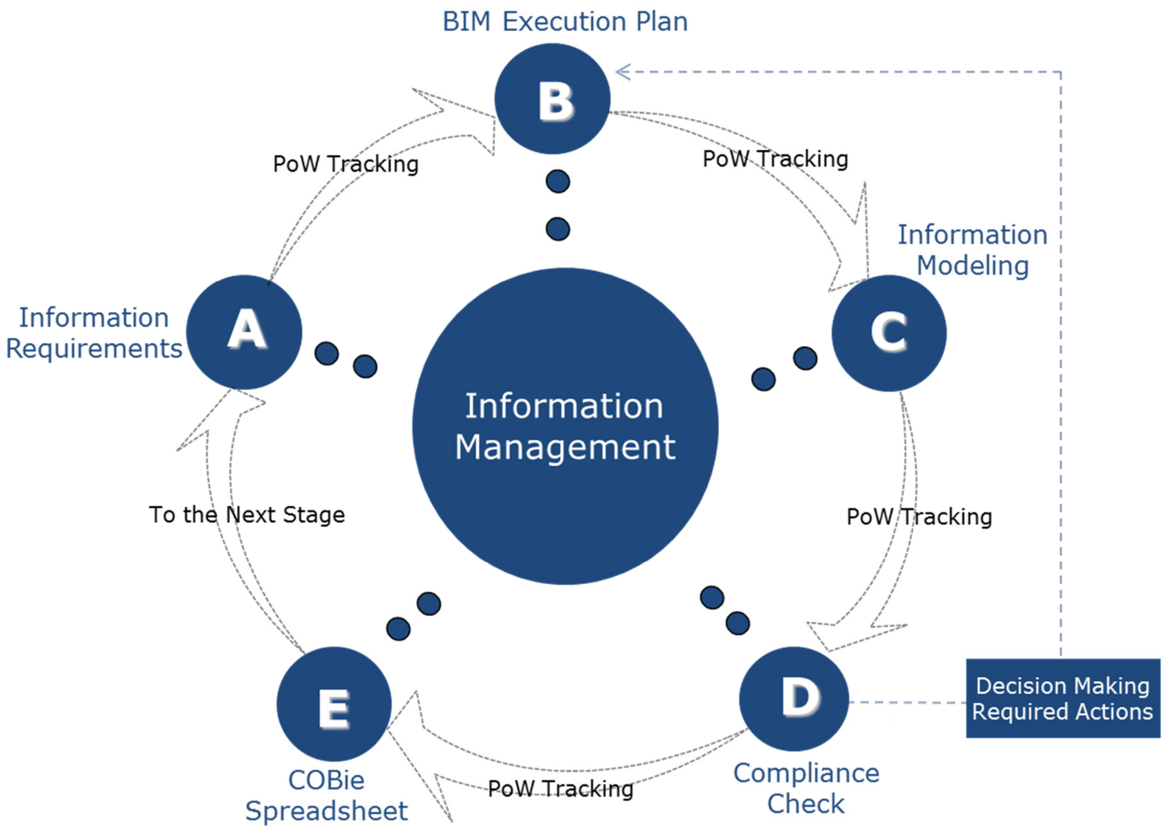


Figure 3.15: The concept of developing an Integrated BIM process

After the analytical activities have been completed, specific Level 2 BIM process maps should be developed using the CIC BIM Project Execution and Planning Guide (CIC, 2010) which will provide standard visual communication (process diagram) that allows users to know the internal and external business procedures related to each Level of Development (LOD).

In addition, these process maps will form the basis of the BIM Execution Plan (BEP) that will guide the project team through the implementation and information modeling procedures following the adopted standards and protocols. Furthermore, the plan should also include specific checkpoints using a real-time evaluation mechanism for assessing the compliance with project requirements within the modeling context and defining the required actions at each project stage. Following the verification of those checkpoints, the Integrated BIM process should facilitate the handover of the accurate project data from the information model to the COBie spreadsheet which would be the main reference for the final project information.

3.12 Conclusion

It is vital for implementing a BIM process to have a clearly defined BIM goals and uses in the project from the early design stage as per the project's targets and requirements. This step requires the involvement of all the team members as part of the Integrated Project Delivery (IPD) approach, which guarantees that all parties are on the same page before starting the execution phase.

In addition, the roles and responsibilities of each involved party should be explicitly identified, assigned and detailed while ensuring that the adopted information exchange protocols and standards have been addressed to the accurate Level of Development (LOD) as per the project requirements and in a useful and easily understood form. This would provide detailed specifications of the exchanged data during the project evolution and facilitate the development of informative building models using advanced BIM software application.

Therefore, a comprehensive information management and tracking worksheet is needed in order to be utilized as a one source of information that defines the roles and responsibilities, data exchange requirements, LOD and responsible team members for each exchange during all the project stages. This would guarantee an efficient interdisciplinary or inter-organizational data transfer for different project workflows by clarifying what, when, who and how data should be exchanged.

Chapter 4: LEED V4 and Life Cycle Assessment

4.1 Leadership in Energy and Environmental Design (LEED) version 4

The Leadership in Energy and Environmental Design (LEED) version 4 is a rating system for designing, constructing, operating and maintaining green buildings. It has been developed by the U.S. Green Building Council (USGBC) so as to promote sustainability practices and environmental awareness within the construction industry.

In the previous versions of LEED, each of the materials and resources (MR) credits has considered only one characteristic of the materials impacts like regional, rapidly renewable or recycled content. Although these characteristics are essential, they separately reveal only a single part of the total impact of a material or product which may satisfies one of the credits while performing poorly in the others (NRMCA, 2014).

However for the purpose of this study the focus will be on the new LEED version 4 (v4) MR credits which attempt to achieve a comprehensive evaluation of materials impacts through life cycle assessment (LCA) and environmental product declarations (EPD).

The first considered LEED V4 credit is the MRc1 (option 4) which provides 3 credit points and requires a whole-building Life-Cycle Assessment (LCA) addressing the building's structural and enclosure elements.

4.2 What is a Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is an analytical approach for measuring and defining the impacts of a product on the environment (Athena, 2014). It can be utilized during the product manufacturing stage or the design stage when a certain level of improvements for impacts reduction is required. In addition, the analysis can be applied through the complete project lifecycle including all the building products in order to generate a "whole-building LCA" which helps for better decision making especially when it comes to materials selection and specification. A good example of that is the installation of more insulation material in the building envelop which increases the immediate impact of building materials but, on the other hand, it will significantly reduce the energy consumption of the facility during its lifecycle.

In addition, different approaches for defining appropriate life cycle stages can be considered in order to allow for a building level LCA (Figure 4.1).

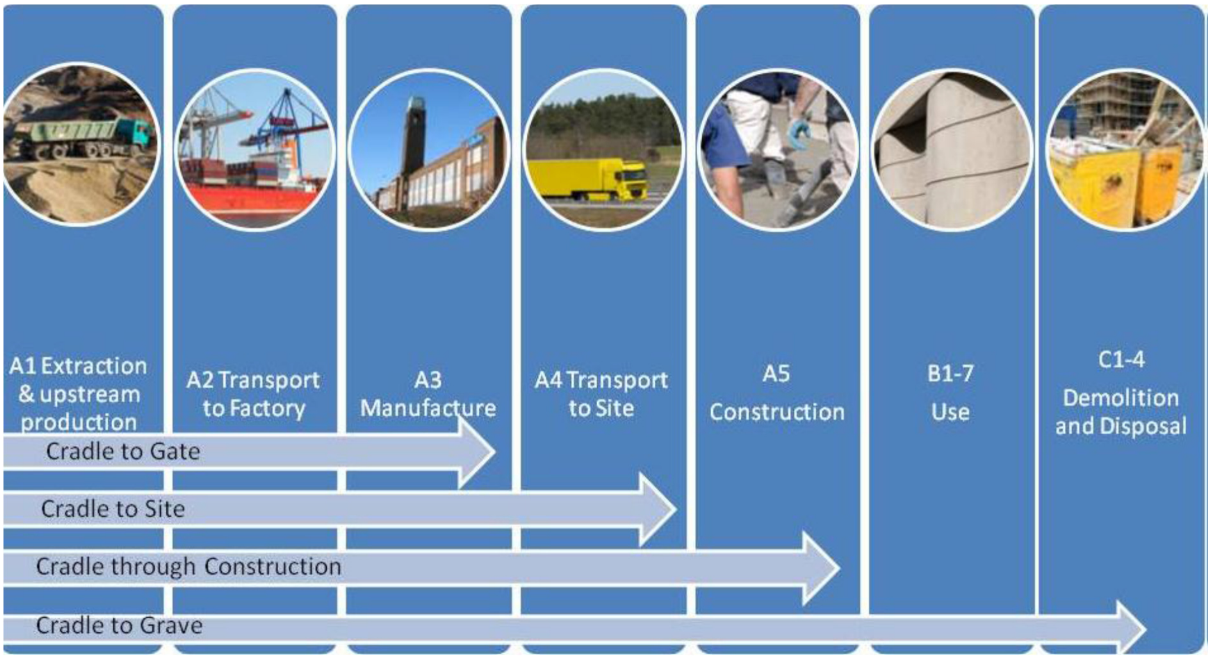


Figure 4.1: Life Cycle Stages (EPD, 2015)

As per LEED V4 MRc1, the whole-building Life-Cycle Assessment (LCA) should be based on six environmental impacts categories as follows:

Global Warming Potential (GWP): the possible effect of greenhouse gases like Carbon Dioxide (CO_2) on the climate change measured as an equivalent kilograms of CO2 emission over a 100-year period.

Ozone Depletion Potential (ODP): the relative impact on the stratospheric ozone layer measured as an equivalent kilograms of trichlorofluoromethane (CFC-11) emission over a 100-year period.

Acidification Potential (AP): the increment of soil and water acidity levels measured in kilograms of Sulphur Dioxide (SO2) equivalent or moles H+.

Eutrophication Potential (EP): the impact on marine habitats caused by nutrients-rich substances especially the ones containing nitrogen and phosphorus measured in kilograms of (N) or kilograms of (P) equivalent.

Photochemical Ozone Creation Potential (POCP): also referred to as summer smog, is the formation of Ozone (O_3) from volatile organic compounds (VOCs), Carbon Monoxide (CO) and Nitrogen Oxides (NO_x) in the presence of sunlight and it is measured in kilograms of (O_3) equivalent, (No_x) or (C_2H_4).

Non-Renewable Primer Energy Consumption (nPE): the total energy consumed through the considered LCA stages and not generated from renewable resources measured in Mega joule (MJ).

In addition, the credit requires an LCA comparison between the proposed building and a benchmark building in order to verify the compliance with the required 10% reduction in the global warming potential along with at least two of the other five environmental impacts, whereas none of the remaining three categories is increased by more than 5% (Figure 4.2).

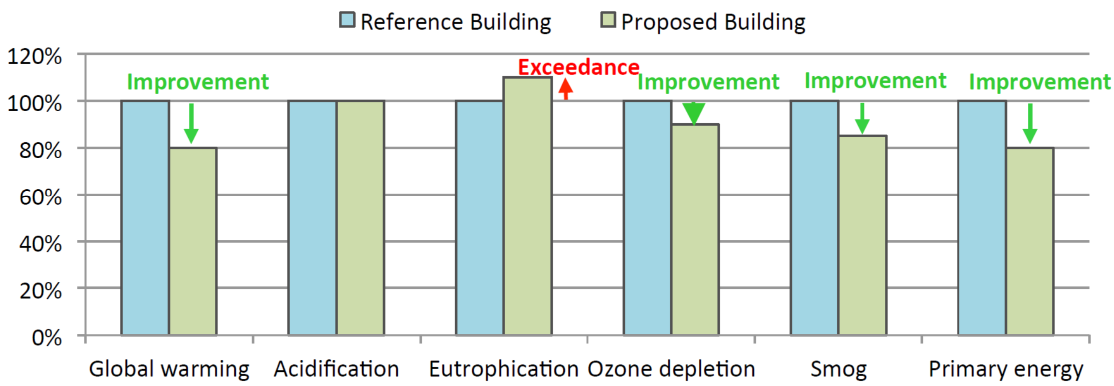


Figure 4.2: LCA comparative concept (NRMCA, 2014)

However, achieving the required whole-building life-cycle assessment as per MRc1 is quite related to MRc2 that addresses the environmental impacts of the building products which form the basis of a whole-building LCA.

LEED v4 MRc2 provides 1 credit point for its first option “products disclosure” which requires the project to include at least 20 products with Environmental Product Declarations (EPDs), on the other hand, the second option of the credit “products optimization” requires that at least 50% of the products - by cost - have less environmental impacts comparing to industry benchmark values. LEED v4 assign values to the different products in a project according to three different categories of EPDs as follows:

- Products with self-declared EPDs which are not verified by a third party worth ¼ value.
- Products with industry average EPDs which are verified by a third party worth ½ value.
- Product Specific EPDs which are verified by a third party worth full product value.

Furthermore, LEED v4 defines a "product" according to its specific use and characteristics which means that some materials-especially concrete-has the advantage of contributing to more than one product because of its wide range of applications and uses starting from the footings and foundations all the way up to columns, beams and slabs. Hence, each concrete use with a particular mix design would be counted as a unique product as per LEED v4. Therefore, concrete can have a significant contribution to the required 20 product values and the 50% compliant products' cost used in a project.

4.3 What is an Environmental Product Declaration (EPD)

The Environmental Product Declaration (EPD) is considered as a product classification which is similar to the nutrition label, but instead of showing the nutrition facts it provides information regarding the environmental impacts of a product like GWP, ODP, AP…etc. (Figure 4.3). An EPD is usually generated by the product manufacturer and released after being certified by an accredited 3rd party (EPD, 2015)

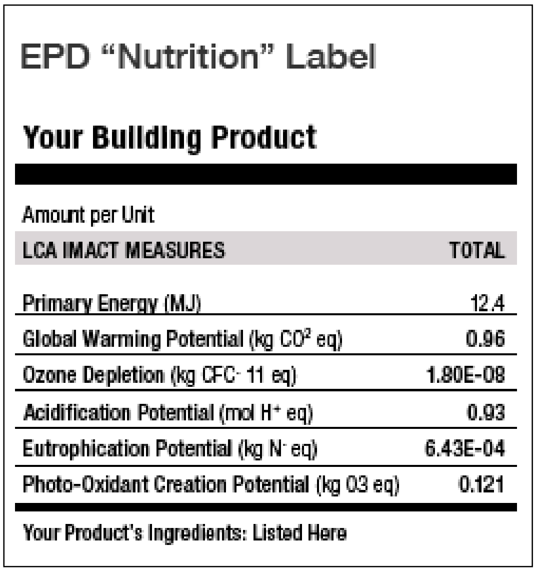


Figure 4.3: EPD as a "Nutrition" Label (Elixir, 2015)

According to the International Standards Organization (ISO), there are three types of EPDs depending on the level of 3rd party review and endorsement (Table 4.1). However, LEED V4 requires type III EPDs which are considered as "nutrition labels" for products and usually provided by the materials manufacturers.

Table 4.1: Types of Environmental Product Declarations (EPD, 2015)

Type	Standard	3rd party reviewed	3rd party endorsement	Description
I	ISO 14024	Yes	Yes	Eco-label
II	ISO 14021	No	Yes	Self-declaration
III	ISO 14025	Yes	No	"Nutrition" label

Furthermore, in order to produce an EPD the manufacturer should conduct a cradle-to-gate Life Cycle Assessment (LCA) on the material or product and include the results within the EPD. However, the development of the LCA should be according to specific Life Cycle Inventory (LCI) and Product Category Rules (PCR) which must be defined by an adopted international standard (Figure 4.4).

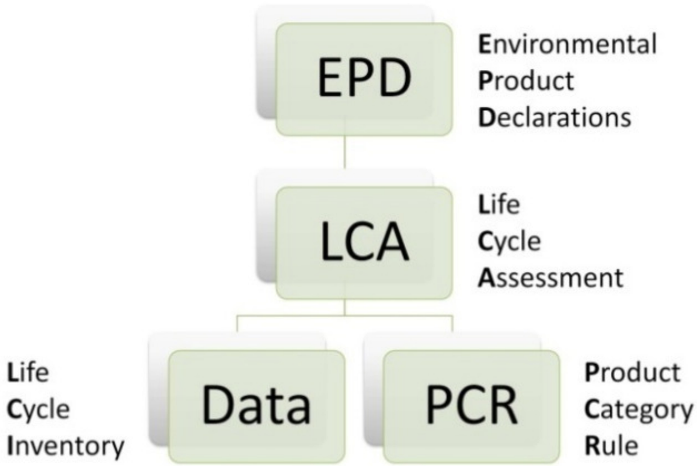


Figure 4.4: Steps of developing an EPD (EPD, 2015)

4.4 Life Cycle Inventory (LCI):

Life Cycle Inventory (LCI) is the first step of producing an EPD as it defines and quantifies all the inputs and outputs of a product during the considered life-cycle stages (EPD, 2015). It contains a list of all the raw materials used in the production process along with the extraction points and all the emissions related to a specific system. The inventory is generated by tracking all the used resources and accompanied emissions through the manufacturing supply chain "upstream" and the waste treatment process "downstream". However, the resulting data should be further analyzed through an Impact Assessment process in order to define the environmental impacts of the identified resources and emissions.

4.5 Product Category Rule (PCR)

A Product Category Rules (PCR) is a series of specific rules and instructions on how to develop the Life Cycle Assessment (LCA) in order to generate EPDs that are consistent and comparable throughout a product category. It is usually produced by industry associations to guarantee that manufacturers using the same PCR can develop EPDs which are precise, independently verified, reliable and applicable at the building or construction activities level to assess and compare various products taking into consideration their environmental impacts. Hence, the PCR mainly outlines the products to be evaluated, stages and limitations to the LCA and the considered environmental impacts.

4.6 Product Life-Cycle Assessment (LCA)

As soon as the LCI is finalized, the adopted PCR will be used to define the rules for conducting an Impact Assessment which characterizes the environmental impacts of the resources and emissions. For example if the emission type is carbon dioxide (CO2) then it will be classified as a Global Warming impact and characterized as per the GWP factor that is defined by the applied standard such as the Intergovernmental Panel on Climate Change (IPCC) Emission Factor Database (Table 4.2).

Table 4.2: GWP factors for the accumulated impact over 100 years according to the IPCC Assessment Reports (Pre, 2015)

Substance	AR1 (1990)	AR2 (1995)	AR3 (2001)	AR4 (2007)	AR5 (2013)
Carbon dioxide, fossil (CO_2)	1	1	1	1	1
Methane, fossil (CH_4)	21	21	23	25	28
Methane, biogenic (CH_4)	18.25	18.25	20.25	22.25	25.25
Dinitrogen monoxide (N_2O)	290	310	296	298	265
HCFC-141b	440	-	700	725	782
HFC-134a	1200	1300	1300	1430	1300
HCFC-22	1500	-	1700	1810	1760
HCFC-142b	1600	-	2400	2310	1980
CFC-11	3500	-	4600	4750	4660
CFC-12	7300	-	10600	10900	10200
Sulfur hexafluoride	-	23900	22200	22800	23500

In general, it is preferred that an LCA for a product would cover the whole life-cycle stages or what is called “cradle-to-cradle” (Figure 4.10). However, most of the products are reporting partial LCAs through raw material acquisition and manufacturing stages only

“Cradle-to-Gate” and sometimes with the site transportation impacts “Cradle-to-Site” as it is almost impossible to address the impacts during the installation, use and end-of-life stages which are usually minimal comparing to the production ones.

Moreover, although it is preferable that the data for conducting an LCA is sourced by the manufacturer, industry average data is available for some product types and can be utilized when the actuals are not available. However, prior to the publication of LCAs and the resulted EPDs they should be reviewed and verified by a 3rd party.

Chapter 5: Developing an Integrated BIM Process

5.1 RIBA Plan of Work 2013

It is vital for any construction project to identify the stages of work that it goes through during its progress. These stages are important for defining the main decision points and organizing project works.

RIBA Plan of Work 2013 is one of the best publicly available standards that can be utilized to arrange and manage project’s activities through organized key project stages. In addition, it defines the required tasks, inputs and outputs for every stage in order to satisfy the project goals. Therefore, it is an ideal tool for mapping Building Information Modeling (BIM) processes and integrating sustainable design requirements while providing flexibility and addressing all sorts of procurement regardless of the facility type and size (RIBA, 2013).

As illustrated in (Figure 5.1), the RIBA Plan of Work 2013 contains eight project stages represented by numbers from stage 0 to stage 7. In addition, it includes eight task bars which are divided into fixed and optional in order to ensure consistency and provide flexibility to generate a customized project specific plan of work.

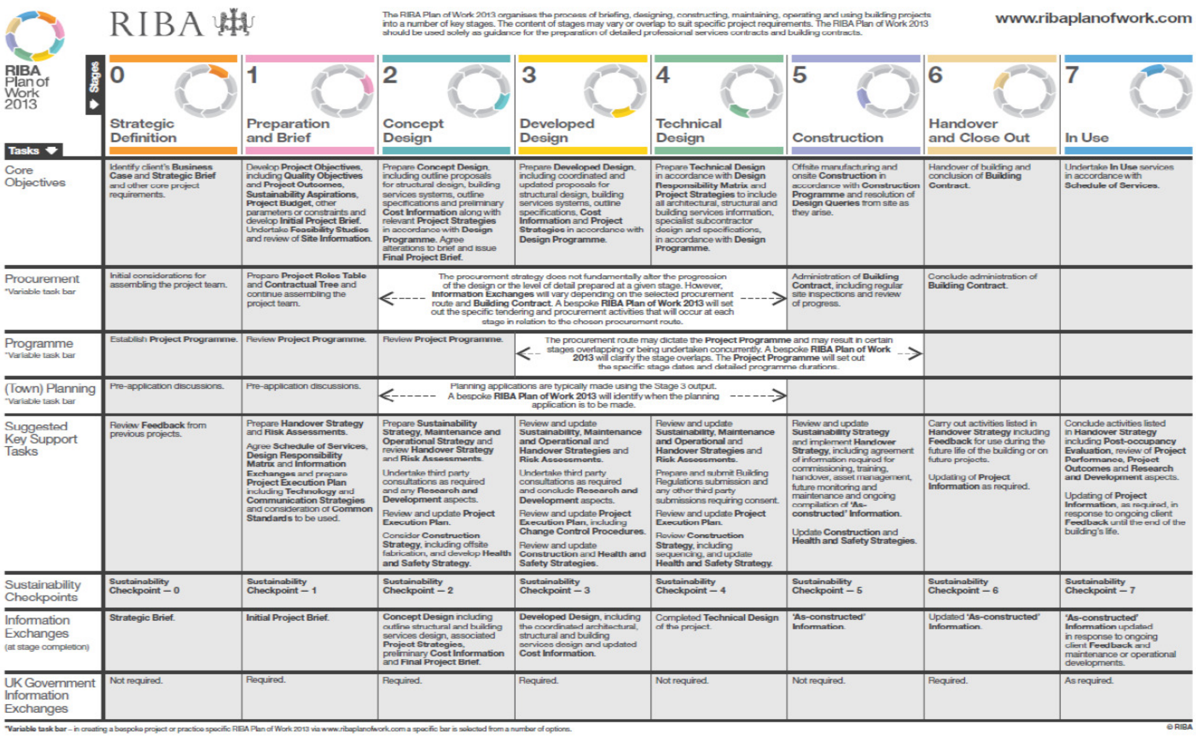


Figure 5.1: RIBA Plan of Work 2013 Template (RIBA, 2013); *refer to Appendix A for the high resolution Template.*

The first stage of the RIBA Plan of Work 2013 is Stage 0 ‘Strategic Definition’ which focuses on the strategic assessment and definition of the project and arrange for the ‘Preparation and Briefing’ tasks at stage 1.The next step of the design process is Stage 2 ‘Concept Design’ which is followed by the Stage 3 ‘Developed Design’ were the tasks would be preliminarily associated with cost information. In addition, the ‘Technical Design’ at Stage 4 covers the outstanding technical activities in order to finalize the design work by the main design team and any involved sub-consultant as per the Design Responsibility Matrix.

