جامعة عين شـــــمس

العمران المتكامل و التصميم المستدام

إمكانات الدمج بين تقييم دورة الحياة و نمذجة معلومات البناء

المحفزات و المعوقات و التوصيات لتطوير البناء الفعال في مصر

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إقرار

هذه الرسالة مقدمة في جامعة عين شمس وجامعة شوتجارت للحصول على درجة العمران المتكامل والتصميم المستدام. إن العمل الذي تحويه هذه الرسالة قد تم إنجازه بمعرفة الباحث سنة 2019

هذا ويقر الباحث أن العمل المقدم هو خلاصة بحثه الشخصي وأنه قد اتبع الإسلوب العلمي السليم في الإشارة إلى المواد المؤخوذه من المراجع العلمية كلٌ في مكانه في مختلف أجزاء الرسالة..

وهذا إقرار مني بذلك،،،

التوقيع: نهى محمد عادل علي رضا رضوان

الباحث:

التاريخ: 28 /7 /2019

ملـــخـــص

المباني هي منتجات معقدة للغاية، عمرها الإفتراضي طويل نسبيا يمكن أن تستمر لعقود. تم إثبات أنها تولد عدد من الآثار السلبية على البيئة المحيطة بها، عندما يتم بنائها بالطرق التقليدية. لذلك، تم تطوير عدد كبير من أنظمة تصنيف المباني الخضراء في العقود القليلة الماضية للحد من هذه الأثار السلبية مع التركيز بشكل كبيرعلى تقييم استدامة هذه المباني. هناك طرق أخرى لتقييم الآثار البيئية للمباني، منها "تقييم دورة الحياة" ، الذي له العديد من الفوائد في توسيع نطاق تقييم الاستدامة من خلال منظور "من المهد إلى اللحد" الذي يتضمن التقييم البيئي لجميع مراحل دورة حياة المبنى. تميزت التكنولوجيا الحديثة مثل نمذجة معلومات البناء ،في الأونة الأخيرة في اتاحة الفرصة لتنظيم عملية تصميم معماري شاملة لتتضمن تمثيلات بصرية ثلاثية الأبعاد (أو أكثر) و تعزيزات بدراسات محاكاة لاداء الطاقة و الحرارة و الضوء الطبيعي مع مدعومة بامكانية التعاون بين اعضاء الفريق و الاطراف المعنيين. أثبت هذا الاسلوب الجديد للتشكيل المبني على فكرة البناء بالاشياء (بمفهومها الحقيقي) القدرة على الحصول على المعلومات المتعلقة لأنواع الخامات و خصائصها و كمياتها و أداء الطاقة مع تحسين عنصر الإستدامة و رفع كفاءة البيئة المبنية. على الرغم من تواجد تكنولوجيا نمذجة البناء من ما يقرب من 20 عاما, لكن ففط في الاونة الاخيرة بدأت انشطة العمارة و الهندسة و التشييد في ادراك قدراتها على جعل عملية البناء أكثر سهولة و أعلى كفاءة. في مصر, و على الرغم من الانتشار الملحوظ لتكنولوجيا نمذجة البناء, إلا انه لا تزال معرفة العاملين في مجال البناء بالامكانات الكاملة لهذة التكنولوجيا الحديثة محدودة بشكل كبير. استخدام تكنولوجيا نمذجة البناء لا يمكنه مفردا تحقيق مستوى الكفاءة المرجو. و لذلك, يهدف هذا البحث لايضاح اهمية دعم نمذجة البناء كأدوات و اضافة مبادئ التصميم التوجيهية المستوحاة من أنظمة تصنيف المباني الخضراء و تطبيقها على مراحل دورة حياة المباني كاملة, يمكن لذلك بدوره تحقيق ناجاحات و تحسين ممارسات البناء الفعال في مصر. من المهم أن نفهم أن الخيارات التي تم اتخاذها في الوقت الحاضر حول كيفية بناء وتصميم وتشغيل المباني يمكن أن تؤثر بشكل كبير على كل من الخدمات الحضرية وقابلية العيش لعقود قادمة. لهذا السبب ، يمكن أن تكون المباني ذات الكفاءة العالية والأداء المنخفض للطاقة عاملاً رئيسياً في إنشاء مدن مستدامة تمثل حجر الأساس لأهداف التنمية المستدامة التي يتم السعي إليها دوليا.

Integrated Urbanism & Sustainable Design (IUSD)

Ain Shams University
Egypt

POTENTIALS OF INTEGRATION BETWEEN LIFE-CYCLE ASSESSMENT AND BUILDING INFORMATION MODELLING

TRIGGERS, OBSTACLES AND RECOMMENDATIONS FOR PROMOTING

EFFICIENT BUILDING IN EGYPT

A Thesis submitted in the Partial Fulfillment for the Requirement of the Degree

of Master of Science in Integrated Urbanism and Sustainable Design

by

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(Cairo 2019)

DISCLAIMER

This dissertation is submitted to Ain Shams University (ASU) and University of Stuttgart - Faculty of Architecture and Urban Planning (USTUTT) for the degree of Integrated Urbanism and Sustainable Design (IUSD), in accordance to IUSD-ASU regulations.

The work included in this thesis was carried out by the author during the period from February - July 2019.

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07/28/2019

(Noha Mohamed Adel Ali Reda Radwan)

Signature

Noha Radwan

DEDICATION

To My Dear Husband,

ACKNOWLEDGEMENTS

First, I thank Allah for granting me such a great opportunity.

I wish to express my deepest gratitude to my academic supervisors Prof. Dr. Samir Sadek Hosny and Prof. Dr. Mohamed A. Salheen for their guidance throughout the development of this study. Prof. Dr. Samir has always provided advice, criticism, and insights in all aspects of this research. Prof. Dr. Mohamed A. Salheen has provided support and attention throughout the whole study.

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Finally, a thank you also goes to IUSD Cairo, all professors and staff.

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ACRONYMS, ABBREVIATIONS AND DEFINITIONS

2D Two-Dimensional

3D Three Dimensional

AEC Architecture, Engineering and Construction

AGC The Associated General Contractors of America

ANSI American National Standards Institute

AP Accredited Professional

ASHRAE American Society of Heating, Refrigeration and Air-Conditioning Engineers

ASTM American Society for Testing and Materials

BEP BIM Execution Plan

BRE Global Building Research Establishment

CAD Computer Aided Design

CASBEE Comprehensive Assessment System for Built Environment Efficiency

CDE Common Data Environment

CF Carbon Footprint

CMMS Computer Maintenance and Management Systems

CO_2 Carbon dioxide

COBIe : Construction Operations Building Information exchange

CPIC Construction Project Information Committee

EA Environmental Assessment

EDMS Electronic Document management System

ECG Egyptian Contractors Group

EGBC Egyptian Green Building Council

EGGBC Egypt Green Building Council

EPA Environmental Protection Agency

EPD Environmental Product Declaration

GBCI Green Business Certification Inc.

GBRS Green Building Rating Systems

gbXML Green Building eXtensible Markup Language

GPP Green Public Procurement

GPRS Green Pyramid Rating System

HQP Highly Qualified Personnel

HVAC Heating, Ventilation and Air Conditioning

IAI Alliance for Interoperability

IPD Integrated Project Delivery

ISO the International Standards Organization

ITC Information Technology for Construction

LCA : Life-Cycle Assessment

LCC Life-Cycle Costing

$LCCO_2A$ Life=Cycle Carbon Dioxide Assessment

LCEA Life-Cycle Energy Assessment

LCI Life cycle Inventory

LCIA Life-Cycle Impact Assessment

LOD Level of Detail and Development

MENA Middle East and North Africa

O & M Operation and Maintenance

PDM Project Delivery Method

PtD Prevention through Design

ROI Return of Investment

SaaS Software as Service

SWOT Strengths, Weaknesses, Opportunities and Threats Analysis

UAE United Arab Emirates

UK United Kingdom

UNEP United Nations' Environmental Programme

USA United States of America

USGBC The U.S. Green Building Council

WBLCA Whole Building Life-cycle Assessment

SOFTWARE GLOSSARY

Life-Cycle Assessment Tools

ATHENA LCA software that provides a user-friendly mechanism for designers to access the LCA databases and quickly estimate footprint of a building assembly or a whole building.