Furthermore, Stages 5-7 are more related to the contractor’s tasks. Stage 5 ‘Construction’ starts with defining the mobilization procedures and goes all the way through the construction activities to the practical completion of the project. This is followed by the ‘Handover and Close Out’ tasks in Stage 6 and the ‘Post-occupancy Assessment’ at Stage 7 where the operation and maintenance activities start.

On the other hand, each of the eight task bars of the RIBA Plan of Work 2013 outlines certain type of activities. The first task bar is fixed in any modified plan and it addresses the core objectives and main tasks for every work stage. The following three task bars cover the procurement, program and town planning activities and provide flexible selection process through a pull-down tasks list for producing a project specific version of the plan.

The tasks in the fixed task bar 5 provide a good management level and support in achieving the defined project objectives at each stage. They basically highlight the sustainability targets and carbon emissions reduction as well as the Building Information Modeling (BIM) requirements. Thus, these tasks are related to the legal requirements and regulations along with the standards, protocols and project roles and responsibilities. Consequently, the task bar 5 is directly connected to the Project Execution Planning and the Construction and Health and Safety Strategies.

In addition, the optional task bar 6 provides more specific details regarding the sustainability targets through multiple sustainability checkpoints. Furthermore, the information delivery guidelines at the end of each project stage would be usually defined within the fixed task bar 7 which also includes tasks for arranging the design responsibility matrix and services schedule incorporating Information Exchange (IE) requirements. However, the last task bar 8 is optional and it is more specific for complying with the U.K. Government Information

Exchange requirements. It outlines the steps for achieving data-rich information models that can be utilized during the operation and maintenance stage.

5.2 Integrated BIM Process

In order to develop an Integrated BIM Process, the RIBA Plan of Work was adopted and developed so it could be used as a one source of information requirements and as a tracking tool throughout all the project stages. The main modification to the plan was the incorporation of the Employer's Information Requirements (EIR) within the plan's sheets which ensures that the project is on the right track and the team is targeting the project specific goals and assigning the related tasks to the appropriate team members from day one. This was firstly indicated by adding the CIC Production and Delivery Table (PDT) (Figure 5.2) which forms along with the existing Project Roles Table (PRT) and Design Responsibility Matrix (DRM) a complete reference for project activities and associated responsible parties.

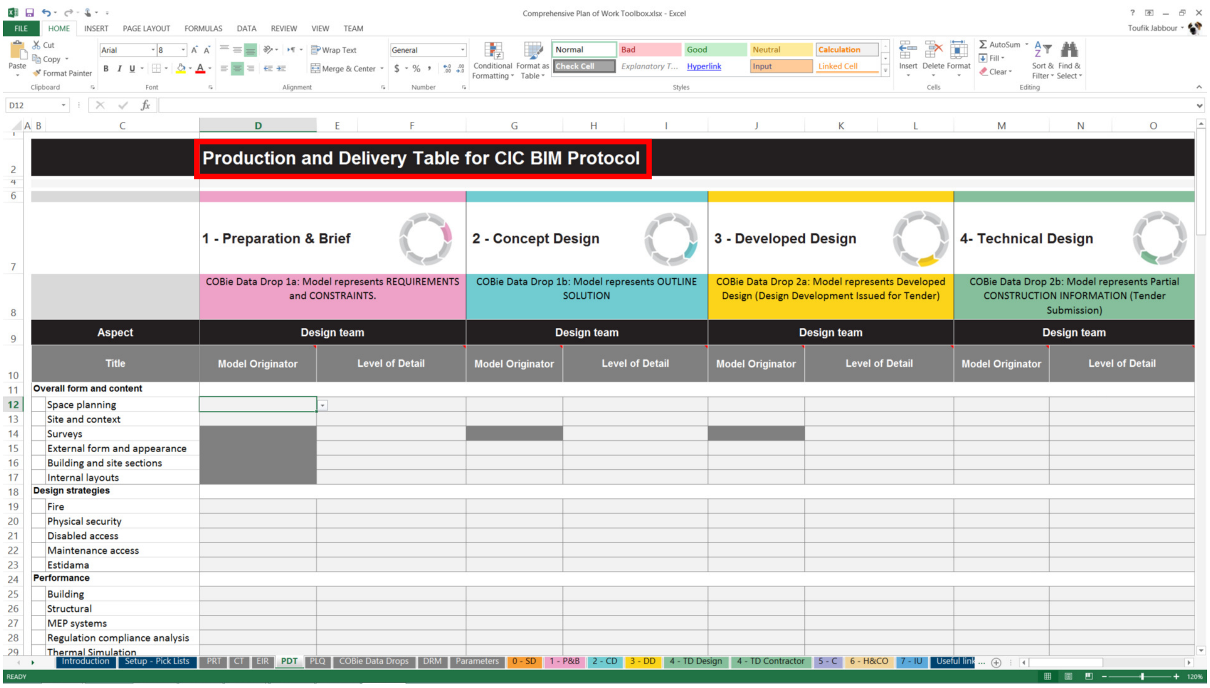


Figure 5.2: adding the CIC Production and Delivery Table (PDT) to the RIBA plan of work 2013

In addition, a specific sheet was also added including sets of plain language questions that need to be answered at each project stage (Figure 5.3). These questions and their related answers reflect the completion levels and support key decision making especially when moving from one stage to another.

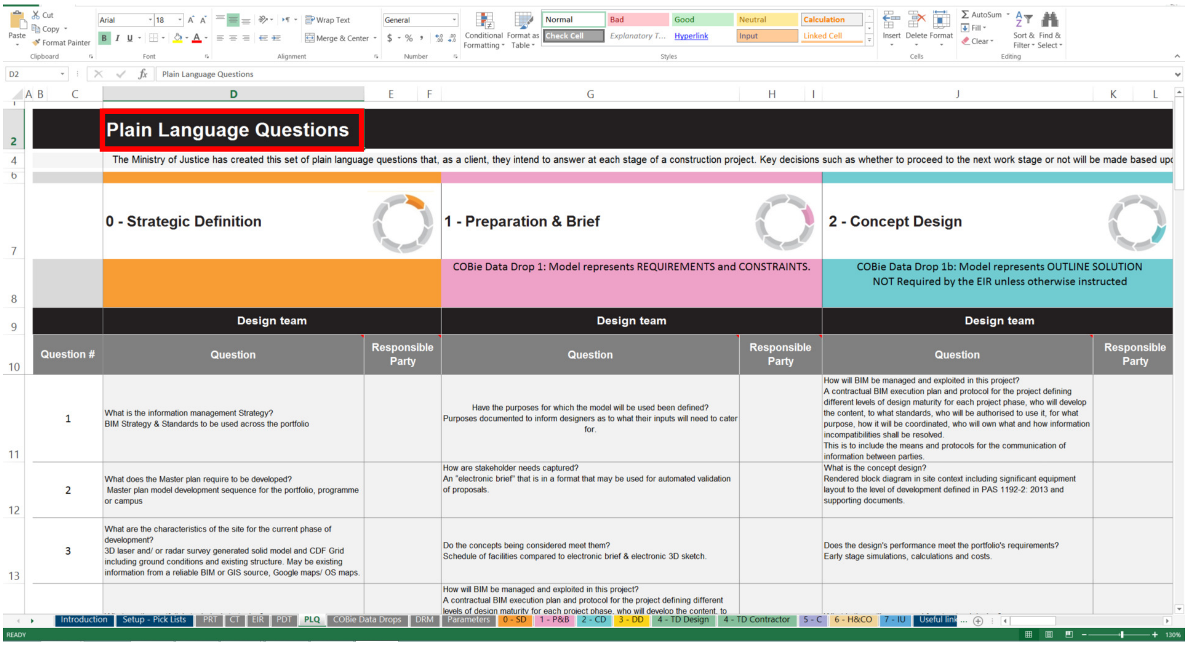


Figure 5.3: Adding the Plain Language Questions to the RIBA plan of work 2013

Furthermore, the required COBie data drops were added to the title of each applicable stage as to emphasize their importance and demonstrate the fundamental connection between the project evolution and data reporting through the COBie reporting tool. These data drops requirements were also detailed within a specific sheet in order to organize the process and make sure that the involved parties are aware of their responsibilities and the timeline for submitting the data (Figure 5.4).

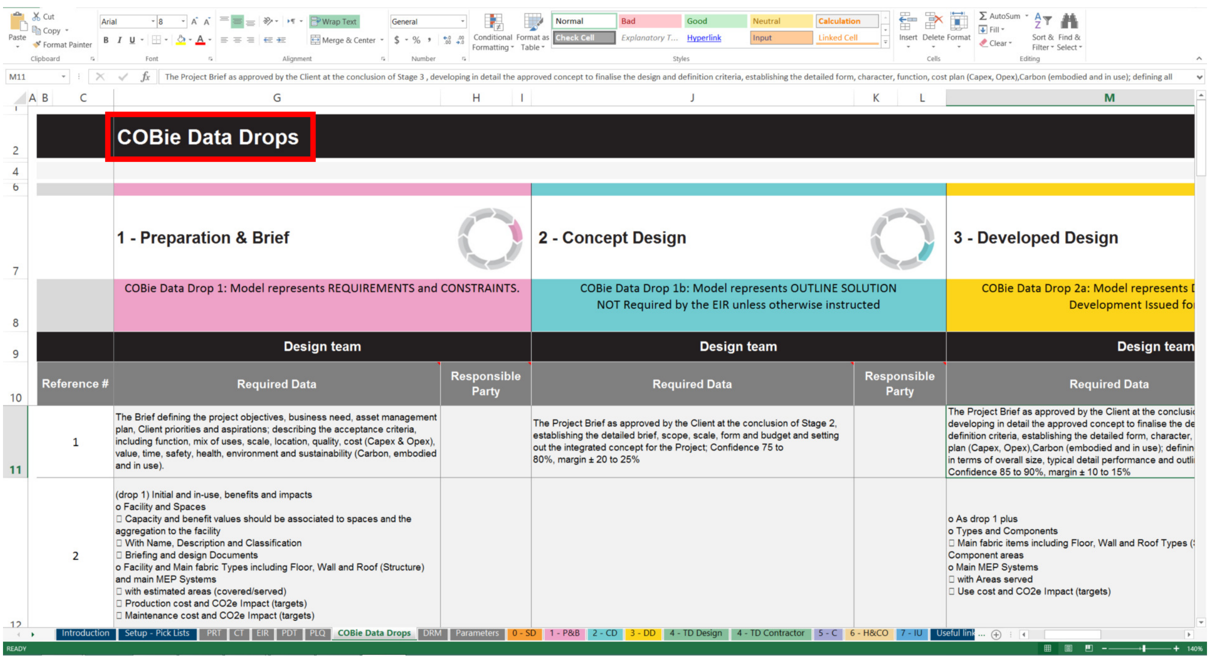


Figure 5.4: Adding the COBie data drops requirements to the RIBA plan of work 2013

However, besides the responsible party, all the listed project activities and required info were accompanied by a Level of Development (LOD) drop-down list in order to ensure that the data will be provided at the specific detailing and information level and avoid insufficient or overdetailed data submissions (Figure 5.5).

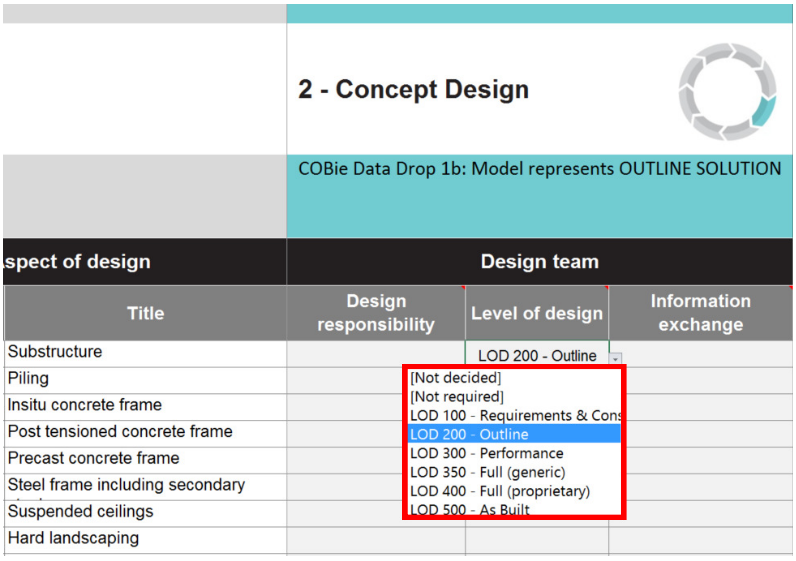


Figure 5.5: Level of Development (LOD) drop-down list

After addressing the project requirements and generating the comprehensive information management and tracking tool, the approaches for satisfying those requirements should be detailed and addressed within a BIM Execution Plan (BEP) which includes all the necessary guidelines and process maps.

Next, in order to start the modeling process, the BEP should include an interpretation of the plain language project information and required actions using a programming language that can be utilized to represent the data and check the compliance within the modeling context of the adopted software.

However, among all the available BIM software packages in the market, Autodesk Revit 2015 was selected for this study due to its unique capabilities and flexibility in adding project specific parameters and use them for developing special evaluation formulas within detailed information schedules. These parameters and formulas along with their required level of development and the responsible parties should be added to the developed information management and tracking tool and included in the BIM Execution Plan (BEP) as they will form the basis for starting the modeling with a real-time evaluation and compliance check within the Revit context.

Following the evaluation process and after conducting any necessary actions to the project's characteristics in order to achieve the requirements at each project stage, the final data should be exported and reported showing the compliance level of each project target. In addition, the resulting data should be distributed to the COBie spreadsheet which would be utilized as the main data reference during the subsequent stages and the project lifecycle.

However, due to the time limitation, this study would not be able to embrace all sets of project requirements when detailing the integrated BIM process. Therefore, and after reviewing the content of the developed information management tool, the significant importance of meeting the sustainability targets and reducing the environmental impacts of a facility was realized, thus, those requirements were considered to be the main focus of this research when demonstrating the development of the proposed Integrated BIM process.

As illustrated in (Figure 5.6), complying with the sustainability requirements as per the adopted green building standards is already addressed as a main target within the Plain Language Questions (PLQ) at the 'Concept Design' stage with a particular interest regarding the environmental impacts and CO2 emissions.

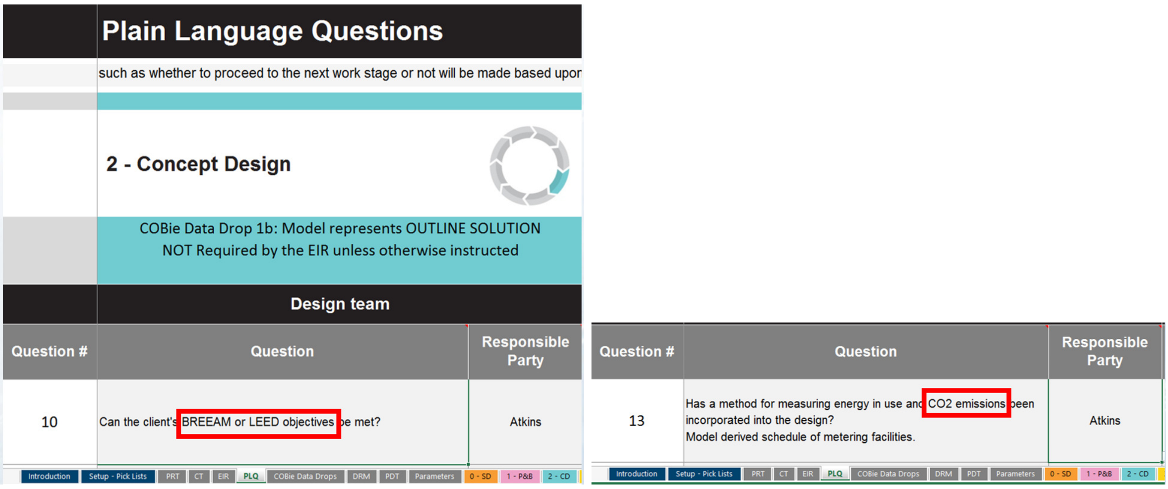


Figure 5.6: Sustainability requirements within the Plain Language Questions

In addition, the COBie data drops also require an early estimation and evaluation during the preparation stage regarding the sustainability targets and environmental impacts of the considered asset (Figure 5.7).

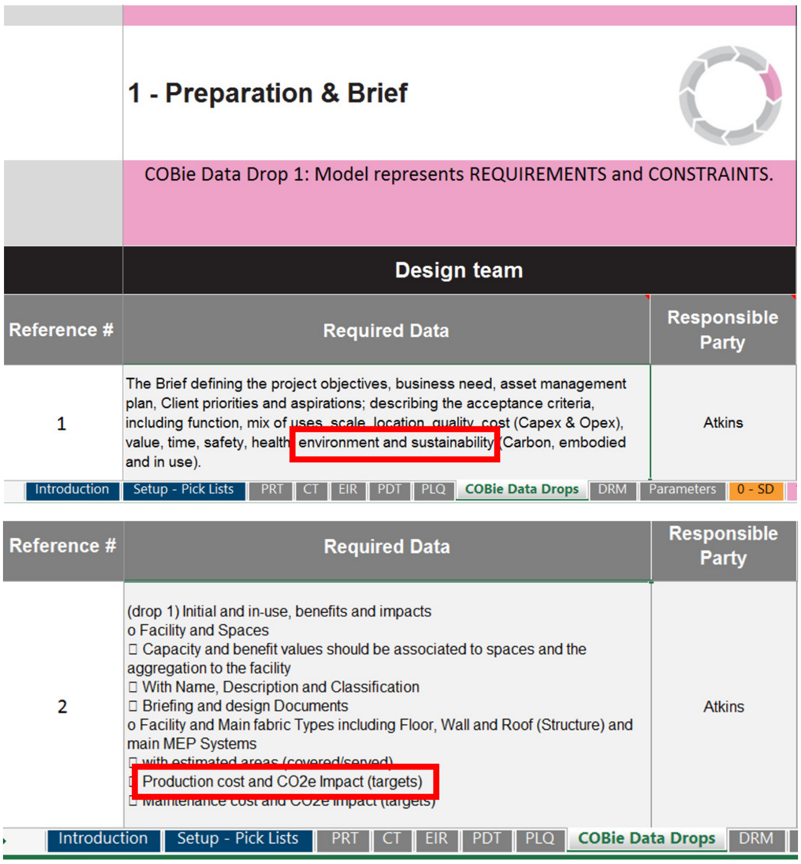
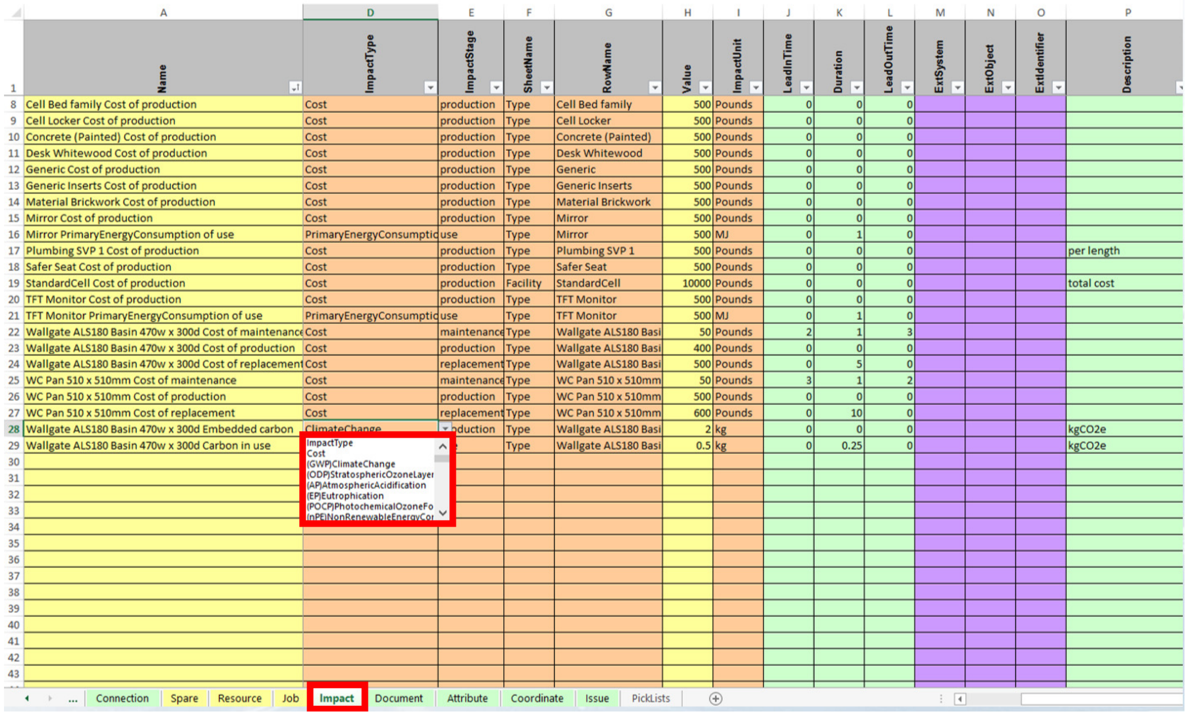


Figure 5.7: COBie Data Drop 1 sustainability requirements

Furthermore, an additional emphasis on the importance of addressing the environmental impacts of an asset has been demonstrated within the COBie spreadsheet which has specified a particular sheet that requires the project team to address all the environmental impacts of the listed building products as shown in (Figure 5.8).



	Name	ImpactType	ImpactStage	SheetName	RowName	Value	ImpactUnit	LeadInTime	Duration	LeadOutTime	ExtSystem	ExtObject	ExtIdentifier	Description
8	Cell Bed family Cost of production	Cost	production	Type	Cell Bed family	500	Pounds	0	0	0				
9	Cell Locker Cost of production	Cost	production	Type	Cell Locker	500	Pounds	0	0	0				
10	Concrete (Painted) Cost of production	Cost	production	Type	Concrete (Painted)	500	Pounds	0	0	0				
11	Desk Whitewood Cost of production	Cost	production	Type	Desk Whitewood	500	Pounds	0	0	0				
12	Generic Cost of production	Cost	production	Type	Generic	500	Pounds	0	0	0				
13	Generic Inserts Cost of production	Cost	production	Type	Generic Inserts	500	Pounds	0	0	0				
14	Material Brickwork Cost of production	Cost	production	Type	Material Brickwork	500	Pounds	0	0	0				
15	Mirror Cost of production	Cost	production	Type	Mirror	500	Pounds	0	0	0				
16	Mirror PrimaryEnergyConsumption of use	PrimaryEnergyConsumptic	use	Type	Mirror	500	MJ	0	1	0				
17	Plumbing SVP 1 Cost of production	Cost	production	Type	Plumbing SVP 1	500	Pounds	0	0	0				per length
18	Safer Seat Cost of production	Cost	production	Type	Safer Seat	500	Pounds	0	0	0				
19	StandardCell Cost of production	Cost	production	Facility	StandardCell	10000	Pounds	0	0	0				total cost
20	TFT Monitor Cost of production	Cost	production	Type	TFT Monitor	500	Pounds	0	0	0				
21	TFT Monitor PrimaryEnergyConsumption of use	PrimaryEnergyConsumptic	use	Type	TFT Monitor	500	MJ	0	1	0				
22	Wallgate ALS180 Basin 470w x 300d Cost of maintenance	Cost	maintenance	Type	Wallgate ALS180 Basi	50	Pounds	2	1	3				
23	Wallgate ALS180 Basin 470w x 300d Cost of production	Cost	production	Type	Wallgate ALS180 Basi	400	Pounds	0	0	0				
24	Wallgate ALS180 Basin 470w x 300d Cost of replacement	Cost	replacement	Type	Wallgate ALS180 Basi	500	Pounds	0	5	0				
25	WC Pan 510 x 510mm Cost of maintenance	Cost	maintenance	Type	WC Pan 510 x 510mm	50	Pounds	3	1	2				
26	WC Pan 510 x 510mm Cost of production	Cost	production	Type	WC Pan 510 x 510mm	500	Pounds	0	0	0				
27	WC Pan 510 x 510mm Cost of replacement	Cost	replacement	Type	WC Pan 510 x 510mm	600	Pounds	0	10	0				
28	Wallgate ALS180 Basin 470w x 300d Embedded carbon	ClimateChange	duction	Type	Wallgate ALS180 Basi	2	kg	0	0	0				kgCO2e
29	Wallgate ALS180 Basin 470w x 300d Carbon in use		e	Type	Wallgate ALS180 Basi	0.5	kg	0	0.25	0				kgCO2e

Figure 5.8: COBie environmental impacts requirements

Moreover, the required targets and reductions of the environmental impacts are usually stated by the client and/or by the governmental authorities through mandating a reliable green building standard. Assessing those impacts has recently become an essential part of most of the green building standards worldwide in order to urge design teams to evaluate the building performance during the early design stage (Athena, 2014).

However, among all the green building standards which have defined the environmental impacts assessment as part of their credits, the Leadership in Energy and Environmental Design (LEED) has been selected as a use case for this research due to its comprehensive approach and strict rules regarding the assessment of the environmental impacts of the considered project.

In order to conduct the first step of the integrated BIM process the project requirements represented by the related LEED credits' requirements should be addressed and detailed.

5.3 Revit parameters and formulas

The modeling process in Autodesk Revit 2015 is mostly based on utilizing pre-created families and components stored within specific elements libraries according to their categories. These elements are accompanied by a series of parameters that carries information about their specific characteristics. In addition, construction materials, which are the base of any building element, are also categorized in libraries and specified as per their graphical and technical parameters. These materials are usually assigned to the related modeling elements as a part of their properties. However, in order to create more realistic informative models, the parameters of the applied materials need to contain accurate data that reflects their actual performance.

Thus, Revit parameters represent the main part of the “I” in BIM within the Revit modeling context. They carry information regarding Revit materials, families and components properties. These parameters and their accompanied attributes can be further extracted into schedules, exported to external applications or used for generating specific Revit formulas. Therefore, prior to starting the Revit modeling process, the project team should define the best approaches for identifying and utilizing the adequate parameters in order to create an information-rich model and achieve accurate outputs through particular Revit schedules.

For the purpose of this study, after addressing and detailing COBie and LEED V4 MRc1 & MRc2 requirements, it was determined that the Level of Development (LOD) of the modelling process should be considered at the materials level. It means that all the related project information should be interpreted into parameters so they can be highlighted within the BIM Execution Plan and applied when creating the Revit project materials representing the products as per LEED V4 definition. These materials/products would form the basis on which the Revit modelling families and components would be evaluated while developing the Revit information model

As illustrated in (Table: 5.1) a list of 26 parameters was created following the detailed analysis of LEED V4 MRc1 (option 4) and MRc2 along with COBie impact sheet information requirements. The list has represented standard parameters group that should be applied to all the Revit project materials and accompanied carefully with their unique names, units and attributes.

Table 5.1: Required Revit parameters as per LEED V4 MRc1 & MRc2

List of Required Information	Unit	Parameter Name	Attribute
COBie Created By	NA	COBie.Created.By	Text
COBie Created On	NA	COBie.Created.On	Text
Product/Material Name (Code)	NA	Already Exists	Text
Product/Material Manufacturer	NA	Already Exists	Text
Product/Material Use	NA	Prod.Use	Text
Structural	NA	Str	Yes/No
Enclosure	NA	Encl	Yes/No
Global Warming Potential	Kg CO_2 eq./ m^3	GWP	Mass Density
Ozone Depletion Potential	Kg CFC-11 eq. / m^3	ODP	Mass Density
Acidification Potential	Kg SO_2 eq. / m^3	AP	Mass Density
Eutrophication Potential	Kg N eq. / m^3	EP	Mass Density
Photochemical Ozone Creation Potential	Kg O_3 eq. / m^3	POCP	Mass Density
Non-renewable Primary Energy Consumption	MJ/ m^3	nPE	Mass Density
EPD as per the International PCR	NA	Intl.PCR	Yes/No
Self-declared EPDs	NA	Self.Dcl.EPD	Yes/No
Industry average EPDs	NA	Ind.Avg.EPD	Yes/No
Product Specific EPDs	NA	Prod.Spec.EPD	Yes/No
USGBC approved program	NA	US.Prg	Yes/No
Sourced within160 km	NA	Wi.160	Yes/No
Distance from factory to site	Km	Dist.To.Site	Number
Mean of Transport	NA	Mean.Of.Trans	Text
Product/Material Cost/m3	AED/ m^3	Prod.Cost/m3	Mass Density
COBie Impact Type	NA	COBie.Impact.Type	Text
COBie Impact Stage	NA	COBie.Impact.Stage	Text
COBie Impact Sheet Name	NA	COBie.Impact.Sheet.Name	Text
COBie Impact Unit	NA	COBie.Impact.Unit	Text

Moreover, a study for the U.S. Green Building Council (USGBC) that was prepared by McDonough Braungart Design Chemistry (MBDC, 2013) has provided a market analysis regarding building products categories and materials according to their impact on the environment and human health. The study has covered twelve product divisions as per the Construction Specifications Institute (CSI) Master Format classification as shown in (Table 5.2).

Table 5.2: Materials divisions according to CSI Master Format (MBDC, 2013)

CSI Division #	Division Name
03	Concrete
04	Masonry
05	Metals
06	Wood, Plastics, & Composites
07	Thermal and Moisture Protection
08	Openings
09	Finishes
10	Specialties
12	Furnishings
22	Plumbing
26	Electrical
32	Exterior Improvements

These divisions were further divided into sixty product categories followed by a large number of building materials which were then analyzed and prioritized according to their accompanied environmental impacts. However, concrete formulation was placed on the top of that priority materials list due to the fact that concrete is an essential component of several product divisions and it is being used in high volumes in the construction industry. In addition, there is a wide range of concrete mix designs which can be used for several concrete products' applications.

According to MBDC (2013) the biggest environmental concern regarding the concrete products are the Green House Gas (GHG) emissions resulting from the cement manufacturing process. This process usually includes the addition of multiple toxic chemicals that have variable environmental impacts. Therefore, addressing the types and percentages of those admixtures has become crucial when evaluating concrete products and selecting the best options for specific uses in a project.

Following the priority level and the high market concern regarding the tremendous environmental impact of concrete products, this study has focused on applying the proposed integrated BIM process for evaluating the compliance of concrete products with LEED V4 materials and resources credit 1 and credit 2 requirements.

According to LEED V4, one material category can be counted for more than one product if it contributes with different characteristics to multiple applications in a project, this means that each product should be unique with its characteristics and use in order to be considered for LEED V4 compliance. Therefore, some product-specific parameters should be added depending on each material category specifications and possible uses in the project.

As a result, additional parameters should be added when creating different concrete products in Revit software in order to allow for more accurate assessment regarding LEED V4 MRc1 & MRc2 requirements (Table 5.3).

Table 5.3: Concrete specific parameters for LEED V4 MRc1 & MRc2 assessment

List of Required Information	Unit	Parameter Name	Attribute
28days Compressive Strength	MPa	CS	Stress
Combination Content	Kg/m^3	Com.Cont	Mass Density
Ordinary Portland Cement	Ratio	OPC	Number
Ground granulated blast-furnace slag	Ratio	GGBS	Number
Fly Ash	Ratio	FA	Number
Micro Silica	Ratio	MS	Number
Water to Concrete Ratio	Ratio	W/C	Number

After defining the required project information and outlining the relevant parameters, the project team can start developing the Revit model by adding those parameters to the project file as shown in (Figure 5.9).

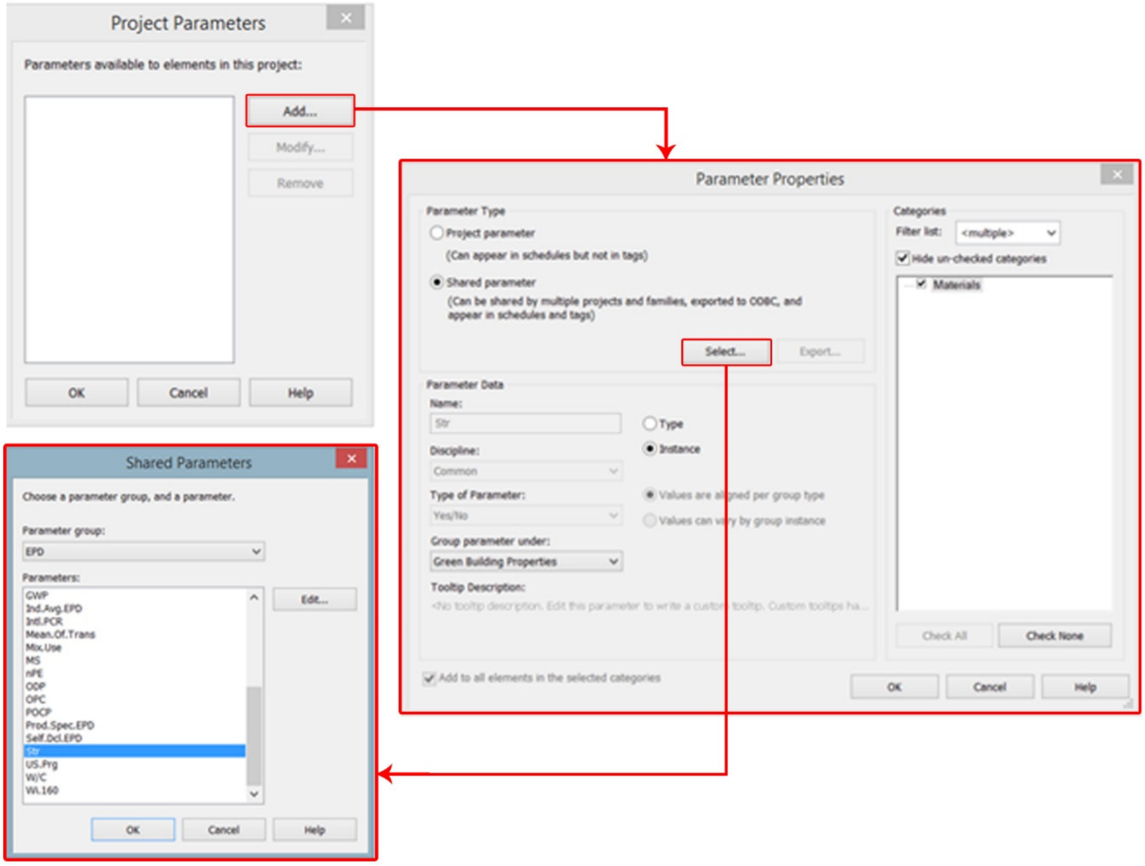


Figure 5.9: Adding Revit project parameters

The next step would be the creation of the project specific concrete products and filling out the newly added parameters list with each product's specific characteristic (Figure 5.10). The proposed naming convention would be to start with the material division name followed by the product category (e.g. cast in place, precast…etc.) then the 28days compressive strength of the concrete mix.

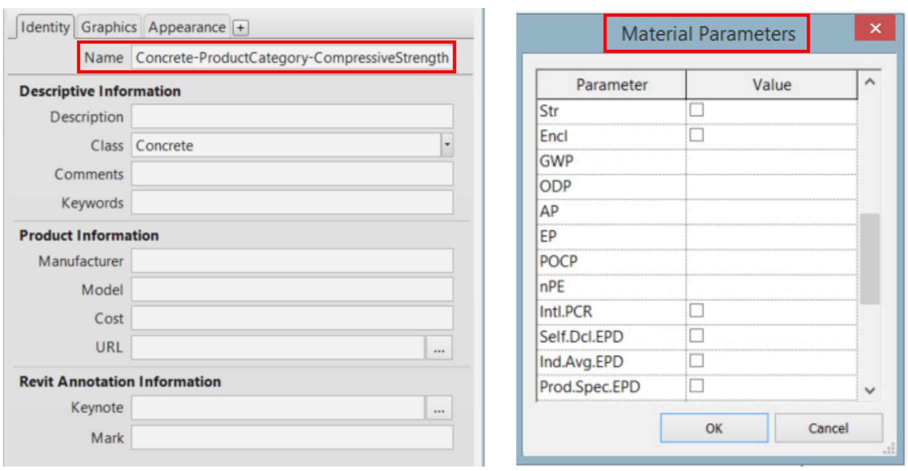


Figure 5.10: Creating project specific concrete products

The best case scenario would be to extract those parameters from product specific EPDs which would qualify the related product for a full value as per LEED V4 MRc2. However, the team can still utilize the concrete industry average environmental impacts which were developed by the National Ready Mix Concrete Association (NRMCA) if the actual EPDs are not available (Table 5.4).

Table 5.4: Sample NRMCA concrete industry average environmental impacts/m³

Indicator/LCI Metric	GWP	ODP	AP	EP	POCP	PEC	NRE	RE	NRM	RM	CBW	CWW	TW	CHW	CNHW
Unit (equivalent)	kg CO2	kg CFC-11	kg SO2	kg N	kg O3	MJ	MJ	MJ	kg	kg	m3	m3	m3	kg	kg
Minimum Indicator/ Metric Value	250.4	4.56E-6	1.32	0.15	17.53	2210	2193	17	2020	0.54	0.13	0.12	0.25	0.41	2.67
Maximum Indicator/ Metric Value	416.1	7.11E-6	1.81	0.19	22.12	3190	3167	22	2347	0.69	0.13	0.12	0.25	0.41	2.67
4000-00-FA/SL	416.1	7.11E-6	1.81	0.19	22.12	3190	3167	22	2347	0.69	0.13	0.12	0.25	0.41	2.67
4000-20-FA	357.1	6.12E-6	1.58	0.17	19.95	2783	2763	20	2199	0.62	0.13	0.12	0.25	0.41	2.67
4000-30-FA	325.2	5.58E-6	1.45	0.16	18.77	2562	2544	18	2119	0.58	0.13	0.12	0.25	0.41	2.67
4000-40-FA	291.6	5.02E-6	1.32	0.15	17.53	2331	2315	17	2034	0.54	0.13	0.12	0.25	0.41	2.67
4000-30-SL	316.6	5.63E-6	1.60	0.18	20.70	2644	2623	20	2177	0.63	0.13	0.12	0.25	0.41	2.67
4000-40-SL	283.5	5.14E-6	1.53	0.17	20.23	2463	2444	20	2121	0.61	0.13	0.12	0.25	0.41	2.67
4000-50-SL	250.4	4.64E-6	1.46	0.17	19.76	2282	2263	19	2064	0.60	0.13	0.12	0.25	0.41	2.67
4000-50-FA/SL	252.5	4.56E-6	1.36	0.16	18.46	2210	2193	17	2020	0.56	0.13	0.12	0.25	0.41	2.67

Please refer to (NRMCA, 2014) for complete list of concrete industry-average environmental impacts.

In parallel, the team can start modelling the Revit families and components once the materials are created so they can be assigned to the concrete items. This will ensure that the model elements contain accurate data regarding their environmental impacts and contribution to the overall facility impacts.

Thereafter, an evaluation mechanism was developed in order to evaluate the compliance with LEED V4 credits requirements on a real-time basis within the Revit modelling context. That mechanism required the development of multiple Revit formulas which were able to interpret the plain language requirements into a programming language to be utilized for real-time data assessment when creating the Revit information model.

The first type of formulas was created using conditional statements in order to evaluate the six environmental impacts categories of the proposed concrete products against the National Ready Mix Concrete Association (NRMCA) benchmark impacts which were defined by Athena Sustainable Materials Institute (Athenasmi, 2014). The following sample shows a small part of the GWP compliance formula which has identified in general that “If the compressive strength of a Concrete Mix is in a certain range, then the GWP should be less than a certain value in order to comply with LEED V4 benchmark" as follows:

If (and (Material: CS > 0 MPa, not (Material: CS > 17.24 MPa)), 288.76 - Material: GWP, If (and (Material: CS > 17.24 MPa, not (Material: CS > 20.68 MPa)), 320.99 - Material: GWP, If (and (Material: CS > 20.68 MPa, not (Material: CS > 27.58 MPa)), 391.53 - Material: GWP, If (and (Material: CS > 27.58 MPa, not (Material: CS > 34.47 MPa)), 482.27 - Material: GWP, If (and (Material: CS > 34.47 MPa, not (Material: CS > 41.37 MPa)), 508.09 - Material: GWP, If (and (Material: CS > 41.37 MPa, not (Material: CS > 55.16 MPa)), 618.02 - Material: GWP, -1))))))

These formulas would also address the performance improvements and/or the recommended impacts reductions for each concrete product compared to the adopted benchmark values.

In addition, two other specific formulas were structured in order to automate the assessment of each product value as per the LEED V4 MRc2 (option 1) guidelines:

If (and(and(Material: Prod.Spec.EPD), Material: Wi.160),or(Material: Str, Material: Encl)), 2,If (and(and(Material: Prod.Spec.EPD), not(Material: Wi.160)), or(Material: Str, Material: Encl)), 1,If (and(and(Material: Ind.Avg.EPD), not(Material: Wi.160)), or(Material: Str, Material: Encl)), 1/2,If (and(and(Material: Ind.Avg.EPD), Material: Wi.160), or(Material: Str, Material: Encl)),1…

Besides, the cost of complying and non-complying products was also considered in a separated type of formulas for demonstrating the achievement level of MRc2 (option 2) requirements:

If (and (and (not (GWP.Compliance.LEED.V4<0), not (ODP.Compliance.LEED.V4<0)), not (AP.Compliance.LEED.V4<0)), Total.Concrete.Cost, if (and (and (not (GWP.Compliance.LEED.V4<0), not (ODP.Compliance.LEED.V4<0)), not (EP.Compliance.LEED.V4<0)), Total.Concrete.Cost…

Moreover, another formulas group has been designed to calculate the total environmental impacts of structural and enclosure building elements in which the concrete mixes would be used. These formulas would also demonstrate the total impact reduction or increment for each building element regarding the six environmental impacts categories. This would be utilized to conduct the facility life cycle impacts assessment according to the LEED v4 MRc1 (option 4) prerequisites as illustrated in the following sample:

If (or (Material: Str, Material: Encl), Material: Volume * Material: GWP, 0)

Furthermore, Dubai Municipality has recently issued some new requirements regarding the usage of sustainable concrete materials for all the new construction projects in the Emirate of Dubai, therefore, the next formulas group has attempted to check the compliance with those guidelines (Table 5.5) as an additional evaluation criteria for projects within the Emirate of Dubai.

Table 5.5: Dubai Municipality green concrete requirements (DM, 2014)

For Substructure					
Options	Lowest Nominal Concrete Cover (mm)	Maximum W/C Ratio		Minimum Combination Content (kg/m³)	Composition
1[D]	50[A] , 75[B]	0.45		360	Portland Cement with 66% to 80% GGBS (Ground Granulated Blastfurnace Slag)
2	50[A] , 75[B]	0.40		380	Portland Cement with 36% to 55% Fly Ash
3[D]	50[A] , 75[B]	0.35		380	Portland Cement with 36% to 65% GGBS (Ground Granulated Blastfurnace Slag)
For Superstructure					
Options	Compressive Strength Class	Lowest Nominal Concrete Cover (mm)	Maximum W/C Ratio	Minimum Combination Content (kg/m³)	Composition
4[D]	C40	30	0.35	380	Portland Cement with 36% to 65% GGBS (Ground Granulated Blastfurnace Slag)
5[D]	C32	30	0.4	380	Portland Cement with 66% to 80% GGBS (Ground Granulated Blastfurnace Slag)
6	C32	30	0.4	380	Portland Cement with 36% to 55% Fly Ash
7[D]	C32	35	0.45	360	Portland Cement with 36% to 65% GGBS (Ground Granulated Blastfurnace Slag)
8[D]	C25	35	0.50	340	Portland Cement with 66% to 80% GGBS (Ground Granulated Blastfurnace Slag)
9[D]	C25	40	0.50	340	Portland Cement with 66% to 80% GGBS (Ground Granulated Blastfurnace Slag)

Reference code number: BS 8500-1: 2006

A) For concrete cast against blinding.
B) For concrete cast directly against the soil.
C) For maximum aggregate size of 20mm
D) Inclusive of low early strength option.

The generated formulas were also capable of highlighting the non-complying mix design properties and indicate the recommended targeted improvements for achieving the Dubai Municipality requirements as shown in this sample:

```
If(and(and(and(and(and(Not(Material: CS < 20), Material: CS < 30),not(Material: Com.Cont < 340)),
Material: Com.Cont < 360), not(Material: OPC > 0.34)), not([Material: W/C]> 0.50)),
1,If(and(and(and(and(and(Not(Material: CS < 30), not(Material: CS > 32)),not(Material: Com.Cont <
360)), Material: Com.Cont < 380), not(Material: OPC > 0.64)), not([Material: W/C]> 0.45)), 1, …
```

However, the developed groups of formulas would be utilized for generating specific Revit schedules for compliance check and real-time decision making. In case of any product insufficiency the total impacts of that product should be evaluated in order to check the acceptable levels and if any further improvements are to be done.

Afterwards, the final results should be arranged within a particular Revit impact schedule that would be exported directly to the COBie spreadsheet addressing all the accurate environmental impacts of the building products as per the client requirements. Refer to Appendix B for sample complete formulas.

5.4 Developing Level 2 BIM process map

Process modeling is an essential procedure for delivering more efficient processes in less time and better quality (Riley et al., 2004). It requires a comprehensive analysis of the process in order to define the sequence of the implementation activities along with the responsible parties and the Information Exchange (IE) requirements.

The proposed Integrated BIM process would require the development of an overall Level 1 BIM process map and multiple Level 2 process maps which should be included in the BIM Execution Plan (BEP) of the project.

The CIC BIM Project Execution Planning Guide (CIC, 2010) is a globally recognized standard that is being utilized by industry professionals worldwide for BIM implementation. It enables an enhanced level of BIM integration by providing detailed guidance for identifying suitable BIM goals and uses in a project and a method for mapping the execution of BIM processes along with the identification of the Information Exchange (IE) requirements and the needed infrastructure for supporting the implementation of the developed BIM process.

The guide has outlined the BIM implementation process at design and construction activities level by providing well-structured process mapping. However, the CIC BIM Project Execution Planning Guide has provided a standard process modelling that can be applied for any BIM use in a project without addressing the specific process mapping approach for achieving project sustainability goals. A typical Level 2 BIM process map should clearly identify the BIM goal and the required reference information which represents the process inputs. In addition, it will detail the process execution activities along with the responsible parties and the Information Exchange (IE) stages as outputs of the process.

Therefore, the CIC BIM Project Execution Planning Guide (CIC, 2010) was adopted in this study for developing a Level 2 BIM process map following a similar method but particularly oriented for achieving LEED V4 MRc1 (option 4) and MRc2 requirements regarding the materials environmental impacts and life cycle assessment.