BEES (Building for Environmental and Economic Sustainability) tool is developed by the National Institute of Standards and Technology (NIST).

Ecoinvent is a leading LCI (not-for-profit) database that provides well documented process data for thousands of products, helping users to make truly informed choices about their environmental impact. Ecoinvent database comprises LCI data from the energy, transport, building materials, chemicals, paper and pulp, waste treatment and agricultural sectors reflecting the production and supply situation.

EPA's TRACI 2 V3.0 the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (developed by US EPA).

One Click LCA offers a wide range of services such as; Early stage LCA calculation and design optimization, circularity assessment, Carbon foot-printing and Life-cycle Costing.

Building Information Modeling Tools

Autodesk's Revit is a Building Information Modeling (BIM) software which allows the user to design with parametric modeling and drafting elements. Revit is a single file database that can be shared among multiple users. Plans, sections, elevations, legends, and schedules are all interconnected, and if a user makes a change in one view, the other views are automatically updated. Thus, Revit drawings and schedules are always fully coordinated in terms of the building objects shown in drawings.

SketchUp is a 3D modeling computer program for a wide range of drawing applications such as architectural, interior design, landscape architecture, civil and mechanical engineering.

Navisworks is a 3D BIM design review package that allows users to open and combine 3D models, navigate around them in real-time and review the model using a set of tools including comments, redlining, viewpoint, and measurements. A selection of plug-ins enhances the package adding interference detection, 4D time simulation, photo-realistic rendering and PDF-like publishing.

Design Builder A modular solution that comprises a core 3D modeller and additional modules which work together to provide in-depth analysis for any building.

Revit Structures Autodesk's BIM software solution for structural engineering companies and structural engineers, that provides a feature rich tool set helping to drive efficient design processes in a BIM (Building Information Modelling) environment.

Simulation Tools

E-Quest is a building energy use analysis tool that is designed to allow users to perform detailed comparative analysis of building designs and technologies by applying building energy use simulation techniques without requiring extensive experience in the art of building performance modeling.

Trane analysis software are created for designers and engineers responsible for assessing system design and function for new construction or existing buildings anywhere in the world.

EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings.

IES Virtual Environment (VE) is an energy analysis and performance modeling software that offers a variety of custom modules designed to address different building performance work flows. IESVE can help you incorporate sustainable building approaches and analyses into your BIM projects.

Radiance is a suite of tools for performing lighting simulation originally. It includes a renderer as well as many other tools for measuring the simulated light levels. It uses ray tracing to perform all lighting calculations, accelerated by the use of an octree data structure.

TAS simulator is the complete tool for modelling, dynamic simulation and thermal analysis of buildings of any size.

Hevacomp is a specialized (BIM) software intended for creating energy efficient buildings through predicting accurate real-world performances. It can implement vital compliance checking and documentation specifically required for creating buildings, multi-discipline plants, factories, and transit facilities.

Cost Estimation

Autodesk's QTO building cost estimating software helps make material costing faster, easier, and more accurate.

Vico Takeoff manager is a 4D simulation presentation tool that provides rich 3D visualization of the project time line to the extended construction team.

ABSTRACT

Buildings are exceedingly complex products with a comparatively long lifetime that can last for decades. They have been found to generate a number of negative environmental impacts, when built in traditional ways. Therefore, a huge number of Green Building Rating Systems have been created in the last few decades with the main focus of evaluating sustainability of buildings.

Another method to assess the environmental impacts of buildings is, Life-Cycle Assessment, which widens the scope of sustainability evaluation to review a 'cradle-to-grave' perspective by including all life-cycle phases of a building.

Modern Technology such as; Building Information Modelling (BIM) have recently made it possible to have a comprehensive architectural design process; provided with visual representations, enhanced by energy and thermal simulations and supported by the collaboration between the different involved parties. The three dimensional (or more) object-oriented modelling gives access to information regarding material types, properties, quantities, energy performance, lighting and site disturbance which are used for analyses, evaluations and assessments. Therefore, as a tool, BIM can support efficient design practices that would contribute in reducing construction-related waste generation, energy consumption while in addition enhance the sustainability and efficiency of the built environment.

Despite the fact that BIM has existed for more than 20 years, it is only recently that the Architectural, Engineering and Construction (AEC) industries

became aware of BIM potentials in making the construction process streamlined and efficient. In Egypt, although practicing BIM is expanding within the construction industry, practitioners still have limited knowledge about BIM's full capabilities.

The utilization of BIM tools on its own cannot achieve the pursued efficient building. This research argues that BIM needs to be supported by guidelines adopted from Green Building Rating Systems (GBRS) in addition to taking into consideration the whole life-cycle of these buildings, in order to realize the holistic sustainable outcome expected from efficient buildings.

Therefore, the research is intended to analyze the situation of GBRS, LCA and BIM adoption in Egypt, arguing that their full integration in one 'holistic framework' can significantly add value to Efficient Building practices within the Egyptian AEC industry.

It is important to understand that the choices made nowadays for how to build, design and operate buildings can significantly affect both urban services and livability for decades to come. This is why, efficient, high-performance, low-energy buildings can be a major factor in creating sustainable cities which are the keystone for the sustainable development goals internationally being sought for.

KEYWORDS: Building Information Modeling, Green Building Rating Systems, Life-Cycle Assessment, Efficient buildings, Egyptian AEC industry

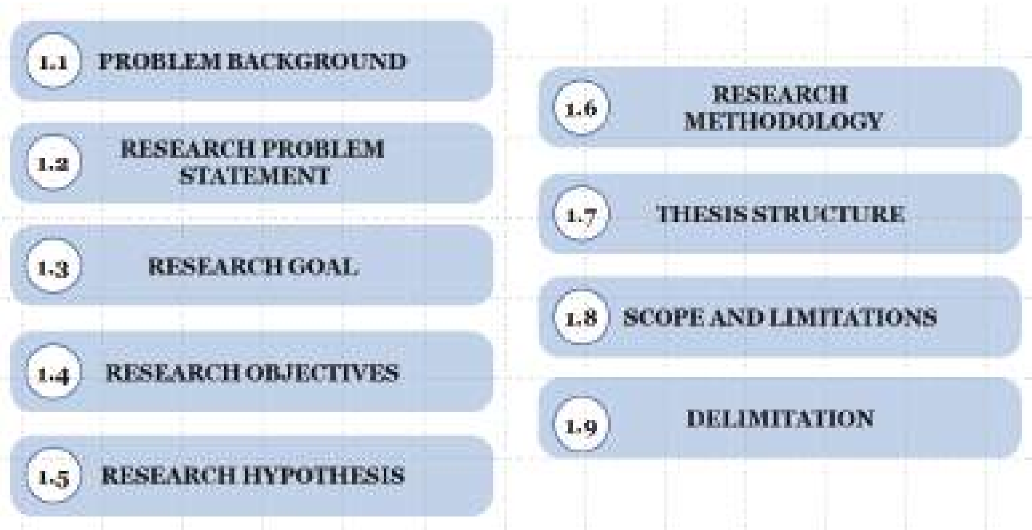


Figure 1. Chapter 1 Scheme (Author, 2019).

"A building's impact on the environment is huge ... But we still can do better"
(paulraffstudio.com)

CHAPTER 1 INTRODUCTION

1.1 Problem Background

In the last few decades, the issues of global warming and natural resources depletion have gained much attention to which buildings have been criticized for contributing (Shoubi, et al., 2015). Buildings are exceedingly complex products with a comparatively long lifetime that can last for decades. They include a massive number of components that are needed for their construction yet they have been proved to be majorly increase carbon and greenhouse gas (GHG) emissions (Ngwepe & Aigbavboa, 2015), energy consumption, air emissions and solid waste generation (Scheuer & Keoleian, 2002).