As illustrated in (Figure 5.11) the first step of the developed process map is to create a preliminary project materials list at the early design stage of a project. This step will promote the early involvement of the multidisciplinary team members in the decision making and will ensure that the list is as accurate as possible through an integrated delivery process. In addition, the team should also categorize and prioritize those materials according to their potential environmental impacts and the targeted LEED V4 credits following the specified materials divisions as per the CSI Master Format and the USGBC.

Thereafter, the team should subdivide the defined list into structure, enclosure and non-structural/enclosure materials in order to distribute the responsibilities among the specialized team members for more efficient implementation when addressing the different products and uses of each of the listed material categories.

In parallel, the BIM team should be arranging the project Revit model by adding the required Revit parameters to the project parameters considering their unique attributes in order to utilize them when creating the project specific materials according to the identified products and uses. Next, the BIM team should fill-in the remaining products' specific characteristics using the environmental impacts data provided by the sustainability team. Subsequently, the BIM team should create specific Revit schedules using the required parameters and utilizing the specific developed Revit formulas which would be applied for checking the compliance with the targeted LEED V4 requirements during the project model progression.

This compliance checkpoint provides a real-time assessment within the Revit context and support the decision making when evaluating the total impacts of non-complying products.

Following the completion of the compliance checking stage, the final accepted data should be exported to excel to support LEED V4 credits submission and filling out the COBie impact sheet as per the client's requirements.

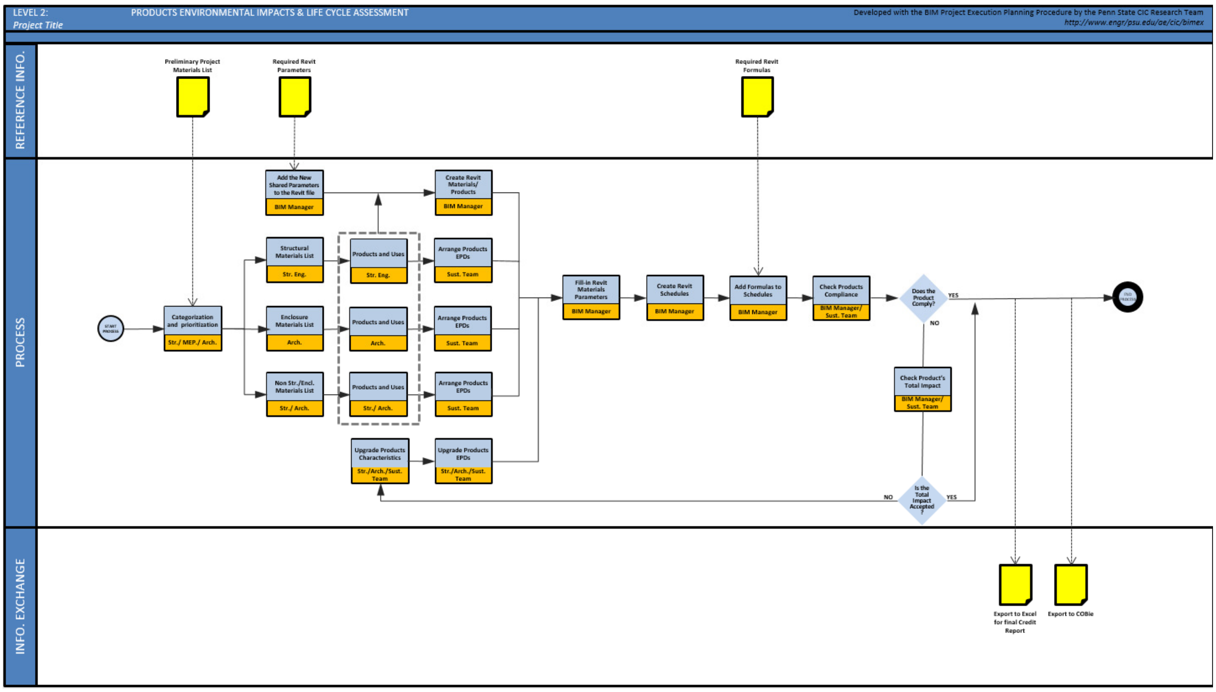


Figure 5.11: BIM process map for achieving LEED V4 MRc1 (option 4) & MRc2 requirements; refer *to Appendix C for the high resolution process map.*

5.5 Conclusion

The proposed Integrated BIM Process has been developed following the progression of the preliminary concept that was illustrated in (Figure 4-1). The 5 suggested stages, A to E, have been explained in detail in this research and were utilized to generate a specific BIM-use case for achieving LEED V4 MRc1 (option 4) and MRc2 requirements.

In addition, the 5 stages of the preliminary concept were further analyzed in order to address a more specific workflow regarding the applications of concrete materials in a project. The details of the resulted workflow were further represented by a Level 2 BIM Process map that has been generated following the CIC BIM Project Execution Planning Guide (Figure 5.12). This Level 2 BIM Process map would become an essential part of project's overall BIM Execution Plan and it would form the basis upon which our case study would be conducted.

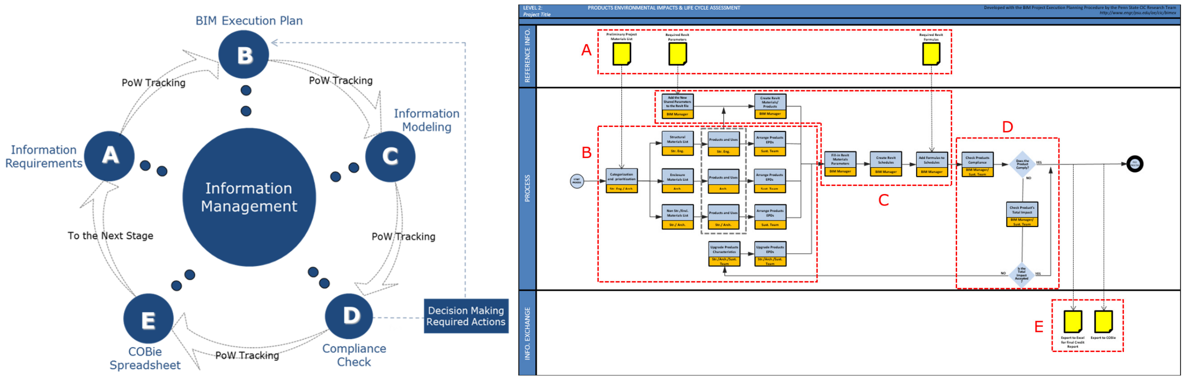


Figure 5.12: Comparison between the preliminary concept stages and the developed Level 2 process map

Although the developed Level 2 BIM process map has identified a specific BIM-based sustainability assessment driven by particular LEED V4 requirements and a specific material division, this process map can be adapted and applied to achieve the MRc1 and MRc2 requirements for multiple materials divisions in a project by simply adding any specific parameters or formulas as discussed earlier in this research for the concrete products use case.

Furthermore, the concept of the proposed BIM process has provided sufficient and adequate guidelines that can be utilized for developing future Level 2 BIM process maps for achieving many other LEED V4 credits and different project requirements.

Chapter 6: Case Study

6.1 Overview

In order to verify the applicability of the proposed Integrated BIM Process an industry case study was needed so to examine the actual execution procedure along with the efficiency of the evaluation mechanism and to explore the opportunity for any further improvements and modifications. The case study was preferred to be a project which was developed using Revit as a BIM tool without utilizing the information management capabilities and functions which were proposed in this study.

In an effort to find such a case study, Atkins engineering and design Consultancy Company was approached due to a sponsorship agreement and collaboration between the multinational firm and the British University in Dubai.

Several interesting projects were recommended by Atkin's team, however, among all the provided options, the most suitable one was the new Al Riyadh Metro Project which is a rapid transit system under construction in the capital city of the Kingdom of Saudi Arabia.

6.2 Al Riyadh Metro project overview

Al Riyadh Metro project is the first metropolitan public transport system in the Kingdom of Saudi Arabia. It is designed to improve the lifestyle of the capital's citizens and connect the different parts of the city while supporting the Saudi economy.

As shown in (Figure 6.1), the project consists of 6 Metro lines covering around 180 km of rail with around 87 stations. The project was divided into 3 packages, however, the 3rd package that was the under construction phase which was considered in this case study. This package contains lines 4, 5 and 6 with 64 km of rail and 25 metro stations.

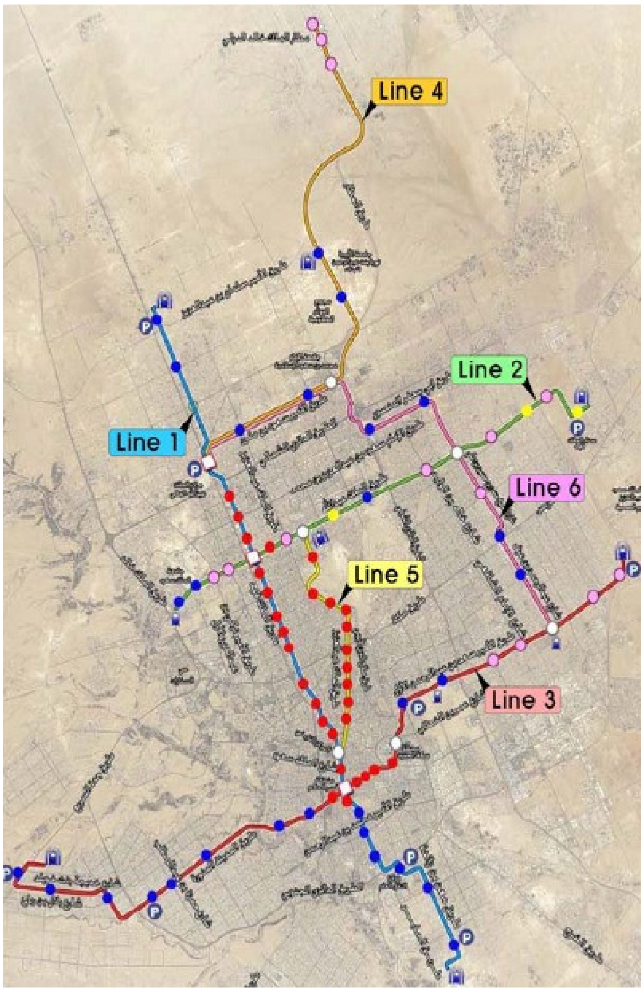


Figure 6.1: Al Riyadh Metro project (Samsung, 2013)

For the purpose of this study, one metro station design (Figure 6.2) was selected to apply the proposed BIM process on as its Revit model was developed with limited amount of project information regarding the used construction materials and their specific environmental impacts characteristics.

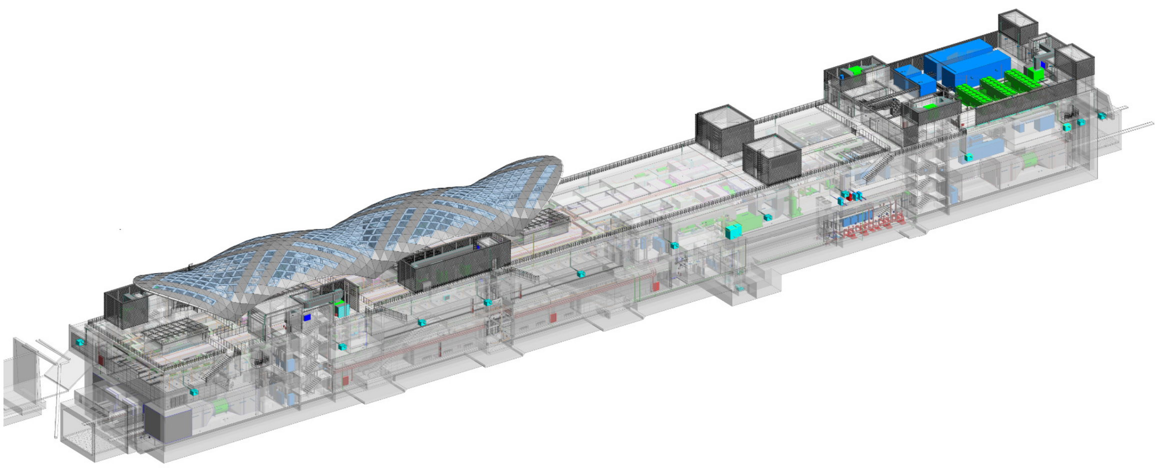


Figure 6.2: Case Study Metro Station

6.3 Applying the proposed integrated BIM process

As discussed earlier in this research, the first step when applying the developed BIM Process is the identification of the required project information which will form the basis for an accurate information modelling procedure.

In this case study, which has been conducted specifically regarding concrete products, a detailed schedule of the project's concrete mix-designs had to be created. Therefore, as part of the integrated project delivery, the responsibility of gathering and arranging the required project information was distributed between both structural and architectural teams. The generated schedule has categorized the different mixes according to their 28-days compressive strength and uses in the project including information about the combination contents of each listed mix design (Table 6.1).

Table 6.1: Al Riyadh Metro Project Package 3 – Concrete Mix Designs

Al Riyadh Metro Package 3 – Concrete Mix Designs									
28 days Compressive Strength	C15	C30	C35-1	C35-3	C35-5	C40-1	C40-2	C40-3	C50
Mix Use	-Blinding	-Ground Barring Slab	-Internal Primary & Secondary Structure	-Underground Structure Exposed to Soil -Cut & Cover Structure/ Tunnel -Foundation/Pile Cap -Ground Barring Slab	-Pile	-Columns -Underground Structure Exposed to Soil -Cut & Cover Structure/ Tunnel -Viaduct Pier & Pier Head -Foundation /Pile Cap -Ground Barring Slab	-Pile	-Concrete Slab -Precast Beams -In-Situ Structural Topping -Precast & In-Situ Column	-Viaduct Section -Concrete Plinth -Platform Viaduct -Precast Planks
Combination Content	220	360	390	390	390	410	410	410	430
OPC	0.50	0.45	0.50	0.43	0.45	0.44	0.45	0.50	0.50
GGBS (slag)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Fly Ash	-	-	-	-	-	-	-	-	-
Admixtures	-	0.05	-	0.07	0.05	0.06	0.05	-	-
W/C Ratio	0.70	0.45	0.40	0.40	0.40	0.40	0.40	0.40	0.35

This table gave a clear view about the number of concrete products that should be created within the Revit model and considered when evaluating the environmental impacts of the adopted metro station where 6 out of the 9 overall concrete mixes were applied.

Prior to creating the relevant concrete materials within the Revit model, the specific Revit shared parameters group that was generated earlier during the development stage had to be added by the responsible BIM coordinator to the Revit project parameters as materials shared parameters as shown in (Figure 6.3).

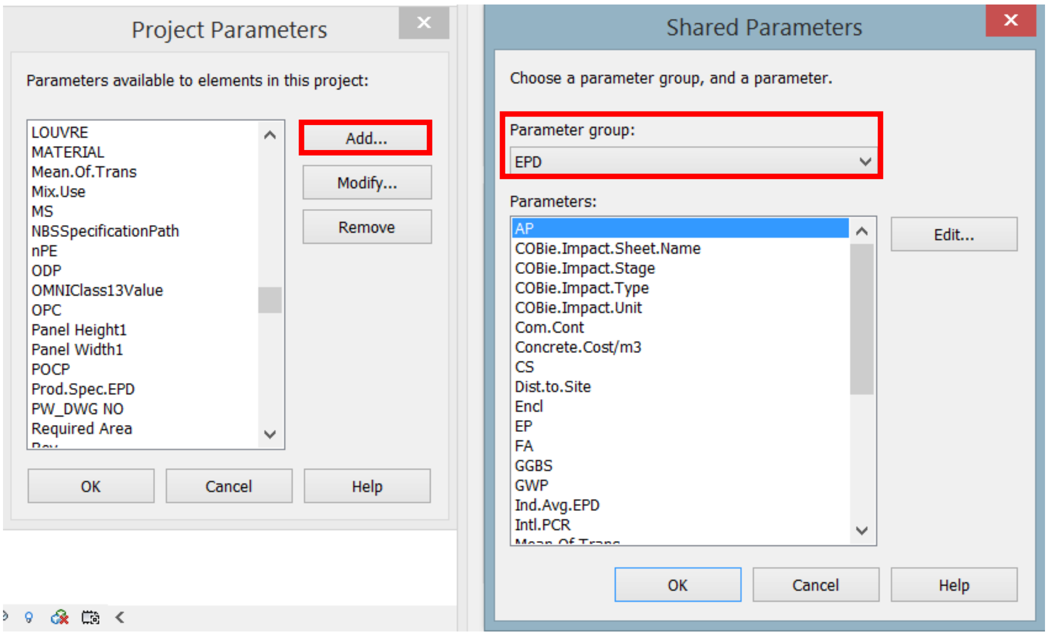


Figure 6.3: Adding the materials specific shared parameters to the Revit project parameters

While completing the parameters addition step, the concrete products' naming had to be modified using the recommended naming convention in order to facilitate the materials selection and filtering processes especially when applying the Revit formulas and creating the particular schedules.

By finishing those steps, the concrete products were ready to accommodate the accurate concrete products information according to the generated mix designs schedule and the products' cradle-to-gate environmental impacts (Figure 6.4).

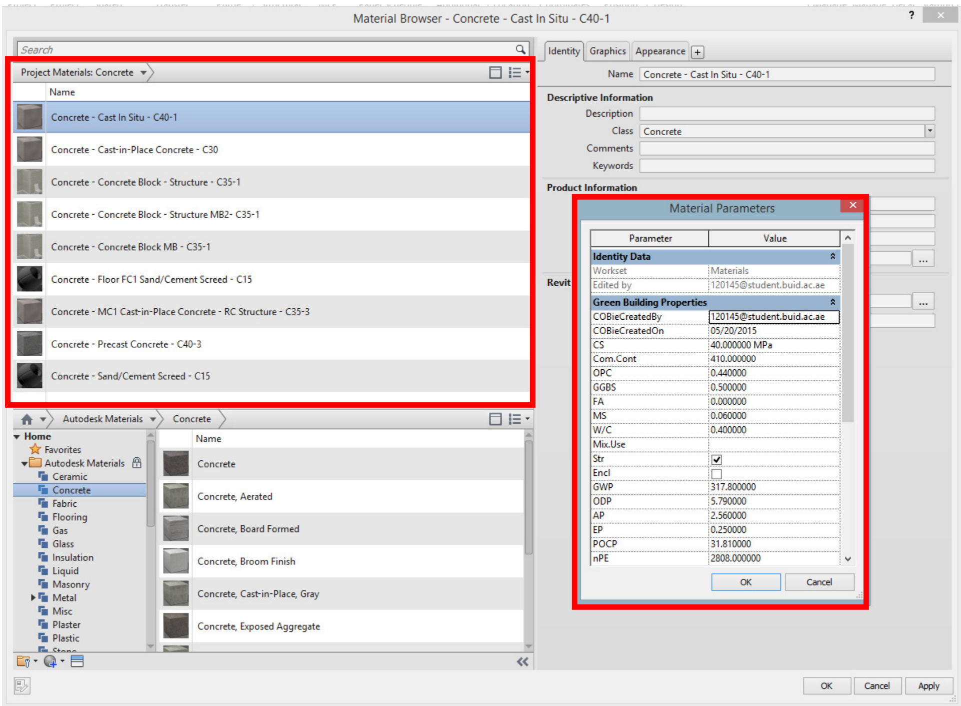


Figure 6.4: Updating the concrete products' characteristics

Following the completion of updating the concrete products data the informative Revit schedules were able to be generated (Table 6.2). The fields/columns of those schedules could be divided into 2 types. The first type was depended on the Revit parameters to illustrate the concrete products information and identify their impact on the Revit families and modeling components, while, on the other hand, the second fields type has utilized the developed Revit formulas for providing the real-time evaluation mechanism within the schedules.

Table 6.2 : Sample of a generated Revit Schedule; refer to Appendix D for high resolution schedule.

A	B	C	D	E	F	G	H	I
Category	Family and Type	COBieTypeCreatedBy	COBieTypeCreatedOn	Count	Material: Name	Material: COBieCreatedBy	Material: COBieCreatedOn	Material: Manufacturer
Floors	Floor: ROOF BUILD UP 150mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC4	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix

However, different schedules were arranged using selected parameters and formulas for each of them according to the specific targets that they were supposed to address.

6.4 Case study Results - LEED V4 MRc2

The first category of the created Revit schedules was concerning LEED V4 MRc2 assessment and compliance check. As shown in (Table 6.3), all the used mix designs where listed within the schedule that contained particular columns showing the compliance of the products' environmental impacts against the LEED V4 benchmark regarding each of the six environmental impacts categories. The schedule didn't only show that all the concrete mixes were complying but also defined the reduction in each of the impacts comparing to the related benchmark.

Table 6.3: LEED V4 MRc2 assessment and compliance check schedule

B	C	D	E	F	G	H
Material: Name	GWP.Compliance.LEED.V4	ODP.Compliance.LEED.V4	AP.Compliance.LEED.V4	EP.Compliance.LEED.V4	POCP.Compliance.LEED.V4	nPE.Compliance.LEED.V4
Concrete - Cast In Situ - C40-1	203.64	2.48	0.35	0.19	3.56	1155.91
Concrete - Cast-in-Place Concrete - C30	143.90	1.58	0.12	0.15	0.92	731.82
Concrete - Concrete Block - Structure - C35-1	179.74	2.12	0.26	0.17	2.50	986.27
Concrete - Concrete Block - Structure MB2- C35-1	179.74	2.12	0.26	0.17	2.50	986.27
Concrete - Concrete Block MB - C35-1	179.74	2.12	0.26	0.17	2.50	986.27
Concrete - Floor FC1 Sand/Cement Screed - C15	108.62	1.29	0.17	0.11	1.28	602.15
Concrete - MC1 Cast-in-Place Concrete - RC Structure - C35-3	179.74	2.12	0.26	0.17	2.50	986.27
Concrete - Precast Concrete - C40-3	203.64	2.48	0.35	0.19	3.56	1155.91
Concrete - Sand/Cement Screed - C15	108.62	1.29	0.17	0.11	1.28	602.15

However, in case of any failure the non-complying field would have been highlighted in red indicating the required impact improvement in order to meet the benchmark value.

In addition, this category of schedules provides a real-time decision making method that allows the project team to evaluate different materials options according to their total environmental impacts and total cost impact on the project in order to achieve the targets through the most feasible materials selection (Table 6.4).

Table 6.4: real-time comparison between the environmental and cost impacts

A	B	C	AB	AC
Material: Name	Total.GWP.Str.Encl.Benchmark.	Total.GWP.Reduction.Str.Encl.	Total.Concrete.Cost	Cost.of.Complying.Concrete
Concrete - Cast In Situ - C40-1	2356385.76	920248.53	903799.38	903799.38
Concrete - Cast-in-Place Concrete - C30	8394.84	2616.45	1818.24	1818.24
Concrete - Concrete Block - Structure - C35-1	141867.69	51250.75	42770.74	42770.74
Concrete - Concrete Block - Structure MB2- C35-1	12707.09	4590.53	3830.98	3830.98
Concrete - Concrete Block MB - C35-1	711191.94	256923.34	142941.66	142941.66
Concrete - Floor FC1 Sand/Cement Screed - C15	0.00	0.00	14305.05	14305.05
Concrete - MC1 Cast-in-Place Concrete - RC Structure - C35-3	43065.99	15557.91	8655.78	8655.78
Concrete - Precast Concrete - C40-3	3297534.13	1287798.88	948584.92	948584.92
Concrete - Sand/Cement Screed - C15	0.00	0.00	3677.68	3677.68

Moreover, the schedules were able to calculate the resulting "product value" of each concrete mix as per LEED V4 MRc2 guidelines. This has made the assessment of the targeted LEED credit a straight forward process which has indicated that, through concrete products only, the case study has fulfilled 6 product values and needed to obtain just 14 more from all the remaining material divisions in order to achieve the mandatory overall 20 product values and gain the LEED V4 MRc2 “option 1” credit point (Figure 6.5).

These results has emphasised the importance of concrete in achieving this credit point as it may contribute with up to 16 product values or even the whole 20 if the mixes are supplied by five different manufacturers as per LEED V4 guidelines.

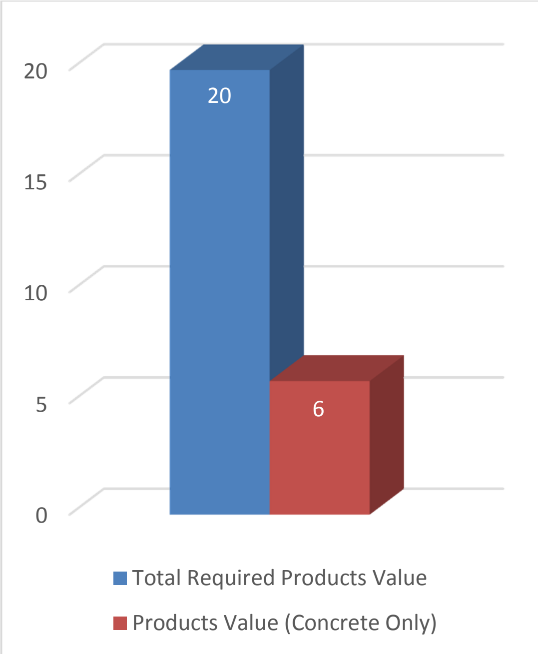


Figure 6.5: LEED V4 MRc2 “option 1” results

On the other hand, the generated cost schedules has detailed the cost of complying and non-complying concrete mixes along with breaking down the complying ones as per their structural or enclosure applications following the instructions of the second option of the MRc2.

Although all the included concrete products have met the required impacts reductions, the contribution of those products’ cost to the overall percentage of complying materials’ cost was restricted by the credit rule that allows the cost of complying structural and enclosure materials to be counted for a maximum of 30% from the required 50% complying project materials cost.

Due to this constrain, 30.86% of the total concrete products’ cost was considered as part of the complying materials calculation (Figure 6.6).

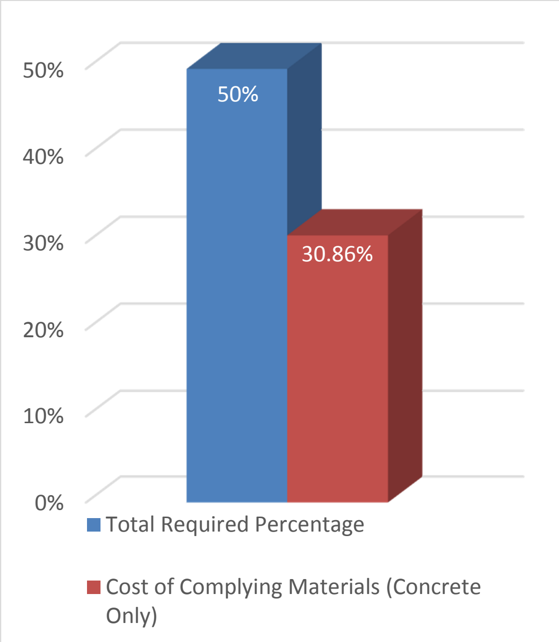


Figure 6.6: LEED V4 MRc2 “option 2” results

However, by expanding the scope of this credit beyond the concrete material division and cover more materials categories, the cost of the complying concrete products might be counted for the majority, if not all, of the 30% complying structural and enclosure materials leaving a room for another 20% to be satisfied by all the remaining non-structural and non-enclosure products where concrete can also add value through some particular products.

6.5 Case study Results - LEED V4 MRc1

The second schedules category was created to identify the total environmental impacts of the facility and compare them directly to the benchmark values in order to conduct a Life Cycle Impact Assessment (LCIA) and check the compliance with LEED V4 MRc1 “option 4” guidelines which requires the inclusion of structural and enclosure materials only when summing up each of the 6 impacts categories (Table 6.5).

Table 6.5: LEED V4 MRc1 “option 4” results

A	B	C	D	E
Material: Name	Total.GWP.Str.Encl.Benchmark	Total.GWP.Reduction.Str.Encl.	Total.ODP.Str.Encl.Benchmark	Total.ODP.Reduction.Str.Encl.
Concrete - Cast In Situ - C40-1	2356385.76	920248.53	37372.10	11207.11
Concrete - Cast-in-Place Concrete - C30	8394.84	2616.45	134.00	28.73
Concrete - Concrete Block - Structure - C35-1	141867.69	51250.75	2255.44	604.49
Concrete - Concrete Block - Structure MB2- C35-1	12707.09	4590.53	202.02	54.14
Concrete - Concrete Block MB - C35-1	711191.94	256923.34	11306.69	3030.36
Concrete - Floor FC1 Sand/Cement Screed - C15	0.00	0.00	0.00	0.00
Concrete - MC1 Cast-in-Place Concrete - RC Structure - C35-3	43065.99	15557.91	684.67	183.50
Concrete - Precast Concrete - C40-3	3297534.13	1287798.88	52298.65	15683.27
Concrete - Sand/Cement Screed - C15	0.00	0.00	0.00	0.00
Grand total: 741	6571147.44	2538986.40	104253.58	30791.61

The bar chart in (Figure 6.7) demonstrates the remarkable performance of the examined concrete mixes regarding their environmental impacts which were reduced in all the six categories compared to the industry benchmark.

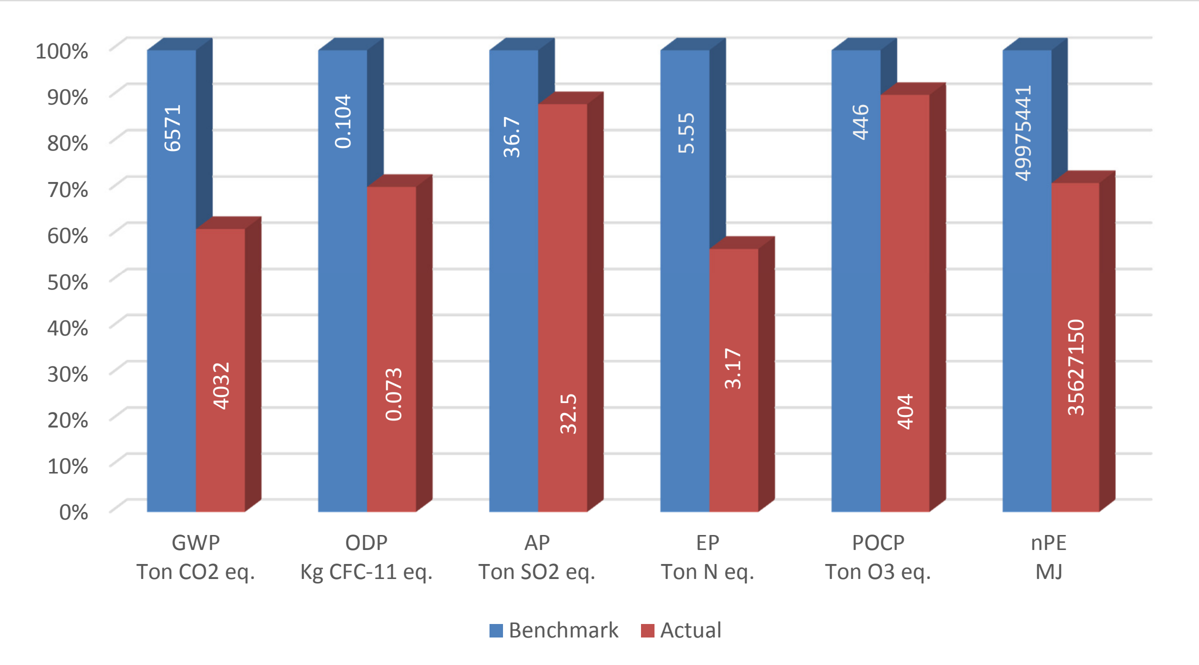


Figure 6.7: Environmental impacts assessment results

The graph shows a tremendous reduction in the Carbon Dioxide (CO_2) equivalent emissions from 6571 tons to 4032 tons cutting around 39% of the Global Warming Potential (GWP).

In addition, the Ozone Depletion Potential (ODP) was dropped by about 30% decreasing the CFC-11 equivalent emissions from 0.104 kg to 0.073 kg.

On the other hand, the Acidification Potential (AP) and the Photochemical Ozone Creating Potential (POCP) could barely achieve the recommended 10% reduction by decreasing the equivalent emissions from 36.7 to 32.5 tons of Sulfur Dioxide (SO_2) and from 446 to 404 tons of Ozone (O_3) respectively.

Moreover, the biggest improvement was accomplished by dropping the Eutrophication Potential (EP) dramatically by more than 40% from 5.55 tons to 3.17 tons of Nitrogen (N) equivalent emissions.

The last impact category also showed a significant saving of the non-primer energy usage which was declined by almost 30% comparing to the baseline case.

The environmental impacts assessment results have indicated the project compliance with LEED V4 MRc1 "option 4" guidelines by achieving more than10% reduction in five impacts categories including the GWP while none of the impacts was increased comparing to the benchmark impacts of the associated concrete mix designs.

Furthermore, similar schedules could be generated for the remaining materials divisions that were used in the structure or enclosure of the station. This would allow the project team to evaluate the environmental impacts of each division and generate a cradle-to-gate whole-building Life Cycle Assessment (LCA) by combining the resulting data in one reference for LEED V4 MRc2 submission.

It is worth noting that the management of the evaluation criteria along with the extraction and verification of the results have been conducted through the collaboration between the BIM team and the sustainability team which has proven again the effective IPD approach in the proposed BIM process especially for achieving sustainability targets.

6.6 Case study Results – Dubai Municipality compliance

In order to expand this case study scope and due to the recent Dubai Municipality emphasis on using eco-friendly concrete mixes especially for the Expo 2020 projects, a special schedule category was generated using the proper parameters and formulas for checking the compliance of the concrete mix-designs with the Dubai Municipality guidelines.

As shown in (Table 6.6), this schedule could identify the non-complying mixes while highlighting the characteristics that failed to meet the requirements.

Table 6.6: Dubai Municipality compliance results

F	G	H	I	J	K	L	M	N	O	P	Q	R
Material: Name	Material: COBieCreatedBy	Material: COBieCreatedOn	Material: Volume	Material: CS (MPa)	Material: Com.Cont (Kg/M3)	Material: OPC (Ratio)	Material: GGBS (Ratio)	Material: FA (Ratio)	Material: MS (Ratio)	Material: W/C (Ratio)	Com.Cont.Check	DM.Complianc
Concrete - Cast In Situ - C40-1	120145@student.buid.	05/20/2015	4518.997	40.0 MPa	410.00	0.44	0.5	0	0.06	0.4	1	0
Concrete - Cast-in-Place Concrete - C30	120145@student.buid.	05/21/2015	18.182	30.0 MPa	360.00	0.45	0.5	0	0.05	0.45	1	1
Concrete - Concrete Block - Structure - C35-1	120145@student.buid.	05/25/2015	285.138	35.0 MPa	390.00	0.5	0.5	0	0	0.4	1	1
Concrete - Concrete Block - Structure MB2- C35-1	120145@student.buid.	05/26/2015	25.540	35.0 MPa	390.00	0.5	0.5	0	0	0.4	1	1
Concrete - Concrete Block MB - C35-1	120145@student.buid.	05/27/2015	1429.417	35.0 MPa	390.00	0.5	0.5	0	0	0.4	1	1
Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.	05/24/2015	286.101	15.0 MPa	220.00	0.5	0.5	0	0	0.7	1	1
Concrete - MC1 Cast-in-Place Concrete - RC Structure - C35-3	120145@student.buid.	05/28/2015	86.558	35.0 MPa	390.00	0.43	0.5	0	0.07	0.4	1	1
Concrete - Precast Concrete - C40-3	120145@student.buid.	05/22/2015	6323.899	40.0 MPa	410.00	0.5	0.5	0	0	0.4	1	0
Concrete - Sand/Cement Screed - C15	120145@student.buid.	05/23/2015	73.554	15.0 MPa	220.00	0.5	0.5	0	0	0.7	1	1
			13047.386									

In this case study the highlighted issues were minor as only two concrete mix designs were slightly exceeding the allowed water to concrete ratio which could be simply identified and solved by a 0.05 reduction in those ratios as demonstrated in (Table 6.7)

Table 6.7: Dubai Municipality updated results

F	G	H	I	J	K	L	M	N	O	P	Q	R
Material: Name	Material: COBieCreatedBy	Material: COBieCreatedOn	Material: Volume	Material: CS (MPa)	Material: Com.Cont (Kg/M3)	Material: OPC (Ratio)	Material: GGBS (Ratio)	Material: FA (Ratio)	Material: MS (Ratio)	Material: W/C (Ratio)	Com.Cont.Check	DM.Complianc
Concrete - Cast In Situ - C40-1	120145@student.buid.	05/20/2015	4518.997	40.0 MPa	410.00	0.44	0.5	0	0.06	0.35	1	1
Concrete - Cast-in-Place Concrete - C30	120145@student.buid.	05/21/2015	18.182	30.0 MPa	360.00	0.45	0.5	0	0.05	0.45	1	1
Concrete - Concrete Block - Structure - C35-1	120145@student.buid.	05/25/2015	285.138	35.0 MPa	390.00	0.5	0.5	0	0	0.4	1	1
Concrete - Concrete Block - Structure MB2- C35-1	120145@student.buid.	05/26/2015	25.540	35.0 MPa	390.00	0.5	0.5	0	0	0.4	1	1
Concrete - Concrete Block MB - C35-1	120145@student.buid.	05/27/2015	1429.417	35.0 MPa	390.00	0.5	0.5	0	0	0.4	1	1
Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.	05/24/2015	286.101	15.0 MPa	220.00	0.5	0.5	0	0	0.7	1	1
Concrete - MC1 Cast-in-Place Concrete - RC Structure - C35-3	120145@student.buid.	05/28/2015	86.558	35.0 MPa	390.00	0.43	0.5	0	0.07	0.4	1	1
Concrete - Precast Concrete - C40-3	120145@student.buid.	05/22/2015	6323.899	40.0 MPa	410.00	0.5	0.5	0	0	0.35	1	1
Concrete - Sand/Cement Screed - C15	120145@student.buid.	05/23/2015	73.554	15.0 MPa	220.00	0.5	0.5	0	0	0.7	1	1
			13047.386									

This case has given an example about the ability of the developed evaluation mechanism to provide an immediate feedback and indicate the needed actions within the Revit modelling context.

In addition, after the verification of the method, the mechanism could be applied to future projects within the Emirate of Dubai which would add value to the whole design process.

6.7 Case study Results – COBie

Due to the growing awareness and industry emphasis regarding the importance of utilizing the Construction Operation Building Information Exchange (COBie) schema as an essential part of project deliverables especially for the facility management purposes, the last category of the generated schedules was specified for facilitating the information exchange during the project progress regarding the COBie data drops requirements and the final COBie submission at the handover stage.

Although few software developers in the market have released special applications for controlling and extracting COBie data from Revit files, none of them-till date-has considered the COBie Impact sheet which is supposed to convey the information regarding the environmental impacts of project’s elements.

Therefore, a unique schedule with a similar structure to the COBie impact sheet format was created using the particular Revit parameters those were added earlier to the project file. This schedule has simplified the COBie reporting process and provided flexibility for the team members by enabling them to select the impact categories that they intend to include in the report.

Once done, the data could be directly exported and reported within the COBie spreadsheet (Table 6.8) saving a tremendous amount of time and effort while ensuring the accuracy of the transferred information and minimizing the potential errors that could be critical for such a huge amount of data.

Table 6.8: COBie Impact data results; refer to Appendix E for high resolution COBie impact data results

	A	B	C	D	E	F	G	H	I
1	Name	CreatedBy	CreatedOn	ImpactType	ImpactStage	SheetName	RowName	Value	ImpactUnit
2	1300mm Retaining Wall1: 1300mm Retaining Wall	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	1261034.72	Kg CO2 eq.
3	1300mm Retaining Wall2: 1300mm Retaining Wall	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	33148.83	Kg CO2 eq.
4	1300mm Retaining Wall: 1300mm Retaining Wall	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	35068.84	Kg CO2 eq.
5	Column Rectangular Conc-Insitu: 300 x 300mm	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Structural Columns	6192.33	Kg CO2 eq.
6	Column Rectangular Conc-Insitu: 800 x 800mm	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Structural Columns	74702.83	Kg CO2 eq.
7	Basic Wall: BW 100mm - 100mm MB1 + PC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	366.28	Kg CO2 eq.
8	Basic Wall: BW 125mm - 100mm MB1 + 25mm WC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	149.08	Kg CO2 eq.
9	Basic Wall: BW 150mm - 100mm MB1 + 50mm INS	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	1461.22	Kg CO2 eq.
10	Basic Wall: BW 150mm - 150mm MB2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	8116.56	Kg CO2 eq.
11	Basic Wall: BW 200mm - 200mm MB3	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	76099.16	Kg CO2 eq.
12	Basic Wall: BW 200mm - 200mm MB3 + ONE SIDE PC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	3725.1	Kg CO2 eq.
13	Basic Wall: BW 200mm - 200mm MB3 + PC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	33759.51	Kg CO2 eq.
14	Basic Wall: BW 200mm - 200mm MB3 + PC2 both sides	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	84697.79	Kg CO2 eq.
15	Basic Wall: BW 200mm - 200mm MC1	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	4966.39	Kg CO2 eq.
16	Basic Wall: BW 225mm - 200mm MB3 + 25mm WC1	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	3837.79	Kg CO2 eq.
17	Basic Wall: BW 225mm - 200mm MB3 + 025mm WC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	7477.1	Kg CO2 eq.
18	Basic Wall: BW 250mm - 200mm MB3 + 025mm WC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	1131.36	Kg CO2 eq.
19	Basic Wall: BW 250mm - 200mm MB3 + 025mm WC2 + 025r	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	1040.4	Kg CO2 eq.
20	Basic Wall: BW 300mm - 200mm MB3 + 100mm WT1	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	150.64	Kg CO2 eq.
21	Basic Wall: BW 300mm - 300mm MB4	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	62598.33	Kg CO2 eq.
22	Basic Wall: BW 300mm - 300mm MB4 + 025mm WC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	715.78	Kg CO2 eq.
23	Basic Wall: BW 325mm - 100mm MB1 + 100mm WP2 + 25m	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	103.19	Kg CO2 eq.
24	Basic Wall: BW 325mm - 200mm MB3 +100mm WT1 + 025r	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	3004.27	Kg CO2 eq.
25	Basic Wall: BW 325mm - 200mm MB3 +100mm WT1 WC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	10257.64	Kg CO2 eq.
26	Basic Wall: BW 350mm - 100mm MB1 + 100mm MB1 + 025r	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	513.6	Kg CO2 eq.
27	Basic Wall: BW 350mm - 200mm MB3 + 050mm INS + 100m	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	16643.81	Kg CO2 eq.
28	Basic Wall: BW 350mm - 200mm MB3 + 100mm MB1 + 50m	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	8178.99	Kg CO2 eq.
29	Basic Wall: BW 350mm - 200mm MB3 + 100mm MB1 + 50m	120145@student.buid.ac.ae	2015-05-25T00	(GWP)ClimateChange	oduction	Type	Walls	6417.78	Kg CO2 eq.
30	Basic Wall: BW 375mm - 200mm MB3 + 100mm MB1 + 025r	120145@student.buid.ac.ae	2015-05-25T00	(ODP)StratosphericOzoneLayerDestructic	oduction	Type	Walls	4525.13	Kg CO2 eq.
31	Basic Wall: Conc 200mm	120145@student.buid.ac.ae	2015-05-25T00	(AP)AtmosphericAcidification (EP)Eutrophication	oduction	Type	Walls	7175.45	Kg CO2 eq.
32	Basic Wall: STR 200mm - 200mm CON	120145@student.buid.ac.ae	2015-05-25T00	(POCP)PhotochemicalOzoneFormation (nPE)NonRenewableEnergyConsumptior	oduction	Type	Walls	357.84	Kg CO2 eq.
33	Cast-In-Place Stair: BOH STAIR.1	120145@student.buid.ac.ae	2015-05-25T00	(TPE)TotalPrimaryEnergyConsumption TotalWaterConsumption	oduction	Type	Stairs	15630.23	Kg CO2 eq.
34	Cast-In-Place Stair: BOH-STAIR 2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Stairs	629.27	Kg CO2 eq.

... Assembly Connection Spare Resource Job Impact Document Attribute Coordinate Issue PickLists

6.8 Conclusion

The conducted case study has clearly proven the applicability and usability of the proposed Integrating BIM Process. It has also shown the efficiency of the process as a real-time evaluation mechanism for checking the compliance of different concrete mix designs with Dubai Municipality Green Concrete guidelines and LEED V4 MRc1 (option 4) and MRc2 requirements. In addition, all the involved team members including structural, architectural, sustainability and BIM departments has expressed a high level of interest and enthusiasm during the implementation of the integrated process which has proven the simplicity and acceptance of the proposed framework and declared the readiness of the team for such an innovative approach.

Chapter 7: Limitations, Recommendations and Conclusions

7.1 Conclusion

Environmental concerns have increased in the recent past as it has become evident that global warming is caused by human activities such as the release of greenhouse gases into the atmosphere. The construction industry contributes substantially to these harmful effects, thereby necessitating the creation of new methods for reducing pollution and enhancing building sustainability. Propelled by improved computation power and information transfer methods, BIM has emerged as one of the most effective methods for creating sustainable buildings. BIM enables designers to analyze a design's sustainability credentials during the design phase. Additionally, it enables different specialists to collaborate to produce highly sustainable designs early in the process. Consequently, BIM eliminates the problems associated with "island" design environments where some specialists are limited in their efforts at sustainability by the design flaws of other specialists. Despite its promise, BIM has yet to be successfully integrated with sustainability assessment. Additionally, management and coordination problems exist since the design environment is still in its infancy.

This study has identified BIM as a process for facilitating the achievement of project's goals in general and sustainability targets in particular. It has recognized the absence of a comprehensive process-driven approach in the market for a BIM-based sustainability assessment through a detailed literature review. After a thorough analysis of industry best practices that have addressed the specificity of those BIM-based sustainability assessment approaches, the research has proposed an integrated BIM implementation process that facilitates the Integrated Project Delivery (IPD) method and provides a real-time data evaluation mechanism within the Autodesk Revit modeling context. This was supported by the use of a customized information management and tracking tool to preserve the consistency of data exchange during the project evolution. The proposed mechanism has been further detailed by developing specific Revit parameters and formulas for checking and facilitating the compliance against LEED V4 MRc1 (option 4) and MRc2 requirements regarding the environmental impacts of concrete products in construction projects. In addition, a Level 2 BIM process map was generated for guiding project teams through the detailed implementation of the integrated workflow of the resulting process.

The applicability of the proposed concept was further tested through a case-study which has verified the ease and efficiency of the developed BIM process and the accuracy of the mechanism outputs that have indicated remarkable reductions in concrete Environmental Impacts through the usage of more sustainable concrete mix designs that contains a higher percentage of cement replacement products.

In conclusion, the study has demonstrated that the integrated BIM-based sustainability assessment approach should be based on the synergies between BIM, IPD and sustainability at the administrative and execution levels. This approach could be achieved by the wide engagement of all project stakeholders at early design stage with a clear definition of BIM goals along with detailed roles and responsibilities and information exchange protocols during the execution process.