The built environment originates most of the mass and energy flows for which man is responsible. Although they contribute to the socio-economic development of our nations (Ramesh, et al., 2010), they utilize a large proportion of energy along with the natural resources. Additionally, there have been health issues generated by the built environment, which intensify the need to further analyze the role buildings play on environmental well-being (Scheuer & Keoleian, 2002).

It is important to understand that the choices made nowadays for how to build, design and operate these buildings can significantly affect both urban services and livability for decades to come. Then, efficient, high-performance, low-energy buildings can be a major factor in creating sustainable cities which are the keystone for the sustainable development goals internationally being sought for.

Therefore, it becomes essential for the construction industry to adopt sustainable development approaches within its activities (Ramesh, et al., 2010). This is why the concept of “going green” and “sustainable construction” has been evolving for many years now trying to solve the environmental impacts buildings cause and attempting to make them more energy efficient and environment-friendly (Chhatwani, 2015) (Wong & Zhou, 2015).

However, the decentralized nature of construction processes makes it quite difficult to define, understand and counteract against the introduced environmental impacts. Traditional practices have been found to contribute unnecessary waste and errors. According to (Eastman, et al., 2011), these practices:

- Have poor field productivity, poor information flow and redundancy in addition to extra efforts and costs.
- Result in inadequate exchange, management of information and interoperability; as the involved individual systems are unable to access and use information imported from other systems.
- Can cause systems’ incompatibility which prevent project team members from sharing information rapidly and accurately.
- Are accounted for increasing construction costs in cases of inefficient interoperability

This is why Green Building Rating Systems (GBRS) and performance-based assessments are being increasingly adopted and widely demanded by developers and owners so as to promote low-energy or even net-zero energy systems in their buildings. (Chhatwani, 2015).

To establish an effective approach for sustainable buildings, it is required to develop a multi-disciplinary approach that covers a number of “environmental-friendly" features such as energy saving, optimization of resource use (like water, materials and energy), consideration of reuse and recycling as well as emissions control. (Ramesh, et al., 2010).

Moreover, during the lifespan of a building it can undergo several changes in form and function that can be quite significant compared to the original product (Chhatwani, 2015). Then to achieve a sustainable construction process, this needs to be fulfilled with the application of tools that deals with, understands and assesses buildings' entire life-cycle, site planning and organization, material selection, use of recycled materials, minimization of energy consumption and waste generation. (Ngwepe & Aigbavboa, 2015). In short, performing a Life-Cycle Energy Analysis (LCEA) of the building can significantly help in formulating the strategies suitable for achieving reductions of the energy use in buildings (Ramesh, et al., 2010).

Yet, performing Life-Cycle Assessment (LCA) methods conventionally can be quite time consuming and information-condense as for relying on quantity survey, inventory data of building materials. Also, the continuous development of building materials significantly increases the components and assemblies present in one building making the loss of details or relation between them quite possible (Yang & Wang, 2013).

This where the technology of Building Information Modeling (BIM) can be beneficial, for offering great opportunities to plan, design, and construct buildings in compliance with sophisticated performance criteria and regulatory requirements as well as enhancing time and data savings for having object-based information models that can correspondingly make the execution of LCA process smoother and more efficient (Yang & Wang, 2013). Integrating BIM also would allow for better decision-making along the whole life-cycle of the building as well as the capability to perform the environmental analyses essential to accomplish sustainability goals (Wu & Issa, 2014).

1.2 Research Problem Statement

The research problem is divided in two parts; the first part is the environmental issues buildings are accounted for, while the second part is neglecting the potentials that Green Building Rating systems, Life-cycle Assessment and Building information Modeling (as tools) can offer to address these issues especially when they are integrated in one holistic framework.

1.3 Research Goal

The main goal of this research is to **Develop an Integrated Framework for GBRS and LCA in BIM environment to enhance Efficient Building Design practices in the Egyptian AEC industry.**

1.4 Research Objectives

The research goal can be divided into several objectives as follows;

O 1. Point out the negative environmental impacts associated with buildings.

O 2. Review solutions corresponding to environmental issues generated by buildings.

O 3. Identify efficient buildings and their benefits, as well as the drivers and barriers of their adoption.

O 4. Establish the criteria targeting environmental, economic and social aspects in buildings design.

O 5. Understand the significance, process and benefits of GBRS for sustainable building design.

O 6. Compare different GBRS systems to identify strengths and weaknesses of each as well as the most suitable system for the study.

O 7. Point out recommendations to enhance the Egyptian GBRS.

O 8. Understand the benefits, process and tools of LCA assessment for sustainable building design.

O 9. Understand potentials, process and tools of BIM for sustainable building design.

O 10. Investigate the possibilities, benefits, challenges and triggers of integration between GBRS and LCA in BIM environments.

O 11. Overlap previous attempts of integration between GBRS, LCA and BIM.

O 12. Point out recommendations to enhance the implementation of the proposed framework.

1.5 Research Hypothesis

The research hypothesizes (Figure 2) that BIM usage in a comprehensive digital methodology that considers GBRS-adopted guidelines and the life-cycle of buildings would be a step in the right direction to enhance Efficient Building Design practices in the Egyptian AEC industry.

By implementing this holistic approach, not only the three processes can be done in a simpler way, without wasting time, cost and effort (compared to how they are conventionally performed), but also each process will be enriched by the potentials the other two provide. This can promote and encourage the adoption of all three trends which eventually can help develop the Egyptian con-

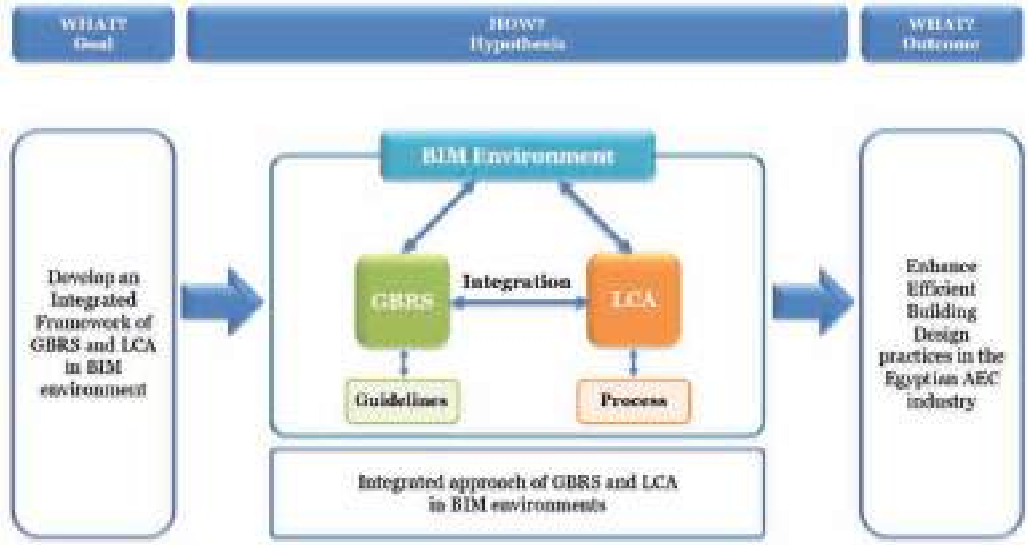


Figure 2. Graphical Representation of Thesis Hypothesis (Author, 2019).

struction industry in general and Efficient Building Design in particular.

1.5.1 Justification

GBRS are selected to provide "guidelines", as they can significantly enhance the environmental performance of buildings and reduce their negative impacts through the comprehensive high environmental standards of criteria they set.

LCA is chosen as the assessment "process" to evaluate the Environmental impacts (EI) of the included products and systems throughout all the life-cycle phases of a building which can considerably improve the production of buildings from a sustainability point of view.