In addition, sound BIM process mapping would considerably improve the efficiency and add value to the integrated BIM workflow. The research has also urged the early materials review procedure and the creation of a standardized materials database to regulate the materials selection for future projects.

After all, the wide acceptance of the proposed integrated BIM process by all team members during the case study application has substantiated the ease and efficiency of the workflow and reflected the team enthusiasm for such an integrated method especially after realizing its immediate positive impacts on project's activities at the management and level by enabling better coordination and decision making while having more control on project's requirements which were arranged within one source of information. In addition, the Integrated BIM Process has added value to the project implementation activities by reducing the time and the cost needed for those actions and supporting in getting more accurate results with less interoperability issues. All of these benefits would be achieved while ensuring the successful compliance with the project goals in general and sustainability targets in particular (Figure: 7.1).

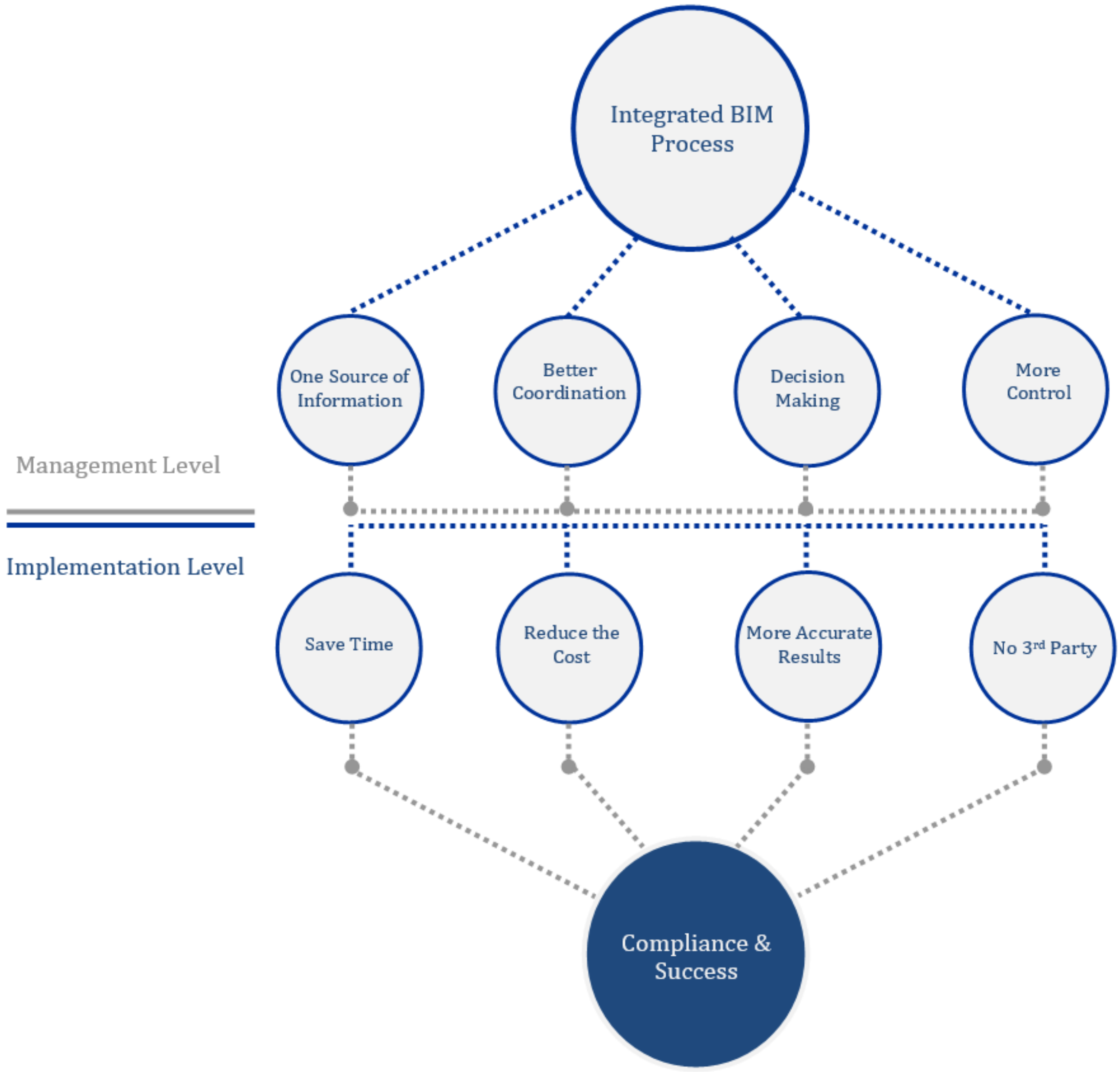


Figure 7.1: Benefits of the proposed Integrated BIM Process

7.2 Limitations of this research

Taking into consideration the large amount of LEED V4 credits and due to the time limitation of this research, this study was not able to generate the BIM level 2 process maps for every single LEED V4 credit.

Instead, a particular credit achievement framework was explained and verified. This has covered BIM usage for evaluating the Environmental Impacts of project's elements and check the compliance with LEED V4 MRc1 and MRc2 requirements. In addition, the generation of a Level 2 BIM process map was also demonstrated following the guidelines of the CIC BIM Project Execution Planning Guide.

7.3 Recommendations for future work

There is much future work that could be done to make the proposed Integrated BIM process more convenient for projects teams. A few are discussed below:

11.3.1 **Level 2 BIM process maps - LEED V4 credits**

Future research should look into applying the developed Level 2 BIM process map to the remaining material divisions taking into consideration the required specific parameters for each division in order to facilitate the real-time evaluation procedures and check the overall compliance with LEED V4 MRc1 and MRc2 environmental impacts requirements while generating a whole-Building Life Cycle Assessment (LCA) within the Revit modeling context.

In addition, further research can be conducted in order to utilize the concept that was provided in this study to develop similar Level 2 BIM process maps regarding more BIM-based LEED V4 credits assessment especially the ones that are related directly to the properties of the applied project materials like sourcing of raw materials for MRc3 and materials ingredients for MRc4. This will generate a set of standardized Level 2 BIM process maps that would be included in the BIM Execution Plans for all the future projects which will systemize the LEED V4 compliance paths and make them as essential parts of project's workflows.

11.3.2 **Standard Revit Materials Libraries**

As suggested in this study, by taking the Level of Detail (LOD) while developing the BIM models to the Materials level, projects teams will be able to generate information-rich modelling elements that would support in providing more accurate and reliable data about the project's properties in general and its sustainability impacts in particular. In addition, by applying the proposed Integrated BIM process to multiple projects types, teams will be able to develop a standard materials database containing all the approved and frequently used products which can be saved in existing or specially created material libraries with all their unique properties and parameters so they can be utilized directly in similar future projects. This method will save a lot of time and effort during the information modeling procedure while ensuring that the used materials would be complying with the required characteristics for achieving project's goals and targets.

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Appendices

Appendix A: RIBA Plan of Work 2013 Template

RIBA Plan of Work 2013

RIBA

The RIBA Plan of Work 2013 organises the process of briefing, designing, constructing, maintaining, operating and using building projects into a number of key stages. The content of stages may vary or overlap to suit specific project requirements. The RIBA Plan of Work 2013 should be used solely as guidance for the preparation of detailed professional services contracts and building contracts.

www.ribaplanofwork.com

Stages / Tasks	0 Strategic Definition	1 Preparation and Brief	2 Concept Design	3 Developed Design	4 Technical Design	5 Construction	6 Handover and Close Out	7 In Use
Core Objectives	Identify client's **Business Case** and **Strategic Brief** and other core project requirements.	Develop **Project Objectives**, including **Quality Objectives** and **Project Outcomes**, **Sustainability Aspirations**, **Project Budget**, other parameters or constraints and develop **Initial Project Brief**. Undertake **Feasibility Studies** and review of **Site Information**.	Prepare **Concept Design**, including outline proposals for structural design, building services systems, outline specifications and preliminary **Cost Information** along with relevant **Project Strategies** in accordance with **Design Programme**. Agree alterations to brief and issue **Final Project Brief**.	Prepare **Developed Design**, including coordinated and updated proposals for structural design, building services systems, outline specifications, **Cost Information** and **Project Strategies** in accordance with **Design Programme**.	Prepare **Technical Design** in accordance with **Design Responsibility Matrix** and **Project Strategies** to include all architectural, structural and building services information, specialist subcontractor design and specifications, in accordance with **Design Programme**.	Offsite manufacturing and onsite **Construction** in accordance with **Construction Programme** and resolution of **Design Queries** from site as they arise.	Handover of building and conclusion of **Building Contract**.	Undertake **In Use** services in accordance with **Schedule of Services**.
Procurement *Variable task bar	Initial considerations for assembling the project team.	Prepare **Project Roles Table** and **Contractual Tree** and continue assembling the project team.	The procurement strategy does not fundamentally alter the progression of the design or the level of detail prepared at a given stage. However, **Information Exchanges** will vary depending on the selected procurement route and **Building Contract**. A bespoke **RIBA Plan of Work 2013** will set out the specific tendering and procurement activities that will occur at each stage in relation to the chosen procurement route.			Administration of **Building Contract**, including regular site inspections and review of progress.	Conclude administration of **Building Contract**.	
Programme *Variable task bar	Establish **Project Programme**.	Review **Project Programme**.	Review **Project Programme**.	The procurement route may dictate the **Project Programme** and may result in certain stages overlapping or being undertaken concurrently. A bespoke **RIBA Plan of Work 2013** will clarify the stage overlaps. The **Project Programme** will set out the specific stage dates and detailed programme durations.				
(Town) Planning *Variable task bar	Pre-application discussions.	Pre-application discussions.	Planning applications are typically made using the Stage 3 output. A bespoke **RIBA Plan of Work 2013** will identify when the planning application is to be made.					
Suggested Key Support Tasks	Review **Feedback** from previous projects.	Prepare **Handover Strategy** and **Risk Assessments**. Agree **Schedule of Services**, **Design Responsibility Matrix** and **Information Exchanges** and prepare **Project Execution Plan** including **Technology** and **Communication Strategies** and consideration of **Common Standards** to be used.	Prepare **Sustainability Strategy**, **Maintenance and Operational Strategy** and review **Handover Strategy** and **Risk Assessments**. Undertake third party consultations as required and any **Research and Development** aspects. Review and update **Project Execution Plan**. Consider **Construction Strategy**, including offsite fabrication, and develop **Health and Safety Strategy**.	Review and update **Sustainability**, **Maintenance and Operational** and **Handover Strategies** and **Risk Assessments**. Undertake third party consultations as required and conclude **Research and Development** aspects. Review and update **Project Execution Plan**, including **Change Control Procedures**. Review and update **Construction** and **Health and Safety Strategies**.	Review and update **Sustainability**, **Maintenance and Operational** and **Handover Strategies** and **Risk Assessments**. Prepare and submit Building Regulations submission and any other third party submissions requiring consent. Review and update **Project Execution Plan**. Review **Construction Strategy**, including sequencing, and update **Health and Safety Strategy**.	Review and update **Sustainability Strategy** and implement **Handover Strategy**, including agreement of information required for commissioning, training, handover, asset management, future monitoring and maintenance and ongoing compilation of **'As-constructed' Information**. Update **Construction** and **Health and Safety Strategies**.	Carry out activities listed in **Handover Strategy** including **Feedback** for use during the future life of the building or on future projects. Updating of **Project Information** as required.	Conclude activities listed in **Handover Strategy** including **Post-occupancy Evaluation**, review of **Project Performance**, **Project Outcomes** and **Research and Development** aspects. Updating of **Project Information**, as required, in response to ongoing client **Feedback** until the end of the building's life.
Sustainability Checkpoints	**Sustainability Checkpoint — 0**	**Sustainability Checkpoint — 1**	**Sustainability Checkpoint — 2**	**Sustainability Checkpoint — 3**	**Sustainability Checkpoint — 4**	**Sustainability Checkpoint — 5**	**Sustainability Checkpoint — 6**	**Sustainability Checkpoint — 7**
Information Exchanges (at stage completion)	**Strategic Brief**.	**Initial Project Brief**.	**Concept Design** including outline structural and building services design, associated **Project Strategies**, preliminary **Cost Information** and **Final Project Brief**.	**Developed Design**, including the coordinated architectural, structural and building services design and updated **Cost Information**.	Completed **Technical Design** of the project.	**'As-constructed' Information**.	Updated **'As-constructed' Information**.	**'As-constructed' Information** updated in response to ongoing client **Feedback** and maintenance or operational developments.
UK Government Information Exchanges	Not required.	Required.	Required.	Required.	Not required.	Not required.	Required.	As required.

***Variable task bar** – in creating a bespoke project or practice specific RIBA Plan of Work 2013 via www.ribaplanofwork.com a specific bar is selected from a number of options.

Appendix B: Sample Revit Formulas used in this study

GWP.Compliance.LEED.V4: (Kg/m3) – Basic as per Athena Benchmark Report:

If (and (Material: CS > 0 MPa, not (Material: CS > 17.24 MPa)), 288.76 - Material: GWP, If (and (Material: CS > 17.24 MPa, not (Material: CS > 20.68 MPa)), 320.99 - Material: GWP, If (and (Material: CS > 20.68 MPa, not (Material: CS > 27.58 MPa)), 391.53 - Material: GWP, If (and (Material: CS > 27.58 MPa, not (Material: CS > 34.47 MPa)), 482.27 - Material: GWP, If (and (Material: CS > 34.47 MPa, not (Material: CS > 41.37 MPa)), 508.09 - Material: GWP, If (and (Material: CS > 41.37 MPa, not (Material: CS > 55.16 MPa)), 618.02 - Material: GWP, -1))))))

GWP.Compliance.LEED.V4: (Kg/m3) – More Detailed as per Concrete Combination Content and Athena Benchmark Report:

If(and(not(Material: Com.Cont < 200), Material: Com.Cont < 205), 272.15 - Material: GWP,If(and(not(Material: Com.Cont < 205), Material: Com.Cont < 210), 277.87 - Material: GWP,If(and(not(Material: Com.Cont < 210), Material: Com.Cont < 215), 283.63 - Material: GWP,If(and(not(Material: Com.Cont < 215), Material: Com.Cont < 220), 289.57 - Material: GWP,If(and(not(Material: Com.Cont < 220), Material: Com.Cont < 225), 295.52 - Material: GWP,If(and(not(Material: Com.Cont < 225), Material: Com.Cont < 230), 301.47 - Material: GWP,If(and(not(Material: Com.Cont < 230), Material: Com.Cont < 235), 307.42 - Material: GWP,If(and(not(Material: Com.Cont < 235), Material: Com.Cont < 240), 313.36 - Material: GWP,If(and(not(Material: Com.Cont < 240), Material: Com.Cont < 245), 319.31 - Material: GWP,If(and(not(Material: Com.Cont < 245), Material: Com.Cont < 250), 325.26 - Material: GWP,If(and(not(Material: Com.Cont < 250), Material: Com.Cont < 255), 331.21 - Material: GWP,If(and(not(Material: Com.Cont < 255), Material: Com.Cont < 260), 337.16 - Material: GWP,If(and(not(Material: Com.Cont < 260), Material: Com.Cont < 265), 343.11 - Material: GWP,If(and(not(Material: Com.Cont < 265), Material: Com.Cont < 270), 349.03 - Material: GWP,If(and(not(Material: Com.Cont < 270), Material: Com.Cont < 275), 354.93 - Material: GWP,If(and(not(Material: Com.Cont < 275), Material: Com.Cont < 280), 360.83 - Material: GWP,If(and(not(Material: Com.Cont < 280), Material: Com.Cont < 285), 366.73 - Material: GWP,If(and(not(Material: Com.Cont < 285), Material: Com.Cont < 290), 372.63 - Material: GWP,If(and(not(Material: Com.Cont < 290), Material: Com.Cont < 295), 378.53 - Material: GWP,If(and(not(Material: Com.Cont < 295), Material: Com.Cont < 300), 384.43 - Material: GWP,If(and(not(Material: Com.Cont < 300), Material: Com.Cont < 305), 390.33 - Material:

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GWP,If(and(not(Material: Com.Cont < 310), Material: Com.Cont < 315), 402.13 - Material:
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GWP,If(and(not(Material: Com.Cont < 320), Material: Com.Cont < 325), 413.93 - Material:
GWP,If(and(not(Material: Com.Cont < 325), Material: Com.Cont < 330), 419.83 - Material:
GWP,If(and(not(Material: Com.Cont < 330), Material: Com.Cont < 335), 425.73 - Material:
GWP,If(and(not(Material: Com.Cont < 335), Material: Com.Cont < 340), 431.63 - Material:
GWP,If(and(not(Material: Com.Cont < 340), Material: Com.Cont < 345), 437.74 - Material:
GWP,If(and(not(Material: Com.Cont < 345), Material: Com.Cont < 350), 443.71 - Material:
GWP,If(and(not(Material: Com.Cont < 350), Material: Com.Cont < 355), 449.76 - Material:
GWP,If(and(not(Material: Com.Cont < 355), Material: Com.Cont < 360), 455.73 - Material:
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GWP,If(and(not(Material: Com.Cont < 365), Material: Com.Cont < 370), 467.67 - Material:
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GWP,If(and(not(Material: Com.Cont < 380), Material: Com.Cont < 385), 485.60 - Material:
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GWP,If(and(not(Material: Com.Cont < 425), Material: Com.Cont < 430), 539.35 - Material:
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GWP,If(and(not(Material: Com.Cont < 445), Material: Com.Cont < 450), 563.23 - Material:
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GWP,If(and(not(Material: Com.Cont < 455), Material: Com.Cont < 460), 575.17 - Material:
GWP,If(and(not(Material: Com.Cont < 460), Material: Com.Cont < 465), 581.14 - Material:
GWP,If(and(not(Material: Com.Cont < 465), Material: Com.Cont < 470), 587.11 - Material:
GWP,If(and(not(Material: Com.Cont < 470), Material: Com.Cont < 475), 593.08 - Material:

GWP,If(and(not(Material: Com.Cont < 475), Material: Com.Cont < 480), 599.05 - Material: GWP,If(and(not(Material: Com.Cont < 480), Material: Com.Cont < 485), 605.02 - Material: GWP,If(and(not(Material: Com.Cont < 485), Material: Com.Cont < 490), 610.99 - Material: GWP,If(and(not(Material: Com.Cont < 490), Material: Com.Cont < 495), 616.96 - Material: GWP,If(and(not(Material: Com.Cont < 495), Material: Com.Cont < 500), 622.93 - Material: GWP,If(and(not(Material: Com.Cont < 500), Material: Com.Cont < 505), 628.90 - Material: GWP,If(and(not(Material: Com.Cont < 505), Material: Com.Cont < 510), 634.87 - Material: GWP,If(not(Material: Com.Cont < 510), 640.84 - Material: GWP, -1))

Conditional Formatting : GWP.Compliance.LEED.V4<0 Red

Total.GWP.Str.Encl: (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * Material: GWP, 0)

Conditional Formatting: Calculate Totals

Total.GWP.Reduction.Str.Encl : (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * GWP.Compliance.LEED.V4, 0)

Conditional Formatting: Calculate Totals

Total.GWP.Str.Encl.Benchmark : (Kg)

Total.GWP.Str.Encl + Total.GWP.Reduction.Str.Encl

ODP.Compliance.LEED.V4: (Kg/m3)

If(and(not(Material: Com.Cont < 200), Material: Com.Cont < 205), 4.47 - Material:
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ODP,If(and(not(Material: Com.Cont < 345), Material: Com.Cont < 350), 7.09 - Material:
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ODP,If(and(not(Material: Com.Cont < 360), Material: Com.Cont < 365), 7.37 - Material: ODP,If(and(not(Material: Com.Cont < 365), Material: Com.Cont < 370), 7.46 - Material: ODP,If(and(not(Material: Com.Cont < 370), Material: Com.Cont < 375), 7.55 - Material: ODP,If(and(not(Material: Com.Cont < 375), Material: Com.Cont < 380), 7.64 - Material: ODP,If(and(not(Material: Com.Cont < 380), Material: Com.Cont < 385), 7.73 - Material: ODP,If(and(not(Material: Com.Cont < 385), Material: Com.Cont < 390), 7.82 - Material: ODP,If(and(not(Material: Com.Cont < 390), Material: Com.Cont < 395), 7.91 - Material: ODP,If(and(not(Material: Com.Cont < 395), Material: Com.Cont < 400), 8.00 - Material: ODP,If(and(not(Material: Com.Cont < 400), Material: Com.Cont < 405), 8.09 - Material: ODP,If(and(not(Material: Com.Cont < 405), Material: Com.Cont < 410), 8.18 - Material: ODP,If(and(not(Material: Com.Cont < 410), Material: Com.Cont < 415), 8.27 - Material: ODP,If(and(not(Material: Com.Cont < 415), Material: Com.Cont < 420), 8.36 - Material: ODP,If(and(not(Material: Com.Cont < 420), Material: Com.Cont < 425), 8.45 - Material: ODP,If(and(not(Material: Com.Cont < 425), Material: Com.Cont < 430), 8.54 - Material: ODP,If(and(not(Material: Com.Cont < 430), Material: Com.Cont < 435), 8.63 - Material: ODP,If(and(not(Material: Com.Cont < 435), Material: Com.Cont < 440), 8.72 - Material: ODP,If(and(not(Material: Com.Cont < 440), Material: Com.Cont < 445), 8.81 - Material: ODP,If(and(not(Material: Com.Cont < 445), Material: Com.Cont < 450), 8.90 - Material: ODP,If(and(not(Material: Com.Cont < 450), Material: Com.Cont < 455), 8.99 - Material: ODP,If(and(not(Material: Com.Cont < 455), Material: Com.Cont < 460), 9.08 - Material: ODP,If(and(not(Material: Com.Cont < 460), Material: Com.Cont < 465), 9.17 - Material: ODP,If(and(not(Material: Com.Cont < 465), Material: Com.Cont < 470), 9.26 - Material: ODP,If(and(not(Material: Com.Cont < 470), Material: Com.Cont < 475), 9.35 - Material: ODP,If(and(not(Material: Com.Cont < 475), Material: Com.Cont < 480), 9.44 - Material: ODP,If(and(not(Material: Com.Cont < 480), Material: Com.Cont < 485), 9.53 - Material: ODP,If(and(not(Material: Com.Cont < 485), Material: Com.Cont < 490), 9.62 - Material: ODP,If(and(not(Material: Com.Cont < 490), Material: Com.Cont < 495), 9.71 - Material: ODP,If(and(not(Material: Com.Cont < 495), Material: Com.Cont < 500), 9.80 - Material: ODP,If(and(not(Material: Com.Cont < 500), Material: Com.Cont < 505), 9.89 - Material: ODP,If(and(not(Material: Com.Cont < 505), Material: Com.Cont < 510), 9.98 - Material: ODP,If(not(Material: Com.Cont < 510), 10.07 - Material: ODP, -1)))

Conditional Formatting: ODP.Compliance.LEED.V4<0 Red

Total.ODP.Str.Enc : (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * Material: ODP,0)

Conditional Formatting: Calculate Totals

Total.ODP.Reduction.Str.Encl : (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * ODP.Compliance.LEED.V4, 0)

Conditional Formatting: Calculate Totals

Total.ODP.Str.Encl.Benchmark : (Kg)

Total.ODP.Str.Encl + Total.ODP.Reduction.Str.Encl

AP.Compliance.LEED.V4: (Kg/m3)

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AP,If(and(not(Material: Com.Cont < 305), Material: Com.Cont < 310), 2.134 - Material:
AP,If(and(not(Material: Com.Cont < 310), Material: Com.Cont < 315), 2.210 - Material:
AP,If(and(not(Material: Com.Cont < 315), Material: Com.Cont < 320), 2.286 - Material:
AP,If(and(not(Material: Com.Cont < 320), Material: Com.Cont < 325), 2.362 - Material:
AP,If(and(not(Material: Com.Cont < 325), Material: Com.Cont < 330), 2.446 - Material:
AP,If(and(not(Material: Com.Cont < 330), Material: Com.Cont < 335), 2.530 - Material:
AP,If(and(not(Material: Com.Cont < 335), Material: Com.Cont < 340), 2.555 - Material:
AP,If(and(not(Material: Com.Cont < 340), Material: Com.Cont < 345), 2.580 - Material:
AP,If(and(not(Material: Com.Cont < 345), Material: Com.Cont < 350), 2.605 - Material:
AP,If(and(not(Material: Com.Cont < 350), Material: Com.Cont < 355), 2.630 - Material:
AP,If(and(not(Material: Com.Cont < 355), Material: Com.Cont < 360), 2.653 - Material:
AP,If(and(not(Material: Com.Cont < 360), Material: Com.Cont < 365), 2.677 - Material:
AP,If(and(not(Material: Com.Cont < 365), Material: Com.Cont < 370), 2.700 - Material:
AP,If(and(not(Material: Com.Cont < 370), Material: Com.Cont < 375), 2.724 - Material:
AP,If(and(not(Material: Com.Cont < 375), Material: Com.Cont < 380), 2.747 - Material:
AP,If(and(not(Material: Com.Cont < 380), Material: Com.Cont < 385), 2.771 - Material:
AP,If(and(not(Material: Com.Cont < 385), Material: Com.Cont < 390), 2.794 - Material:
AP,If(and(not(Material: Com.Cont < 390), Material: Com.Cont < 395), 2.818 - Material:
AP,If(and(not(Material: Com.Cont < 395), Material: Com.Cont < 400), 2.841 - Material:
AP,If(and(not(Material: Com.Cont < 400), Material: Com.Cont < 405), 2.865 - Material:
AP,If(and(not(Material: Com.Cont < 405), Material: Com.Cont < 410), 2.888 - Material:
AP,If(and(not(Material: Com.Cont < 410), Material: Com.Cont < 415), 2.912 - Material:
AP,If(and(not(Material: Com.Cont < 415), Material: Com.Cont < 420), 2.935 - Material:
AP,If(and(not(Material: Com.Cont < 420), Material: Com.Cont < 425), 2.959 - Material:
AP,If(and(not(Material: Com.Cont < 425), Material: Com.Cont < 430), 2.982 - Material:
AP,If(and(not(Material: Com.Cont < 430), Material: Com.Cont < 435), 3.006 - Material:

AP,If(and(not(Material: Com.Cont < 435), Material: Com.Cont < 440), 3.029 - Material: AP,If(and(not(Material: Com.Cont < 440), Material: Com.Cont < 445), 3.053 - Material: AP,If(and(not(Material: Com.Cont < 445), Material: Com.Cont < 450), 3.076 - Material: AP,If(and(not(Material: Com.Cont < 450), Material: Com.Cont < 455), 3.100 - Material: AP,If(and(not(Material: Com.Cont < 455), Material: Com.Cont < 460), 3.123 - Material: AP,If(and(not(Material: Com.Cont < 460), Material: Com.Cont < 465), 3.147 - Material: AP,If(and(not(Material: Com.Cont < 465), Material: Com.Cont < 470), 3.170 - Material: AP,If(and(not(Material: Com.Cont < 470), Material: Com.Cont < 475), 3.194 - Material: AP,If(and(not(Material: Com.Cont < 475), Material: Com.Cont < 480), 3.217 - Material: AP,If(and(not(Material: Com.Cont < 480), Material: Com.Cont < 485), 3.241 - Material: AP,If(and(not(Material: Com.Cont < 485), Material: Com.Cont < 490), 3.264 - Material: AP,If(and(not(Material: Com.Cont < 490), Material: Com.Cont < 495), 3.288 - Material: AP,If(and(not(Material: Com.Cont < 495), Material: Com.Cont < 500), 3.311 - Material: AP,If(and(not(Material: Com.Cont < 500), Material: Com.Cont < 505), 3.335 - Material: AP,If(and(not(Material: Com.Cont < 505), Material: Com.Cont < 510), 3.358 - Material: AP,If(not(Material: Com.Cont < 510), 3.382 - Material: AP, -1)))

Conditional Formatting: AP.Compliance.LEED.V4<0 Red

Total.AP.Str.Encl : (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * Material: AP, 0)

Conditional Formatting: Calculate Totals

Total.AP.Reduction.Str.Encl : (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * AP.Compliance.LEED.V4, 0)

Conditional Formatting: Calculate Totals

Total.AP.Str.Encl.Benchmark : (Kg)

Total.AP.Str.Encl + Total.AP.Reduction.Str.Encl

EP.Compliance.LEED.V4: (Kg/m3)

If(and(not(Material: Com.Cont < 200), Material: Com.Cont < 205), 0.2228 - Material: EP,If(and(not(Material: Com.Cont < 205), Material: Com.Cont < 210), 0.2268 - Material: EP,If(and(not(Material: Com.Cont < 210), Material: Com.Cont < 215), 0.2307 - Material: EP,If(and(not(Material: Com.Cont < 215), Material: Com.Cont < 220), 0.2345 - Material: EP,If(and(not(Material: Com.Cont < 220), Material: Com.Cont < 225), 0.2383 - Material: EP,If(and(not(Material: Com.Cont < 225), Material: Com.Cont < 230), 0.2420 - Material: EP,If(and(not(Material: Com.Cont < 230), Material: Com.Cont < 235), 0.2458 - Material: EP,If(and(not(Material: Com.Cont < 235), Material: Com.Cont < 240), 0.2496 - Material: EP,If(and(not(Material: Com.Cont < 240), Material: Com.Cont < 245), 0.2534 - Material: EP,If(and(not(Material: Com.Cont < 245), Material: Com.Cont < 250), 0.2571 - Material: EP,If(and(not(Material: Com.Cont < 250), Material: Com.Cont < 255), 0.2609 - Material: EP,If(and(not(Material: Com.Cont < 255), Material: Com.Cont < 260), 0.2647 - Material: EP,If(and(not(Material: Com.Cont < 260), Material: Com.Cont < 265), 0.2685 - Material: EP,If(and(not(Material: Com.Cont < 265), Material: Com.Cont < 270), 0.2748 - Material: EP,If(and(not(Material: Com.Cont < 270), Material: Com.Cont < 275), 0.2827 - Material: EP,If(and(not(Material: Com.Cont < 275), Material: Com.Cont < 280), 0.2907 - Material: EP,If(and(not(Material: Com.Cont < 280), Material: Com.Cont < 285), 0.2987 - Material: EP,If(and(not(Material: Com.Cont < 285), Material: Com.Cont < 290), 0.3066 - Material: EP,If(and(not(Material: Com.Cont < 290), Material: Com.Cont < 295), 0.3146 - Material: EP,If(and(not(Material: Com.Cont < 295), Material: Com.Cont < 300), 0.3225 - Material: EP,If(and(not(Material: Com.Cont < 300), Material: Com.Cont < 305), 0.3305 - Material: EP,If(and(not(Material: Com.Cont < 305), Material: Com.Cont < 310), 0.3385 - Material: EP,If(and(not(Material: Com.Cont < 310), Material: Com.Cont < 315), 0.3465 - Material: EP,If(and(not(Material: Com.Cont < 315), Material: Com.Cont < 320), 0.3544 - Material: EP,If(and(not(Material: Com.Cont < 320), Material: Com.Cont < 325), 0.3624 - Material: EP,If(and(not(Material: Com.Cont < 325), Material: Com.Cont < 330), 0.3704 - Material: EP,If(and(not(Material: Com.Cont < 330), Material: Com.Cont < 335), 0.3784 - Material: EP,If(and(not(Material: Com.Cont < 335), Material: Com.Cont < 340), 0.3821 - Material:

EP,If(and(not(Material: Com.Cont < 340), Material: Com.Cont < 345), 0.3847 - Material:

EP,If(and(not(Material: Com.Cont < 345), Material: Com.Cont < 350), 0.3873 - Material:

EP,If(and(not(Material: Com.Cont < 350), Material: Com.Cont < 355), 0.3900 - Material:

EP,If(and(not(Material: Com.Cont < 355), Material: Com.Cont < 360), 0.3942 - Material:

EP,If(and(not(Material: Com.Cont < 360), Material: Com.Cont < 365), 0.3984 - Material:

EP,If(and(not(Material: Com.Cont < 365), Material: Com.Cont < 370), 0.4026 - Material:

EP,If(and(not(Material: Com.Cont < 370), Material: Com.Cont < 375), 0.4068 - Material:

EP,If(and(not(Material: Com.Cont < 375), Material: Com.Cont < 380), 0.4110 - Material:

EP,If(and(not(Material: Com.Cont < 380), Material: Com.Cont < 385), 0.4153 - Material:

EP,If(and(not(Material: Com.Cont < 385), Material: Com.Cont < 390), 0.4195 - Material:

EP,If(and(not(Material: Com.Cont < 390), Material: Com.Cont < 395), 0.4237 - Material:

EP,If(and(not(Material: Com.Cont < 395), Material: Com.Cont < 400), 0.4279 - Material:

EP,If(and(not(Material: Com.Cont < 400), Material: Com.Cont < 405), 0.4321 - Material:

EP,If(and(not(Material: Com.Cont < 405), Material: Com.Cont < 410), 0.4363 - Material:

EP,If(and(not(Material: Com.Cont < 410), Material: Com.Cont < 415), 0.4406 - Material:

EP,If(and(not(Material: Com.Cont < 415), Material: Com.Cont < 420), 0.4448 - Material:

EP,If(and(not(Material: Com.Cont < 420), Material: Com.Cont < 425), 0.4490 - Material:

EP,If(and(not(Material: Com.Cont < 425), Material: Com.Cont < 430), 0.4532 - Material:

EP,If(and(not(Material: Com.Cont < 430), Material: Com.Cont < 435), 0.4574 - Material:

EP,If(and(not(Material: Com.Cont < 435), Material: Com.Cont < 440), 0.4616 - Material:

EP,If(and(not(Material: Com.Cont < 440), Material: Com.Cont < 445), 0.4658 - Material:

EP,If(and(not(Material: Com.Cont < 445), Material: Com.Cont < 450), 0.4700 - Material:

EP,If(and(not(Material: Com.Cont < 450), Material: Com.Cont < 455), 0.4742 - Material:

EP,If(and(not(Material: Com.Cont < 455), Material: Com.Cont < 460), 0.4784 - Material:

EP,If(and(not(Material: Com.Cont < 460), Material: Com.Cont < 465), 0.4826 - Material:

EP,If(and(not(Material: Com.Cont < 465), Material: Com.Cont < 470), 0.4868 - Material:

EP,If(and(not(Material: Com.Cont < 470), Material: Com.Cont < 475), 0.4910 - Material:

EP,If(and(not(Material: Com.Cont < 475), Material: Com.Cont < 480), 0.4952 - Material:

EP,If(and(not(Material: Com.Cont < 480), Material: Com.Cont < 485), 0.4994 - Material:

EP,If(and(not(Material: Com.Cont < 485), Material: Com.Cont < 490), 0.5036 - Material:

EP,If(and(not(Material: Com.Cont < 490), Material: Com.Cont < 495), 0.5078 - Material:

EP,If(and(not(Material: Com.Cont < 495), Material: Com.Cont < 500), 0.5120 - Material:

EP,If(and(not(Material: Com.Cont < 500), Material: Com.Cont < 505), 0.5162 - Material:

EP,If(and(not(Material: Com.Cont < 505), Material: Com.Cont < 510), 0.5204 - Material:

EP,If(not(Material: Com.Cont < 510), 0.5246 - Material: EP, -
1)))

Conditional Formatting: EP.Compliance.LEED.V4<0 Red

Total.EP.Str.Encl : (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * Material: EP, 0)

Conditional Formatting: Calculate Totals

Total.EP.Reduction.Str.Encl : (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * EP.Compliance.LEED.V4, 0)

Conditional Formatting: Calculate Totals

Total.EP.Str.Encl.Benchmark : (Kg)

Total.EP.Str.Encl + Total.EP.Reduction.Str.Encl

POCP.Compliance.LEED.V4: (Kg/m3)

If(and(not(Material: Com.Cont < 200), Material: Com.Cont < 205), 16.27 - Material: POCP,If(and(not(Material: Com.Cont < 205), Material: Com.Cont < 210), 16.52 - Material: POCP,If(and(not(Material: Com.Cont < 210), Material: Com.Cont < 215), 16.77 - Material: POCP,If(and(not(Material: Com.Cont < 215), Material: Com.Cont < 220), 17.03 - Material: POCP,If(and(not(Material: Com.Cont < 220), Material: Com.Cont < 225), 17.30 - Material: POCP,If(and(not(Material: Com.Cont < 225), Material: Com.Cont < 230), 17.56 - Material: POCP,If(and(not(Material: Com.Cont < 230), Material: Com.Cont < 235), 17.82 - Material: POCP,If(and(not(Material: Com.Cont < 235), Material: Com.Cont < 240), 18.08 - Material: POCP,If(and(not(Material: Com.Cont < 240), Material: Com.Cont < 245), 18.35 - Material:

POCP,If(and(not(Material: Com.Cont < 245), Material: Com.Cont < 250), 18.61- Material:
POCP,If(and(not(Material: Com.Cont < 250), Material: Com.Cont < 255), 18.88 - Material:
POCP,If(and(not(Material: Com.Cont < 255), Material: Com.Cont < 260), 19.14 - Material:
POCP,If(and(not(Material: Com.Cont < 260), Material: Com.Cont < 265), 19.40 - Material:
POCP,If(and(not(Material: Com.Cont < 265), Material: Com.Cont < 270), 20.01 - Material:
POCP,If(and(not(Material: Com.Cont < 270), Material: Com.Cont < 275), 20.85 - Material:
POCP,If(and(not(Material: Com.Cont < 275), Material: Com.Cont < 280), 21.69 - Material:
POCP,If(and(not(Material: Com.Cont < 280), Material: Com.Cont < 285), 22.53 - Material:
POCP,If(and(not(Material: Com.Cont < 285), Material: Com.Cont < 290), 23.36 - Material:
POCP,If(and(not(Material: Com.Cont < 290), Material: Com.Cont < 295), 24.20 - Material:
POCP,If(and(not(Material: Com.Cont < 295), Material: Com.Cont < 300), 25.04 - Material:
POCP,If(and(not(Material: Com.Cont < 300), Material: Com.Cont < 305), 25.88 - Material:
POCP,If(and(not(Material: Com.Cont < 305), Material: Com.Cont < 310), 26.72 - Material:
POCP,If(and(not(Material: Com.Cont < 310), Material: Com.Cont < 315), 27.56 - Material:
POCP,If(and(not(Material: Com.Cont < 315), Material: Com.Cont < 320), 28.39 - Material:
POCP,If(and(not(Material: Com.Cont < 320), Material: Com.Cont < 325), 29.23 - Material:
POCP,If(and(not(Material: Com.Cont < 325), Material: Com.Cont < 330), 30.07 - Material:
POCP,If(and(not(Material: Com.Cont < 330), Material: Com.Cont < 335), 30.91 - Material:
POCP,If(and(not(Material: Com.Cont < 335), Material: Com.Cont < 340), 31.31 - Material:
POCP,If(and(not(Material: Com.Cont < 340), Material: Com.Cont < 345), 31.61 - Material:
POCP,If(and(not(Material: Com.Cont < 345), Material: Com.Cont < 350), 31.90 - Material:
POCP,If(and(not(Material: Com.Cont < 350), Material: Com.Cont < 355), 32.20 - Material:
POCP,If(and(not(Material: Com.Cont < 355), Material: Com.Cont < 360), 32.46 - Material:
POCP,If(and(not(Material: Com.Cont < 360), Material: Com.Cont < 365), 32.73 - Material:
POCP,If(and(not(Material: Com.Cont < 365), Material: Com.Cont < 370), 32.99 - Material:
POCP,If(and(not(Material: Com.Cont < 370), Material: Com.Cont < 375), 33.26 - Material:
POCP,If(and(not(Material: Com.Cont < 375), Material: Com.Cont < 380), 33.52 - Material:
POCP,If(and(not(Material: Com.Cont < 380), Material: Com.Cont < 385), 33.78 - Material:
POCP,If(and(not(Material: Com.Cont < 385), Material: Com.Cont < 390), 34.04 - Material:
POCP,If(and(not(Material: Com.Cont < 390), Material: Com.Cont < 395), 34.31 - Material:
POCP,If(and(not(Material: Com.Cont < 395), Material: Com.Cont < 400), 34.57 - Material:
POCP,If(and(not(Material: Com.Cont < 400), Material: Com.Cont < 405), 34.84 - Material:
POCP,If(and(not(Material: Com.Cont < 405), Material: Com.Cont < 410), 35.10 - Material:
POCP,If(and(not(Material: Com.Cont < 410), Material: Com.Cont < 415), 35.37 - Material:

POCP,If(and(not(Material: Com.Cont < 415), Material: Com.Cont < 420), 35.63 - Material:
POCP,If(and(not(Material: Com.Cont < 420), Material: Com.Cont < 425), 35.89 - Material:
POCP,If(and(not(Material: Com.Cont < 425), Material: Com.Cont < 430), 36.15 - Material:
POCP,If(and(not(Material: Com.Cont < 430), Material: Com.Cont < 435), 36.42 - Material:
POCP,If(and(not(Material: Com.Cont < 435), Material: Com.Cont < 440), 36.68 - Material:
POCP,If(and(not(Material: Com.Cont < 440), Material: Com.Cont < 445), 36.94 - Material:
POCP,If(and(not(Material: Com.Cont < 445), Material: Com.Cont < 450), 37.20 - Material:
POCP,If(and(not(Material: Com.Cont < 450), Material: Com.Cont < 455), 37.46 - Material:
POCP,If(and(not(Material: Com.Cont < 455), Material: Com.Cont < 460), 37.72 - Material:
POCP,If(and(not(Material: Com.Cont < 460), Material: Com.Cont < 465), 37.98 - Material:
POCP,If(and(not(Material: Com.Cont < 465), Material: Com.Cont < 470), 38.24 - Material:
POCP,If(and(not(Material: Com.Cont < 470), Material: Com.Cont < 475), 38.50 - Material:
POCP,If(and(not(Material: Com.Cont < 475), Material: Com.Cont < 480), 38.76 - Material:
POCP,If(and(not(Material: Com.Cont < 480), Material: Com.Cont < 485), 39.02 - Material:
POCP,If(and(not(Material: Com.Cont < 485), Material: Com.Cont < 490), 39.28 - Material:
POCP,If(and(not(Material: Com.Cont < 490), Material: Com.Cont < 495), 39.54 - Material:
POCP,If(and(not(Material: Com.Cont < 495), Material: Com.Cont < 500), 39.80 - Material:
POCP,If(and(not(Material: Com.Cont < 500), Material: Com.Cont < 505), 40.06 - Material:
POCP,If(and(not(Material: Com.Cont < 505), Material: Com.Cont < 510), 40.32 - Material:
POCP,If(not(Material: Com.Cont < 510), 40.58 - Material: POCP, -
1))

Conditional Formatting: POCP.Compliance.LEED.V4<0 Red

Total.POCP.Str.Encl : (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * Material: POCP, 0)

Conditional Formatting: Calculate Totals

Total.POCP.Reduction.Str.Encl: (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * POCP.Compliance.LEED.V4, 0)

Conditional Formatting: Calculate Totals

Total.POCP.Str.Encl.Benchmark : (Kg)

Total.POCP.Str.Encl + Total.POCP.Reduction.Str.Encl

nPE.Compliance.LEED.V4: (Kg/m3)

If(and(not(Material: Com.Cont < 200), Material: Com.Cont < 205), 2194.36 - Material: nPE,If(and(not(Material: Com.Cont < 205), Material: Com.Cont < 210), 2234.16 - Material: nPE,If(and(not(Material: Com.Cont < 210), Material: Com.Cont < 215), 2274.37 - Material: nPE,If(and(not(Material: Com.Cont < 215), Material: Com.Cont < 220), 2316.26 - Material: nPE,If(and(not(Material: Com.Cont < 220), Material: Com.Cont < 225), 2358.15 - Material: nPE,If(and(not(Material: Com.Cont < 225), Material: Com.Cont < 230), 2400.035 - Material: nPE,If(and(not(Material: Com.Cont < 230), Material: Com.Cont < 235), 2441.92 - Material: nPE,If(and(not(Material: Com.Cont < 235), Material: Com.Cont < 240), 2483.805 - Material: nPE,If(and(not(Material: Com.Cont < 240), Material: Com.Cont < 245), 2525.69 - Material: nPE,If(and(not(Material: Com.Cont < 245), Material: Com.Cont < 250), 2567.58 - Material: nPE,If(and(not(Material: Com.Cont < 250), Material: Com.Cont < 255), 2609.47 - Material: nPE,If(and(not(Material: Com.Cont < 255), Material: Com.Cont < 260), 2651.355 - Material: nPE,If(and(not(Material: Com.Cont < 260), Material: Com.Cont < 265), 2693.24 - Material: nPE,If(and(not(Material: Com.Cont < 265), Material: Com.Cont < 270), 2735.01 - Material: nPE,If(and(not(Material: Com.Cont < 270), Material: Com.Cont < 275), 2776.78 - Material: nPE,If(and(not(Material: Com.Cont < 275), Material: Com.Cont < 280), 2818.52 - Material: nPE,If(and(not(Material: Com.Cont < 280), Material: Com.Cont < 285), 2860.26 - Material: nPE,If(and(not(Material: Com.Cont < 285), Material: Com.Cont < 290), 2902 - Material: nPE,If(and(not(Material: Com.Cont < 290), Material: Com.Cont < 295), 2943.74 - Material: nPE,If(and(not(Material: Com.Cont < 295), Material: Com.Cont < 300), 2985.475 - Material: nPE,If(and(not(Material: Com.Cont < 300), Material: Com.Cont < 305), 3027.21 - Material: nPE,If(and(not(Material: Com.Cont < 305), Material: Com.Cont < 310), 3068.95 - Material:

nPE,If(and(not(Material: Com.Cont < 310), Material: Com.Cont < 315), 3110.69 - Material:
nPE,If(and(not(Material: Com.Cont < 315), Material: Com.Cont < 320), 3152.43 - Material:
nPE,If(and(not(Material: Com.Cont < 320), Material: Com.Cont < 325), 3194.17 - Material:
nPE,If(and(not(Material: Com.Cont < 325), Material: Com.Cont < 330), 3235.91- Material:
nPE,If(and(not(Material: Com.Cont < 330), Material: Com.Cont < 335), 3277.65 - Material:
nPE,If(and(not(Material: Com.Cont < 335), Material: Com.Cont < 340), 3321.85 - Material:
nPE,If(and(not(Material: Com.Cont < 340), Material: Com.Cont < 345), 3366.05 - Material:
nPE,If(and(not(Material: Com.Cont < 345), Material: Com.Cont < 350), 3410.525 - Material:
nPE,If(and(not(Material: Com.Cont < 350), Material: Com.Cont < 355), 3455 - Material:
nPE,If(and(not(Material: Com.Cont < 355), Material: Com.Cont < 360), 3497.41 - Material:
nPE,If(and(not(Material: Com.Cont < 360), Material: Com.Cont < 365), 3539.82 - Material:
nPE,If(and(not(Material: Com.Cont < 365), Material: Com.Cont < 370), 3582.225 - Material:
nPE,If(and(not(Material: Com.Cont < 370), Material: Com.Cont < 375), 3624.63 - Material:
nPE,If(and(not(Material: Com.Cont < 375), Material: Com.Cont < 380), 3667.04 - Material:
nPE,If(and(not(Material: Com.Cont < 380), Material: Com.Cont < 385), 3709.45 - Material:
nPE,If(and(not(Material: Com.Cont < 385), Material: Com.Cont < 390), 3751.86 - Material:
nPE,If(and(not(Material: Com.Cont < 390), Material: Com.Cont < 395), 3794.27 - Material:
nPE,If(and(not(Material: Com.Cont < 395), Material: Com.Cont < 400), 3836.68 - Material:
nPE,If(and(not(Material: Com.Cont < 400), Material: Com.Cont < 405), 3879.09 - Material:
nPE,If(and(not(Material: Com.Cont < 405), Material: Com.Cont < 410), 3921.5 - Material:
nPE,If(and(not(Material: Com.Cont < 410), Material: Com.Cont < 415), 3963.91 - Material:
nPE,If(and(not(Material: Com.Cont < 415), Material: Com.Cont < 420), 4006.32 - Material:
nPE,If(and(not(Material: Com.Cont < 420), Material: Com.Cont < 425), 4048.73 - Material:
nPE,If(and(not(Material: Com.Cont < 425), Material: Com.Cont < 430), 4091.14 - Material:
nPE,If(and(not(Material: Com.Cont < 430), Material: Com.Cont < 435), 4133.55 - Material:
nPE,If(and(not(Material: Com.Cont < 435), Material: Com.Cont < 440), 4175.96 - Material:
nPE,If(and(not(Material: Com.Cont < 440), Material: Com.Cont < 445), 4218.37 - Material:
nPE,If(and(not(Material: Com.Cont < 445), Material: Com.Cont < 450), 4260.78 - Material:
nPE,If(and(not(Material: Com.Cont < 450), Material: Com.Cont < 455), 4303.19 - Material:
nPE,If(and(not(Material: Com.Cont < 455), Material: Com.Cont < 460), 4345.6 - Material:
nPE,If(and(not(Material: Com.Cont < 460), Material: Com.Cont < 465), 4388.01 - Material:
nPE,If(and(not(Material: Com.Cont < 465), Material: Com.Cont < 470), 4430.42 - Material:
nPE,If(and(not(Material: Com.Cont < 470), Material: Com.Cont < 475), 4472.83 - Material:
nPE,If(and(not(Material: Com.Cont < 475), Material: Com.Cont < 480), 4515.24 - Material:

nPE,If(and(not(Material: Com.Cont < 480), Material: Com.Cont < 485), 4557.65 - Material:
nPE,If(and(not(Material: Com.Cont < 485), Material: Com.Cont < 490), 4600.06 - Material:
nPE,If(and(not(Material: Com.Cont < 490), Material: Com.Cont < 495), 4642.47 - Material:
nPE,If(and(not(Material: Com.Cont < 495), Material: Com.Cont < 500), 4684.88 - Material:
nPE,If(and(not(Material: Com.Cont < 500), Material: Com.Cont < 505), 4727.29 - Material:
nPE,If(and(not(Material: Com.Cont < 505), Material: Com.Cont < 510), 4769.7 - Material:
nPE,If(not(Material: Com.Cont < 510), 4812.11 - Material: nPE, -
1)))