BIM, which had achieved measured successes in many high-profile projects worldwide, can provide the containing "environment" and the linking "tools" which has recently proved to offer the most denominated ways of approaching design, construction and operation processes of buildings (El Barbary, 2018).

1.6 Research Methodology

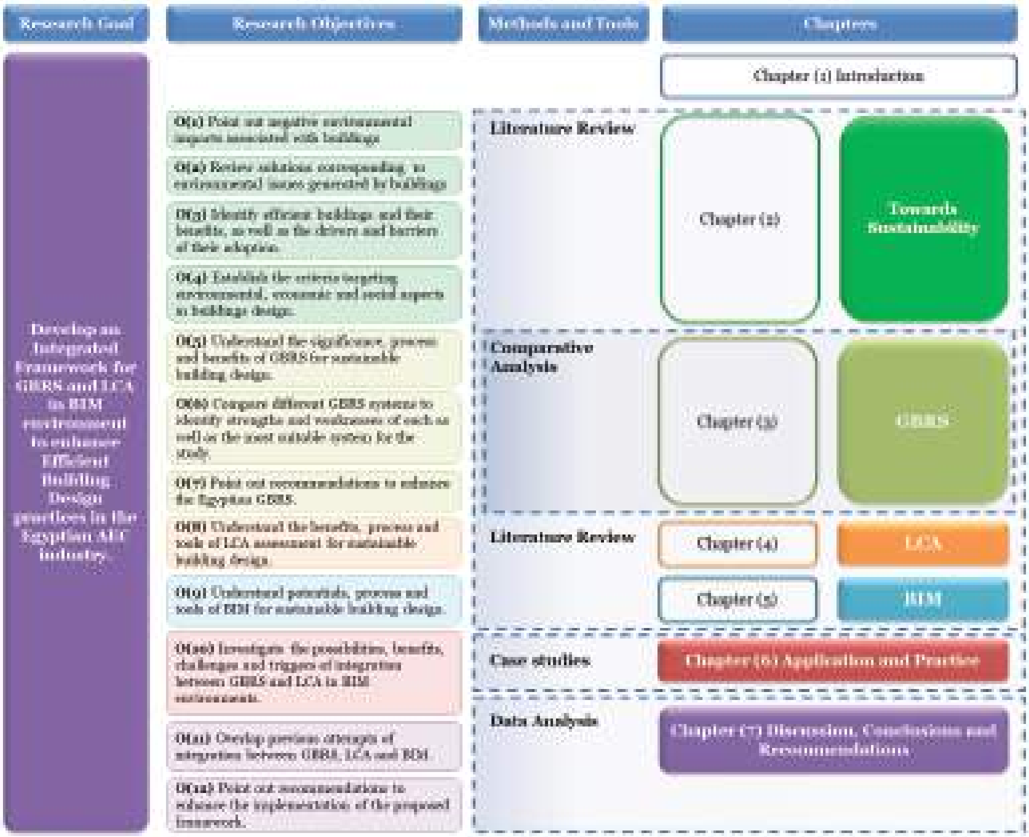


Figure 3. Graphical representation of Research Methodology and Thesis Structure (Author, 2019).

(Figure 3) illustrates the Thesis Methodology, as follows;

The main goal of this research is to "Develop an Integrated Framework for GBRS and LCA in BIM environment to enhance Efficient Building Design practices in the Egyptian AEC industry". While there are many tools and methods that can be used for this purpose in the Egyptian market, yet this thesis is focusing on three systems that have now been used for decades in sustainable design of buildings, but they are not ultimately made use of compared to their full potentials and capabilities; Green Building Rating systems (GBRS), Life-Cycle Assessment (LCA) and Building Information Modeling (BIM). Each of these methodologies has individually made a great influence in improving the production of sustainable buildings on an international level in terms of enhanced design process, reduced negative environmental impact and better payback benefits.

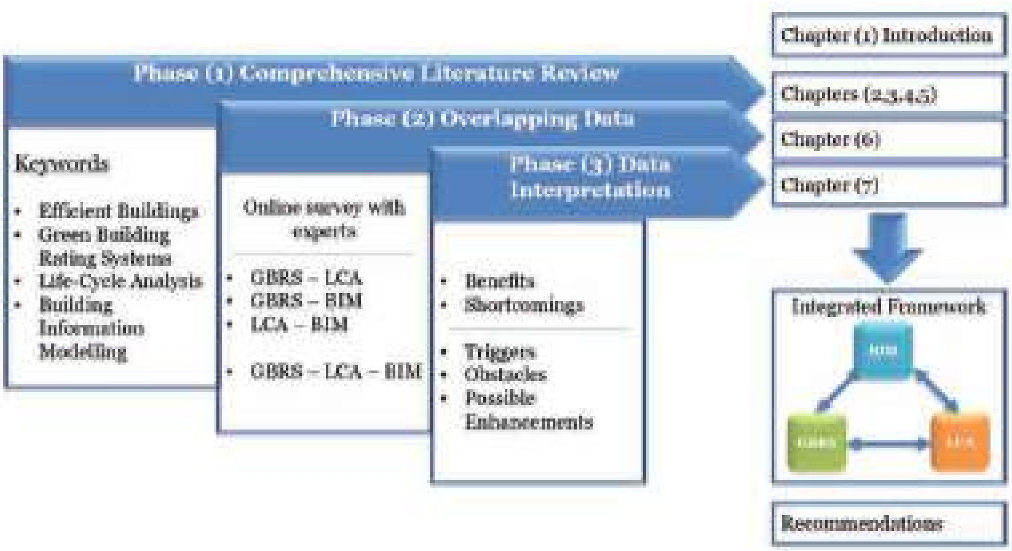


Figure 4. Graphical Illustration of Thesis Phases (Author, 2019).

This motivated the author to investigate how the whole design process can be enhanced when these methodologies or Green Building Rating systems (as “guidelines”), Life-Cycle Assessment (as a “process”) and Building Information Modeling (“tools”) are all integrated in one holistic framework.

The research is divided into three phases; the first phase is exploratory which is done by desktop research and extensive literature review to identify the current position of BIM, LCA and GBRS usage in AEC industry in general and especially with regards to green building design from researches, conference papers, studies, books, BIM handbooks and GBRS certification manuals. Also, best practices and case studies from all over the world will be analyzed, to explore the points of strengths and weaknesses in the implementation of GBRS, LCA and BIM. Concerning GBRS, a comparative analysis will be carried out between some of the internationally well-known GBRS to identify the points of strengths and weaknesses of each and to highlight the adjustments needed to encourage practitioners to utilize the Egyptian GPRS.

For data triangulation (to ensure the credibility of the study), it did not only depend on literature review (of which most is not local), but an online survey with local practitioners has been conducted to convey their personal experience with the tools available in the Egyptian AEC industry.

Finally, in the third phase, conclusions could then be identified from the data and SWOT analysis and recommendations in terms of technical, procedural, regulations and educational measures and actions could be pointed out to fulfill the main objective of the research.

1.7 Thesis Structure

The Thesis is structured as illustrated in (Figure 4) where;

Chapter (1) includes the research introduction.

1.7.1 Phase 1: Literature Review

Chapter (2) is divided in three parts; the first introduces the environmental problems associated with buildings whereas the second part defines efficient buildings and the drivers and obstacles of their adoption. The third part highlights some of the trends counteracting these negative environmental impacts such as Green Building Rating Systems and Life-Cycle Assessment.

Chapter (3) will review GBRS background; compare between a number of international Green Building assessment systems along with the Egyptian GPRS and TARSHEED, so as to highlight points of strengths and weaknesses of each, which will be the basis for recommendations and actions that need to be taken to enhance the implementation of GBRS in Egypt.

Chapter (4) will give an overview about LCA; process, different types and identification of its benefits.

In chapter (5), an overview about BIM; process, terminologies and benefits.

Each of the previous chapters would be summarized in a form of SWOT analysis to identify their Strengths, Weaknesses, Opportunities and Threats.

1.7.2 Phase 2: Overlapping Data

Chapter (6) will include; first, the identification of the triggers and obstacles facing the individual implementation of each approach to identify strengths and weaknesses. The data gathered from this review will be used as a basis for designing the surveys used in the next step.

Then, an online survey (with experts of GBRS, LCA and BIM fields) is conducted based on the outcomings of this analysis to support the findings from the literature review. A sample of experienced professionals in the three fields has been selected; based on their relevant educational background, experience and for working on projects utilizing either GBRS, LCA or BIM in order to find out more about users' experience regarding the potentials of each, the challenges that hinder their wider adoption and the opportunities, actions and measures suggested to enhance their implementation.

In GBRS interviews, the participant will be asked about the GBRS they are mostly using and the benefits, challenges and drivers to widen their adoption.

Whereas in BIM interviews, participants will be mainly asked about the benefits of using BIM compared to CAD, the types of BIM software and how data is exchanged between them, whether they have used BIM in sustainable building design and the differences they encountered.

Secondly, the application of integrated versions of (LCA-BIM, LCA-GBRS, BIM-GBRS) and (BIM-LCA-GBRS) as deduced from literature review and case studies are being reviewed to find out how the integration helps to maximize the benefits of each and overcome the challenges hindering their adoption.

1.7.3 Phase 3: Data Interpretation

Chapter (7) will be divided as follows; the first part (Discussion) will accumulate the data collected in phase 2, in a SWOT Analysis briefing the Strengths, Weaknesses, Opportunities and Threats for each of GBRS, LCA, BIM methods. The third part (Recommendations) will present a 'conceptual framework' integrating GBRS, LCA and BIM developed to enhance Efficient Building Design practices in the Egyptian AEC industry (research goal). Then will point out the actions and measures recommended for better implementation of the proposed strategy and the parties responsible for their accomplishment.

1.8 Scope and Limitations

This research was decided to focus on:

- GBRS known within the Egyptian AEC industry;
- Providing a brief introduction for LCA assessments, mentioning the aspects that would benefit the purpose of the research, and
- Concise overall of BIM as a method, technology and tools.

Conducting this research has encountered some limitations such as;

- The limited access to information regarding the application of GBRS (especially GPRS) in the Egyptian context;
- Finding LCA experts for interviews, which was overcome by including more of international LCA literature, and;
- Limited sustainable and BIM literature in the Egyptian context.

1.9 Delimitation

The research's focus will be to analyze frameworks already established that integrate GBRS and LCA assessments within BIM environments and overlap them in one holistic framework. This will help not only to ease the whole process, but also will promote the adoption of efficient building principles in Egypt.

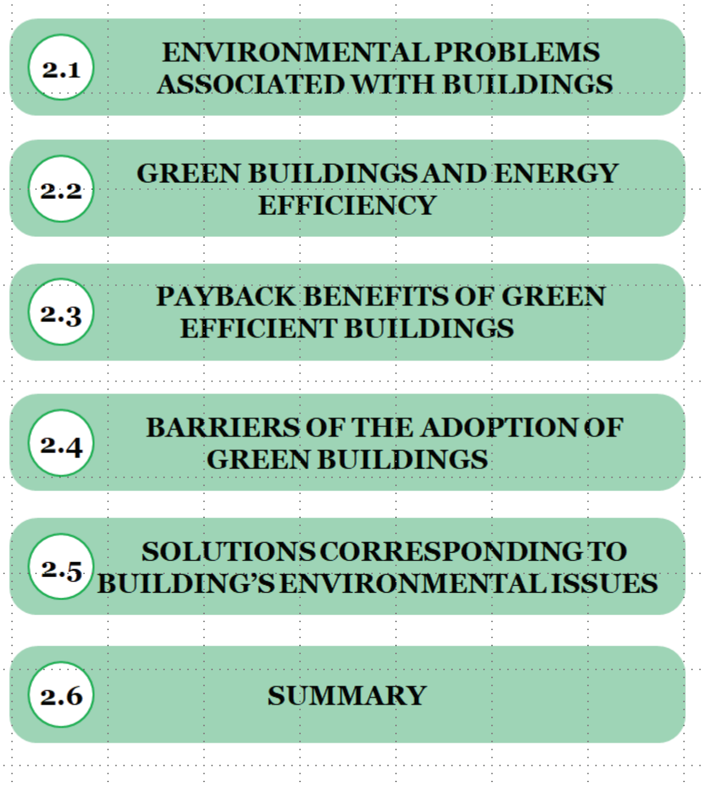


Figure 5. Chapter 2 Scheme (Author, 2019).

CHAPTER 2 TOWARDS SUSTAINABILITY

The following chapter is intended to outline how built environments affect its natural surroundings in detail in terms of processes, energy and material resources as well as generation of pollution and waste. This will help to define the most suitable mitigations emerged to resolve these negative impacts. This part will be used as a foundation for the later research phases.

2.1 Environmental Problems Associated with Buildings

While buildings provide countless benefits to society, they also result in many significant environmental and health problems. This part presents some basic facts about these issues (Figure 6).

2.1.1 Natural Resources Depletion

Buildings take up large areas of land where they remain for a long period of time, requiring a great amount of materials and resources for their construction to become possible. Most of these materials are either supplemented by raw materials or manufactured elements purchased by export (which also add to the resources used for transportation). Buildings continue to consume natural resources such as water and energy during their operation phases (Ngwepe & Aigbavboa, 2015).

2.1.2 Waste

The built environment is one of the sectors that greatly contribute to waste generation in any country. The construction industry contributes to waste generation both directly (such as the used constructed structures and the related maintenance) and indirectly (like the waste generated from the extraction and manufacturing processes of construction materials). And finally, the demolition of these structures which probably makes the most contribution to the waste generated compared to other phases. These types of waste leach to the surrounding environment (depending on the means of disposal) causing long-term impacts and probably irreversible changes to local ecosystems as well as water contamination (Ngwepe & Aigbavboa, 2015).

2.1.3 Climate Change and Global Warming

Global warming is one of the highest profile environmental impacts happening in our time. The main cause of global warming is the greenhouse gases -which have recently increased in the atmosphere due to the increasing concentrations of human activities- as they absorb and emit solar radiation affecting global temperatures (Saada, 2015). These gases include CO2 which is mainly caused by rising populations, economic growth as well as the increasing energy consumption (Ngwepe & Aigbavboa, 2015).

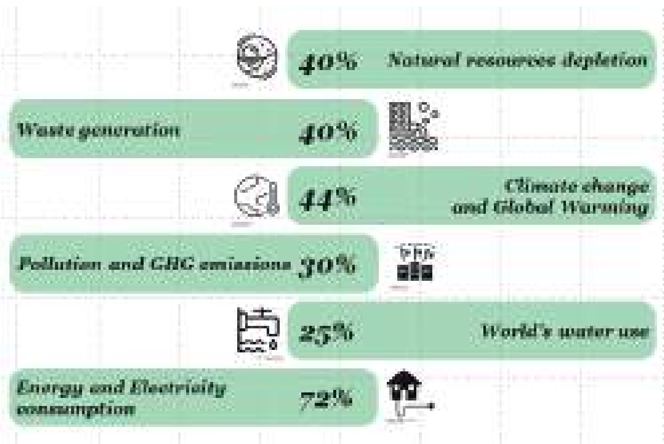


Figure 6. Impacts of the Built Environment. Adapted from: United Nations' Environnemental Programme (UNEP) and www.environmentalleader.com

2.1.4 Pollution and Carbon Emissions

Emissions related to energy generation and manufacturing processes pollute the air, affect global climate along with the health of humans, animals and plants. In relation to the construction processes, they require long distance transportation which include a great amount of carbon dioxide emissions, worsening the greenhouse gas effect (Ngwepe & Aigbavboa, 2015).