Conditional Formatting: nPE.Compliance.LEED.V4<0 Red

Total.nPE.Str.Encl : (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * Material: nPE, 0)

Conditional Formatting: Calculate Totals

Total.nPE.Reduction.Str.Encl : (Kg)

If (or(Material: Str, Material: Encl), Material: Volume * nPE.Compliance.LEED.V4, 0)

Conditional Formatting: Calculate Totals

Total.nPE.Str.Encl.Benchmark : (Kg)

Total.nPE.Str.Encl + Total.nPE.Reduction.Str.Encl

DM.Compliance:

If(and(and(and(and(and(Not(Material: CS < 25 MPa), Material: CS < 30 MPa),not(Material: Com.Cont < 340)), Material: Com.Cont < 360), not(Material: OPC > 0.34)), not([Material: W/C]> 0.50)), 1,If(and(and(and(and(and(Not(Material: CS < 30 MPa), not(Material: CS > 32 MPa)),not(Material: Com.Cont < 360)), Material: Com.Cont < 380), not(Material: OPC > 0.64)), not([Material: W/C]> 0.45)), 1,If(and(and(and(and(Not(Material: CS < 32 MPa), Material: CS < 40 MPa),not(Material: Com.Cont < 380)), not(Material: OPC > 0.64)), not([Material: W/C]> 0.40)), 1,If(and(and(Not(Material: CS < 40 MPa),not(Material: Com.Cont < 380)), not([Material: W/C]> 0.35)), 1, If (Material: CS < 25 MPa, 1, 0)))))

Conditional Formatting: DM.Compliance = 0 Red

If (Material: CS= 30, 1, 0)

Com.Cont.Check:

If (Material: OPC + Material: GGBS + Material: FA + Material: MS = 1, 1, 0)

Conditional Formatting: Com.Cont.Check = 0 Red

Prod.Value.Str.Encl :

If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Prod.Spec.EPD), Material: Wi.160),or(Material: Str, Material: Encl)), 2,

If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Prod.Spec.EPD), not(Material: Wi.160)), or(Material: Str, Material: Encl)), 1, If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Ind.Avg.EPD), not(Material: Wi.160)), or(Material: Str, Material: Encl)), 1/2,If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Ind.Avg.EPD), Material: Wi.160), or(Material: Str, Material: Encl)), 1,If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Self.Dcl.EPD), Material: Wi.160), or(Material: Str, Material: Encl)), 1/2 ,If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Self.Dcl.EPD), not(Material: Wi.160)), or(Material: Str, Material: Encl)), 1/4,0))))))

If (and(and(Material: Prod.Spec.EPD), Material: Wi.160),or(Material: Str, Material: Encl)), 2,If (and(and(Material: Prod.Spec.EPD), not(Material: Wi.160)), or(Material: Str, Material: Encl)), 1,If (and(and(Material: Ind.Avg.EPD), not(Material: Wi.160)), or(Material: Str, Material: Encl)), 1/2,If (and(and(Material: Ind.Avg.EPD), Material: Wi.160), or(Material: Str, Material: Encl)), 1,If (and(and(Material: Self.Dcl.EPD), Material: Wi.160), or(Material: Str, Material: Encl)), 1/2,If (and(and(Material: Self.Dcl.EPD), not(Material: Wi.160)), or(Material: Str, Material: Encl)), 1/4,0)

Prod.Value.Not.Str.Encl :

If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Prod.Spec.EPD), Material: Wi.160),not(or(Material: Str, Material: Encl))), 2,If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Prod.Spec.EPD), not(Material: Wi.160)), not(or(Material: Str, Material: Encl))), 1,If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Ind.Avg.EPD), not(Material: Wi.160)), not(or(Material: Str, Material: Encl))), 1/2,If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Ind.Avg.EPD), Material: Wi.160), not(or(Material: Str, Material: Encl))), 1,If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Self.Dcl.EPD), Material: Wi.160), not(or(Material: Str, Material: Encl))), 1/2 ,If (and(and(and(and(and(and(and(and(not(GWP.Compliance.LEED.V4 < 0), not(ODP.Compliance.LEED.V4 < 0)), not(AP.Compliance.LEED.V4 < 0)), not(EP.Compliance.LEED.V4 < 0)), not(POCP.Compliance.LEED.V4 < 0)), not(nPE.Compliance.LEED.V4 < 0)), Material: Self.Dcl.EPD), not(Material: Wi.160)), not(or(Material: Str, Material: Encl))), 1/4,0))))))

If (and(and(Material: Prod.Spec.EPD), Material: Wi.160),not(or(Material: Str, Material: Encl))), 2,If (and(and(Material: Prod.Spec.EPD), not(Material: Wi.160)),not(or(Material: Str, Material: Encl))), 1,If (and(and(Material: Ind.Avg.EPD), not(Material: Wi.160)),not(or(Material: Str, Material: Encl))), 1/2,If (and(and(Material: Ind.Avg.EPD), Material: Wi.160),not(or(Material: Str, Material: Encl))), 1,If (and(and(Material: Self.Dcl.EPD), Material: Wi.160),not(or(Material: Str, Material: Encl))), 1/2,If (and(and(Material: Self.Dcl.EPD), not(Material: Wi.160)),not(or(Material: Str, Material: Encl))), 1/4,0)

Total.Concrete.Cost: (Kg)

Material: Volume * [Material: Concrete.Cost/m3]

Calculate Totals

Cost.of.Complying.Concrete: (Kg)

If (and(and (not(GWP.Compliance.LEED.V4<0), not(ODP.Compliance.LEED.V4<0)),not(AP.Compliance.LEED.V4<0)), Total.Concrete.Cost,if(and(and (not(GWP.Compliance.LEED.V4<0), not(ODP.Compliance.LEED.V4<0)),not(EP.Compliance.LEED.V4<0)), Total.Concrete.Cost,if(and(and (not(GWP.Compliance.LEED.V4<0), not(ODP.Compliance.LEED.V4<0)),not(POCP.Compliance.LEED.V4<0)), Total.Concrete.Cost,if(and(and (not(GWP.Compliance.LEED.V4<0), not(ODP.Compliance.LEED.V4<0)),not(nPE.Compliance.LEED.V4<0)), Total.Concrete.Cost,if(and(and (not(GWP.Compliance.LEED.V4<0), not(AP.Compliance.LEED.V4<0)),not(EP.Compliance.LEED.V4<0)), Total.Concrete.Cost,if(and(and (not(GWP.Compliance.LEED.V4<0), not(AP.Compliance.LEED.V4<0)),not(POCP.Compliance.LEED.V4<0)), Total.Concrete.Cost,if(and(and (not(GWP.Compliance.LEED.V4<0), not(AP.Compliance.LEED.V4<0)),not(nPE.Compliance.LEED.V4<0)), Total.Concrete.Cost,if(and(and (not(GWP.Compliance.LEED.V4<0), not(EP.Compliance.LEED.V4<0)),not(POCP.Compliance.LEED.V4<0)),

Total.Concrete.Cost,if(and(and (not(GWP.Compliance.LEED.V4<0),
not(EP.Compliance.LEED.V4<0)),not(nPE.Compliance.LEED.V4<0)),
Total.Concrete.Cost,if(and(and (not(GWP.Compliance.LEED.V4<0),
not(POCP.Compliance.LEED.V4<0)),not(nPE.Compliance.LEED.V4<0)),
Total.Concrete.Cost,if(and(and (not(ODP.Compliance.LEED.V4<0),
not(AP.Compliance.LEED.V4<0)),not(EP.Compliance.LEED.V4<0)),
Total.Concrete.Cost,if(and(and (not(ODP.Compliance.LEED.V4<0),
not(AP.Compliance.LEED.V4<0)),not(POCP.Compliance.LEED.V4<0)),
Total.Concrete.Cost,if(and(and (not(ODP.Compliance.LEED.V4<0),
not(AP.Compliance.LEED.V4<0)),not(nPE.Compliance.LEED.V4<0)),
Total.Concrete.Cost,if(and(and (not(ODP.Compliance.LEED.V4<0),
not(EP.Compliance.LEED.V4<0)),not(POCP.Compliance.LEED.V4<0)),
Total.Concrete.Cost,if(and(and (not(ODP.Compliance.LEED.V4<0),
not(EP.Compliance.LEED.V4<0)),not(nPE.Compliance.LEED.V4<0)),
Total.Concrete.Cost,if(and(and (not(ODP.Compliance.LEED.V4<0),
not(POCP.Compliance.LEED.V4<0)),not(nPE.Compliance.LEED.V4<0)),
Total.Concrete.Cost,if(and(and (not(AP.Compliance.LEED.V4<0),
not(EP.Compliance.LEED.V4<0)),not(POCP.Compliance.LEED.V4<0)),
Total.Concrete.Cost,if(and(and (not(AP.Compliance.LEED.V4<0),
not(EP.Compliance.LEED.V4<0)),not(nPE.Compliance.LEED.V4<0)),
Total.Concrete.Cost,if(and(and (not(EP.Compliance.LEED.V4<0),
not(POCP.Compliance.LEED.V4<0)),not(nPE.Compliance.LEED.V4<0)),
Total.Concrete.Cost,0))))))))))))))))))))

Calculate Totals

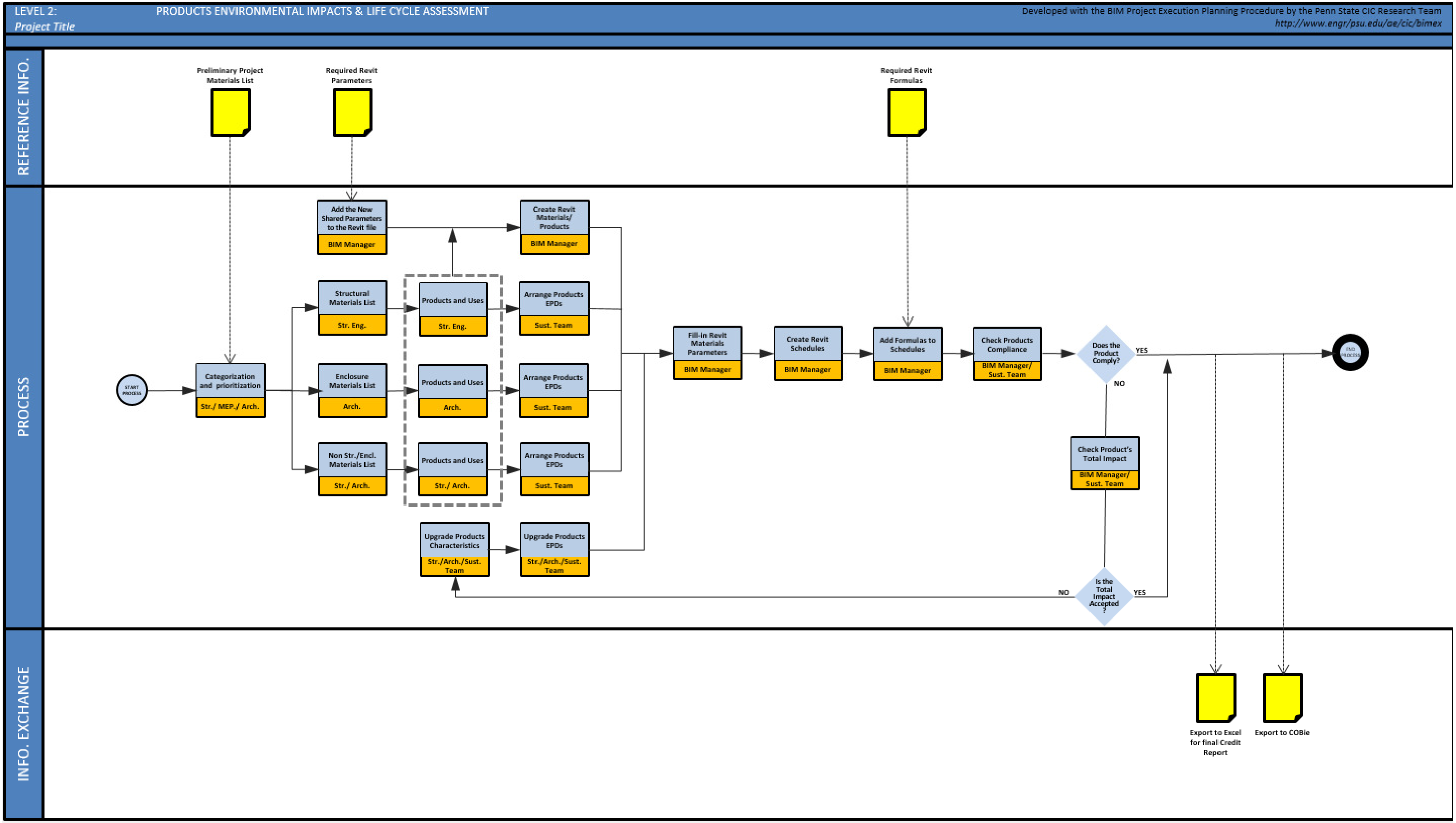
Cost.of.Complying.Concrete.Str.Encl:

If (or(Material: Str,Material: Encl), Cost.of.Complying.Concrete,0)

Cost.of.Complying.Concrete.Not.Str.Encl:

If (and (not(Material: Str),not(Material: Encl)), Cost.of.Complying.Concrete,0)

Appendix C: BIM process map for achieving LEED V4 MRc1 (option 4) & MRc2 requirements



LEVEL 2:
Project Title
PRODUCTS ENVIRONMENTAL IMPACTS & LIFE CYCLE ASSESSMENT
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team
http://www.engr/psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Preliminary Project Materials List
Required Revit Parameters
Required Revit Formulas
START PROCESS
Categorization and prioritization
Str./ MEP./ Arch.
Add the New Shared Parameters to the Revit file
BIM Manager
Create Revit Materials/ Products
BIM Manager
Structural Materials List
Str. Eng.
Products and Uses
Str. Eng.
Arrange Products EPDs
Sust. Team
Enclosure Materials List
Arch.
Products and Uses
Arch.
Arrange Products EPDs
Sust. Team
Non Str./Encl. Materials List
Str./ Arch.
Products and Uses
Str./ Arch.
Arrange Products EPDs
Sust. Team
Upgrade Products Characteristics
Str./Arch./Sust. Team
Upgrade Products EPDs
Str./Arch./Sust. Team
Fill-in Revit Materials Parameters
BIM Manager
Create Revit Schedules
BIM Manager
Add Formulas to Schedules
BIM Manager
Check Products Compliance
BIM Manager/ Sust. Team
Does the Product Comply?
YES
NO
Check Product's Total Impact
BIM Manager/ Sust. Team
Is the Total Impact Accepted?
NO
YES
END PROCESS
Export to Excel for final Credit Report
Export to COBie

Appendix D: Sample of a generated Revit Schedule

A	B	C	D	E	F	G	H	I
Category	Family and Type	COBieTypeCreatedBy	COBieTypeCreatedOn	Count	Material: Name	Material: COBieCreatedBy	Material: COBieCreatedOn	Material: Manufacturer
Floors	Floor: ROOF BUILD UP 150mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: ROOF BUILD UP 100mm	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/23/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC4	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix
Floors	Floor: FLOOR FINISH-PC1	120145@student.buid.ac.ae	05/25/2015	1	Concrete - Floor FC1 Sand/Cement Screed - C15	120145@student.buid.ac.ae	05/24/2015	Arabian Mix

Appendix E: COBie impact data results

	A	B	C	D	E	F	G	H	I
1	Name	CreatedBy	CreatedOn	ImpactType	ImpactStage	SheetName	RowName	Value	ImpactUnit
2	1300mm Retaining Wall1: 1300mm Retaining Wall	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	1261034.72	Kg CO2 eq.
3	1300mm Retaining Wall2: 1300mm Retaining Wall	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	33148.83	Kg CO2 eq.
4	1300mm Retaining Wall: 1300mm Retaining Wall	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	35068.84	Kg CO2 eq.
5	Column Rectangular Conc-Insitu: 300 x 300mm	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Structural Columns	6192.33	Kg CO2 eq.
6	Column Rectangular Conc-Insitu: 800 x 800mm	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Structural Columns	74702.83	Kg CO2 eq.
7	Basic Wall: BW 100mm - 100mm MB1 + PC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	366.28	Kg CO2 eq.
8	Basic Wall: BW 125mm - 100mm MB1 + 25mm WC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	149.08	Kg CO2 eq.
9	Basic Wall: BW 150mm - 100mm MB1 + 50mm INS	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	1461.22	Kg CO2 eq.
10	Basic Wall: BW 150mm - 150mm MB2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	8116.56	Kg CO2 eq.
11	Basic Wall: BW 200mm - 200mm MB3	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	76099.16	Kg CO2 eq.
12	Basic Wall: BW 200mm - 200mm MB3 + ONE SIDE PC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	3725.1	Kg CO2 eq.
13	Basic Wall: BW 200mm - 200mm MB3 + PC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	33759.51	Kg CO2 eq.
14	Basic Wall: BW 200mm - 200mm MB3 + PC2 both sides	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	84697.79	Kg CO2 eq.
15	Basic Wall: BW 200mm - 200mm MC1	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	4966.39	Kg CO2 eq.
16	Basic Wall: BW 225mm - 200mm MB3 + 25mm WC1	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	3837.79	Kg CO2 eq.
17	Basic Wall: BW 225mm - 200mm MB3 + 025mm WC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	7477.1	Kg CO2 eq.
18	Basic Wall: BW 250mm - 200mm MB3 + 025mm WC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	1131.36	Kg CO2 eq.
19	Basic Wall: BW 250mm - 200mm MB3 + 025mm WC2 + 025	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	1040.4	Kg CO2 eq.
20	Basic Wall: BW 300mm - 200mm MB3 + 100mm WT1	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	150.64	Kg CO2 eq.
21	Basic Wall: BW 300mm - 300mm MB4	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	62598.33	Kg CO2 eq.
22	Basic Wall: BW 300mm - 300mm MB4 + 025mm WC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	715.78	Kg CO2 eq.
23	Basic Wall: BW 325mm - 100mm MB1 + 100mm WP2 + 25m	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	103.19	Kg CO2 eq.
24	Basic Wall: BW 325mm - 200mm MB3 +100mm WT1 + 025	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	3004.27	Kg CO2 eq.
25	Basic Wall: BW 325mm - 200mm MB3 +100mm WT1 WC2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	10257.64	Kg CO2 eq.
26	Basic Wall: BW 350mm - 100mm MB1 + 100mm MB1 + 025	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	513.6	Kg CO2 eq.
27	Basic Wall: BW 350mm - 200mm MB3 + 050mm INS + 100m	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Walls	16643.81	Kg CO2 eq.
28	Basic Wall: BW 350mm - 200mm MB3 + 100mm MB1 + 50m	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	oduction	Type	Walls	8178.99	Kg CO2 eq.
29	Basic Wall: BW 350mm - 200mm MB3 + 100mm MB1 + 50m	120145@student.buid.ac.ae	2015-05-25T00		oduction	Type	Walls	6417.78	Kg CO2 eq.
30	Basic Wall: BW 375mm - 200mm MB3 + 100mm MB1 + 025	120145@student.buid.ac.ae	2015-05-25T00		oduction	Type	Walls	4525.13	Kg CO2 eq.
31	Basic Wall: Conc 200mm	120145@student.buid.ac.ae	2015-05-25T00		oduction	Type	Walls	7175.45	Kg CO2 eq.
32	Basic Wall: STR 200mm - 200mm CON	120145@student.buid.ac.ae	2015-05-25T00		oduction	Type	Walls	357.84	Kg CO2 eq.
33	Cast-In-Place Stair: BOH STAIR.1	120145@student.buid.ac.ae	2015-05-25T00		oduction	Type	Stairs	15630.23	Kg CO2 eq.
34	Cast-In-Place Stair: BOH-STAIR 2	120145@student.buid.ac.ae	2015-05-25T00:00:00	(GWP)ClimateChange	Production	Type	Stairs	629.27	Kg CO2 eq.

(GWP)ClimateChange
(ODP)StratosphericOzoneLayerDestructic
(AP)AtmosphericAcidification
(EP)Eutrophication
(POCP)PhotochemicalOzoneFormation
(nPE)NonRenewableEnergyConsumptior
(TPE)TotalPrimaryEnergyConsumption
TotalWaterConsumption

... Assembly | Connection | Spare | Resource | Job | **Impact** | Document | Attribute | Coordinate | Issue | PickLists