2.1.5 Water

Regarding water, construction works can be a double agent; acting beneficially in case of building water treatment and desalination plants but adversely when contaminated produces are dumped affecting the surrounding water sources. (Ngwepe & Aigbavboa, 2015).

2.1.6 Energy

Energy is a basic requirement for human civilization's daily life as well as being centrally essential for industries, transportation systems and for the provision of everyday life amenities such as heating, cooling and artificial lighting needed indoors (Ngwepe & Aigbavboa, 2015). Energy generation and use can directly affect local and global warming, found to be accounted for 25.9% of global greenhouse gas emissions and production of "waste heat" which contributes to raising air temperatures both on local and global scales (Saada, 2015).

2.2 Green Buildings and Energy Efficiency

2.2.1 Overview

Green construction has recently gained increasing attention all over the world which boosted the development of sustainable building design and construction tools in many perspectives. Thus, developing Environmental Assessment (EA) tools is quite an important task to provide guidelines for greener design and management of green building projects which can powerfully support decision-making by using quantitative data and verifiable indicators (Kajikawa, et al., 2011).

Sustainable construction can be described as; the building activity to create and operate a healthy built environment based on resource efficiency and ecology principles (Figure 7) (Mohamed, 2018). It should have the lowest negative impacts on the environment while maintaining the highest possible social and economic development levels (Antón & Díaz, 2014).

2.2.2 What is an Efficient Green Building?

An efficient green building, according to the Environmental Protection Agency (EPA), is the practice of creating structures that are environmentally conscious and maintain resource-efficiency. While a high-performance building, as defined by the Energy Independence and Security Act, is the integration of all high-performance considerations along the life-cycle of the building adding to the environmentally responsible energy conservation and sustainability; the safety, security, durability, accessibility, cost-benefit, productivity, func-

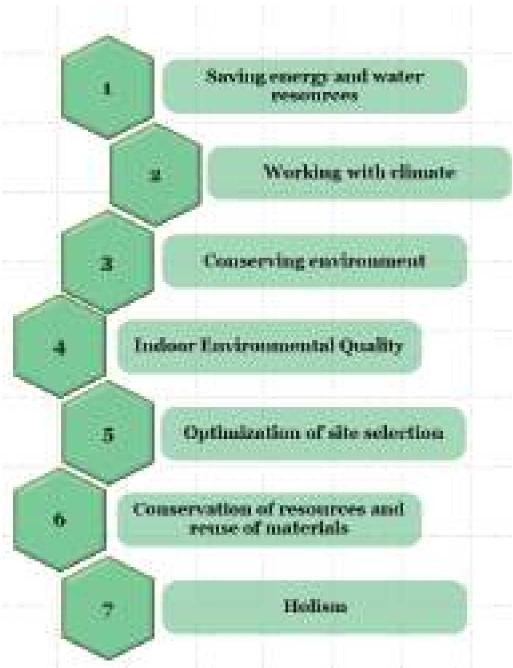


Figure 7. Basic principles of efficient buildings. Adapted from (World Resources Institute, 2016).

tionality and operation attributes. These buildings contain complex, high performance systems that require 'ongoing adjustments and change of users' behavior after the initial commissioning'. If it is a high-performance building, then it has to be operated through integrated and optimized systems such as; Heating, Ventilation and Air Conditioning (HVAC), fire safety, lighting efficiency which all interact with the building's occupants (Wong & Zhou, 2015).

2.2.3 Energy Efficiency

Energy efficiency is one of the most important criteria (if not the most) that defines if a building is "green" or not. Therefore, it usually gets the highest credits when a building is seeking for green-building-rating (EnergyStar, N.D.). When energy is saved, this does not only limit financial values of the utility bills, but it also extends to raise the asset's value (EnergyStar, N.D.).

Therefore, the United Nations' Environmental Programme (UNEP) recommends analyzing the energy performance of buildings using life-cycle approach (LCA), as it has been proven that the most proportion of energy (consumed for heating, cooling, ventilation, lighting and electrical appliances) happens throughout the use-phase of buildings. (Saada, 2015). In another report entitled "Life cycle Assessment of Building Products" by Arsenault, P. (2013), he has proved (using LCA approach) that over 75% of the energy consumption in buildings is accounted to the on-going operational phase. Therefore, it can be argued that it is now a tremendous priority to study initiatives of operational energy reduction (Saada, 2015).

Moreover, building efficiency generally relates to how productive the resources like energy and water are used to provide the services needed in a building. These services range from heating, cooling and lighting up to operating electrical equipment. Energy efficiency can be prioritized as it can in many ways improve the efficiency of other resources like water, materials and even waste (World Resources Institute, 2016).

Increasing energy productivity can be achieved by adopting concepts like 'Building Efficiency' which offers the possibility to slow the increasing energy demand – especially in developing countries- by more than half by 2020. Building efficiency frees up capital for other competing investments which governments have to respond to (World Resources Institute, 2016).

Moreover, Energy efficiency in buildings could deliver CO_2 emissions savings up to 5.8 billion tons by 2050 (equals to 83% below the conventional expected scenario). These measures can be implemented using some of the readily available technologies (such as BIM) which have been proven to deliver positive financial returns within relatively short payback periods (World Resources Institute, 2016).

2.3 Payback Benefits of Green Efficient Buildings

2.3.1 Environmental Benefits

- Minimized depletion of natural resources and habitats (Kshirsagar, et al., 2015).
- Protection of biodiversity and ecosystems (Kshirsagar, et al., 2015).
- Lower CO_2 and Greenhouse Gas emissions and consequently fewer negative impacts on Climate change and Global warming (Kshirsagar, et al., 2015).
- Provision of cleaner, healthier and greener indoor and outdoor environments (EnergyStar, N.D.).

- Limited waste generation along the whole life-cycle of the building (reductions can reach up to 70%) (Gin, 2018) (Kshirsagar, et al., 2015).

2.3.2 Economic Benefits

- Savings in energy (up to 50%[1]) and water consumption (up to 40%) (Kshirsagar, et al., 2015).
- Lowered operating costs (by almost 14%) (Wong & Zhou, 2015).
- Increased leasing and property values by up to 11% (Wong & Zhou, 2015).

2.3.3 Social Benefits

- Improved indoor and outdoor users' comfort (World Resources Institute, 2016).
- Enhanced productivity (additional 38 work hours per year, occupants' health (users' claim to feel less frustrated and more patient) (Smith, 2011) as well as improved air quality (Kshirsagar, et al., 2015).
- Enhancing aesthetic qualities of buildings (Kshirsagar, et al., 2015).
- Improved overall quality of life (Kshirsagar, et al., 2015).

Accordingly, it can be concluded that focusing on the energy performance aspects of a building in the operational phase can dramatically enhance its green-ability.

2.4 Barriers of the Adoption of Green Buildings Principles

There have been many attempts to integrate sustainability considerations into the design process of buildings, but there have been some barriers hin-

1 1 *Data sources from* http://gogreengoarch.wordpress.com/tag/green-buildings/

dering its full adoption (Figure 8), such as;

Figure 8. Barriers to Energy Efficiency procurement (World Resources Institute, 2016).

- The various information needed for design disciplines exacerbates the problem making optimal design decisions even more difficult. In addition to lacking the factor of sequencing of activities as well as the reasoning of decisions (Zanni, et al., 2017).
- The restrictive procedures, limited technology and knowledge on sustainable practice building codes and regulations (Zanni, et al., 2017), in addition to the duration spent by designers to overcome this limited knowledge and understand the requirements of the rating system (Karmany, 2016).
- The lack of incentives (either regulatory or financial), higher expenses, hidden costs and benefits compared to conventional construction methods (Karmany, 2016).
- Limited financial resources to pay the initial higher cost
- Lack of client demand (or behavioral inertia), awareness, stakeholder interest still hinder the different industry stakeholders from adopting greener developments, where they mostly seek for easier and faster construction methods as well as mainly concern about the lower-cost

solutions regardless of the pay-back financial benefits on the long run (Mohamed, 2018).

- Weak governance, which can cause new risks in situations of complex procurement arrangements (World Resources Institute, 2016).

In Egypt, the top reasons that hinder the adoption of green building principles are: the high initial costs required for green building construction and practices, the procedural and market difficulties, the complication of certification processes and the unawareness about how necessary it became now to use resources efficiently (Karmany, 2016).

2.5 Solutions Corresponding to Buildings' Environmental Issues

As the construction industry is moving forward, it faces new challenges; in terms of expectation of quality improvements and cost reduction. In some regions, sustainable design now became a mandatory part of modern architectural theory and design practices (Stamenov, et al., 2016) which demands to reduce energy and resources consumption to meet the current sustainability targets (Antón & Díaz, 2014).

International organizations consciously responded by initiating rating systems for sustainable construction and setting regulations to mandate targets for energy and resource efficiency and to encourage environmental impact mitigation for either new building developments or retrofitting projects. Internationally, different Green Building Rating Systems (GBRS) have been introduced to assess environmental performances of buildings. These methods mainly intend to encourage architects and planners to consider the possible ways to minimize negative environmental impacts and energy consumption of the buildings they design (Wong & Zhou, 2015).

Also, recent studies show how stakeholders' perception and requirements have shifted demanding for green and efficient buildings rather than being mainly concerned about cost-efficiency as they had proven to achieve significant reductions in operating costs besides having lower negative impacts on the environment, minimal waste, air pollution and water consumption (Stamenov, et al., 2016). This gave a better chance for scientific methodologies such as Life-Cycle Assessment (LCA) to become well recognized and required to estimate the environmental impacts of buildings in accordance with sustainability principles. The focus also expanded to include a broader range of the issues and environmental impacts generated by products during their manufacture, use and reuse (Vierra, 2019).

In addition, it can be quite beneficial to develop the construction industry by utilizing the new available knowledge and technologies to improve its sustainable performance. There are readily available tools that can be used for environmental performance assessment such as Building Information Modeling (BIM), although they still need further development regarding their provision of universal evaluation. What can be of great benefit is to find a comprehensive way that evaluates the construction performance against a number of criteria while using the outcome to improve the design framework. In this way, it could be possible to compare design alternatives and select which might be best (Antón & Díaz, 2014).

There is now a proliferation of standards, rating tools and certification systems that guide, demonstrate and document how sustainable, high performance and efficient buildings can be delivered, where more than 600 green product certifications and green building rating programs (and the number continues to grow) are now available all around the world (Vierra, 2019).

2.5.1 Building Standards

Standards are the guidelines and criteria used to judge products related to building practices; created by organizations such as The American National Standards Institute (ANSI), American Society for Testing and Materials (ASTM) or American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) or supported by organizations like the International Standards Organization (ISO). ISO defines and develops worldwide standards which become basis of industry norms. Standard requirements are either perspective- (which identify methods of achievement) or performance-oriented (which state expected end results) (Vierra, 2019).

2.5.2 Green Codes

Green codes seek to push the standard of building design and construction to higher levels of sustainability and performance. They also come in the following formats; either perspective, performance or outcome-based. Perspective approach is a fast, definitive and conservative path to comply code where materials and equipment must meet a minimum stringency level of requirements for individual building components, that are later quantified in tables. Whereas, performance-based codes are designed to help achieve particular results and outcome-based codes establish a target for energy use which needs measurement and reporting to assure that the building (after completion) performs at the established levels (Vierra, 2019).

2.5.3 Green Building Product Certifications

A Green Building Product Certification is a confirmation that a product meets the defined criteria and fulfills the requirements of a particular standard. Recently, there have been labels and certification programs that certify products based on their life-cycle parameters like; energy use, recycled content, air and water emissions (Vierra, 2019).

Third-party certified products are considered most respectful as they have been tested and awarded the certification independently from the product manufacturer, contractor, designer and specifier. These product certifications can be recognized within comprehensive Green Building Rating Systems (GBRS), which significantly encourage the demand for greener products (Vierra, 2019). Examples of Green Building Product certifications are; EnergyStar and Environmental Product Declaration (EPD).

2.5.3.1 EnergyStar for Buildings

EnergyStar is a voluntary energy efficiency and labelling program which is government-administered by the US Environmental Protection Agency (EPA). This agency was created to encourage the 'good businesses' of energy management where top-performing products, homes and buildings are certified (Gin, 2018). EnergyStar standards are updated every two years (Vierra, 2019).

Energy Star certification can be earned by existing buildings just like appliances. Since 1992, it has been awarded to nearly 30,000 buildings and more than 450,000 commercial buildings in the U.S whose energy usage is actively measured and tracked using the EnergyStar tool; Portfolio Manager. This tool can be used to manage energy, water and waste all in an online environment

(Gin, 2018).

Energy Star certification is awarded only when an Energy Star score of 75 or higher is achieved. This means that the building is operating among the top 25% of similar facilities nationwide. Over 20 different types of buildings are eligible for Energy Star certification. However, an eligible project must be in the United States or owned by the US government. Energy Star certification is based on building attributes and the actual energy consumption (starting from 12 months) according to utility bills and invoices for fuel purchases (Gin, 2018).

2.5.3.2 Environmental Product Declaration (EPD)

An Environmental Product Declaration (EPD) is a global program for environmental declarations based on ISO standards to independently verify and register documents of transparent and comparable information about the environmental impacts of products. This program now has a database containing more than 500 EPDs registered by 150 manufacturers from 27 different countries (Vierra, 2019).

However, an EPD does not mean the product is environmentally better than its alternatives, it is just a declaration of the product's life-cycle and the related environmental impacts which can be quite useful for applications such as Green Public Procurement (GPP) and building assessment schemes (Vierra, 2019).

2.5.3.3 The Materials Red list

The Red List is a compilation of harmful-to-human chemicals and materials which must not be used in buildings seeking for Living Building status. There are seven performance areas "or petals", included in the Living Building Challenge[2] that avoids Red List products. This requirement is intended to ensure the sustainability of buildings regarding energy conservation, waste limitation and occupants' health protection (Green Building Alliance, 2016).

2.5.4 Green Building Rating and Certification systems

While standards and products certification play an un-neglectable role in determining the level of sustainability performance of a product, yet they need to be considered in a larger process to be integrated into the project's overall goals which would ensure how sustainable the entire project would be (Vierra, 2019).

Sustainability assessments and sustainability rating systems represent the framework that should be applied on sustainable constructions (Berardi, 2013), used to rate or reward levels of compliance and performance of that building against a set of specific environmental goals and requirements (Vierra, 2019). According to many studies, sustainability assessment is essential to increase the 'diffusion' of green buildings (Berardi, 2011). Despite the growing number of assessment systems existing now worldwide yet, unfortunately, the construction sector has limited familiarity with performance measurements and the diffusion of assessment systems is still low (Berardi, 2011). However, sustainability meas-

1 *The Living Building Challenge is the world's most rigorous proven performance standard for buildings. Source:* (https://living-future.org/lbc/)

urements in the building sector are getting much attention worldwide, effectively moving from just fashionable certifications to on-ground practices (Berardi, 2011). Proof of this, in 2010, 650 million square meters obtained sustainability certifications all over the world, with projections for 1100 million square meters in 2012 and more than 4600 million square meters in 2020 (Berardi, 2011).

Possible approaches to sustainability evaluation are: 1) Cumulative Energy Demand (CED) systems which evaluate energy consumption; 2) Life-Cycle Assessment (LCA) which only considers environmental aspects and; Green Building Rating Systems (GBRS) which assess the total quality of ecological, economical and social aspects of projects (Karmany, 2016).

2.6 Summary

Buildings have been found to generate many negative environmental impacts such as; depleting natural resources of materials and energy, generating waste, pollution and carbon emissions, affecting global temperatures, water and air qualities.

However, international responses have initiated many mitigation measures to counteract against these negative impacts, similar to; Building Standards, Green Codes, Green Product Certifications (like Energy Star and Environmental Product Declaration), Life-Cycle Assessment (LCA) as well as Green building Rating Systems (GBRS), just to name a few.

Reduction of the environmental impacts associated with the design, construction, operation and management of the built environment requires a coordinated decision making by all the involved stakeholders across all the stages of the buildings' lifecycle.

Thus, an efficient green building should mirror the three pillar-aspects (e.g. economic, social and environmental) which is known as 'the triple bottom line principle' of sustainable development.

Additionally, in order to fulfill these objectives, there has to be a synergistic 'holistic' relationship between these pillars, corresponding to the basic principles of efficient buildings (Figure 9, Figure 10, Figure 11 and Figure 12), and each should be over-arched by a set of process-oriented measures (Akadiri, et al., 2012). All of these measures will form a framework that will guide the construction into an iterative process at all levels within all disciplines, supporting learning and improving implementation all along the process, and eventually assuring that the taken decisions follow the road of sustainable development (Akadiri, et al., 2012).

In short, a green building needs to be a healthy facility adopted to a cradle-to-cradle resource-efficient manner, using ecological principles, social equity, and life-cycle quality as the main design guidelines (Berardi, 2013).

Environmental assessments can offer many benefits providing the main sustainable design guidelines and documenting environmental impacts so as the resulted information can be communicated to the different involved stakeholders (Scheuer & Keoleian, 2002).

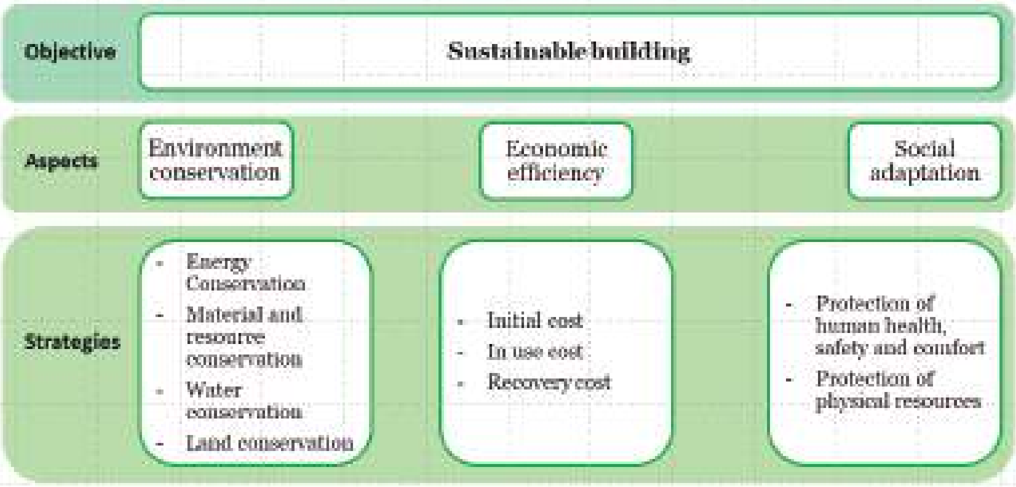


Figure 9. Framework for Sustainable Building Delivery Process. Adapted from (Akadiri, et al., 2012).

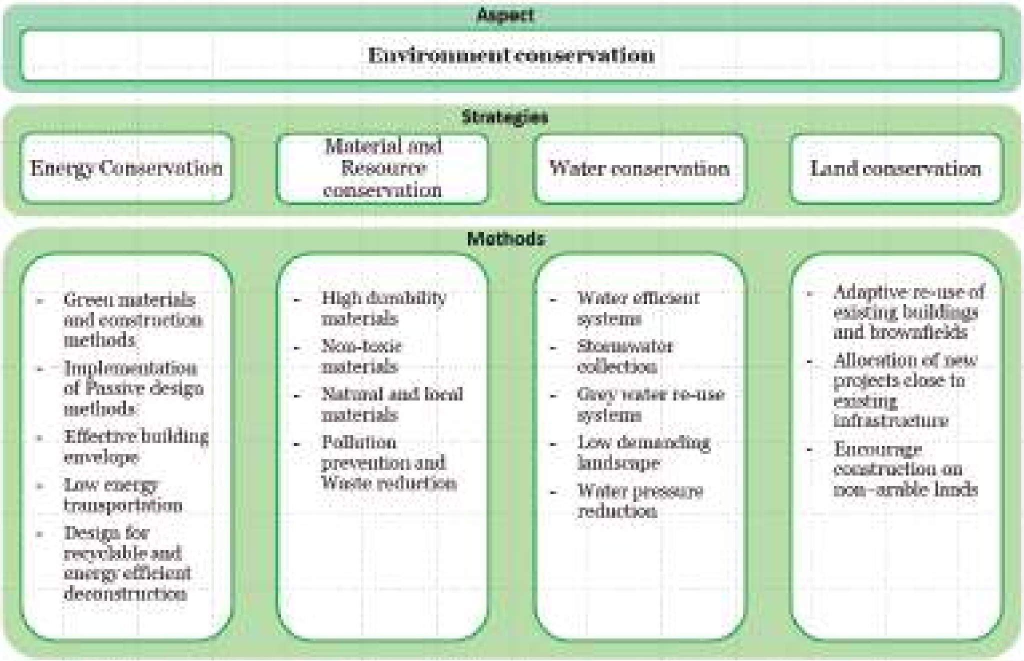


Figure 10. Framework for Sustainable Building Delivery Process (Part 1: Environment Conservation). Adapted from (Akadiri, et al., 2012).

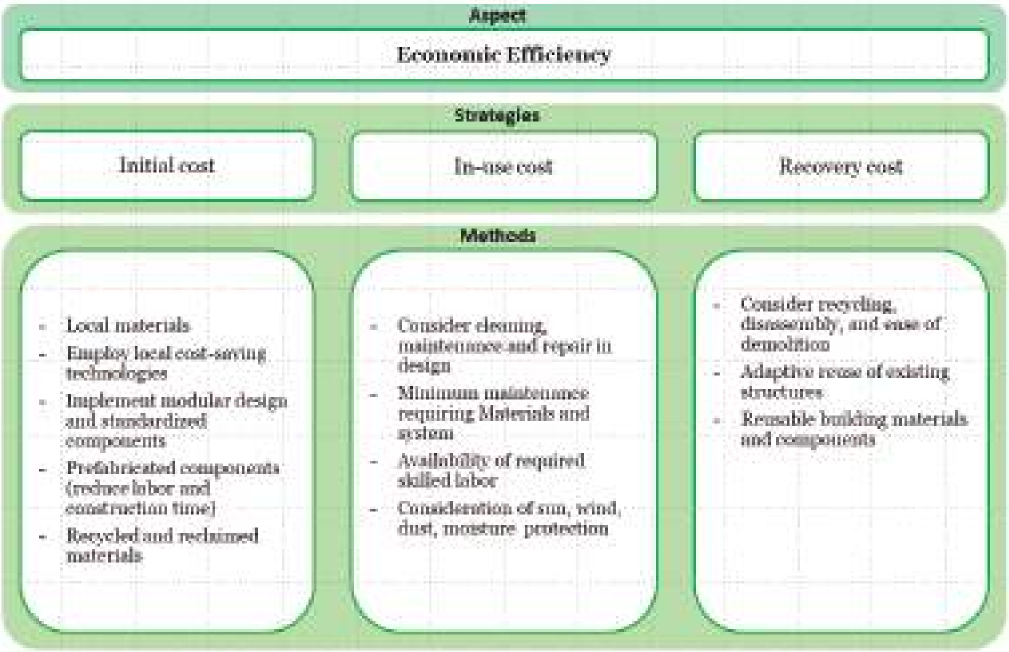


Figure 11. Framework for Sustainable Building Delivery Process (Part 2: Economic Efficiency). Adapted from (Akadiri, et al., 2012).

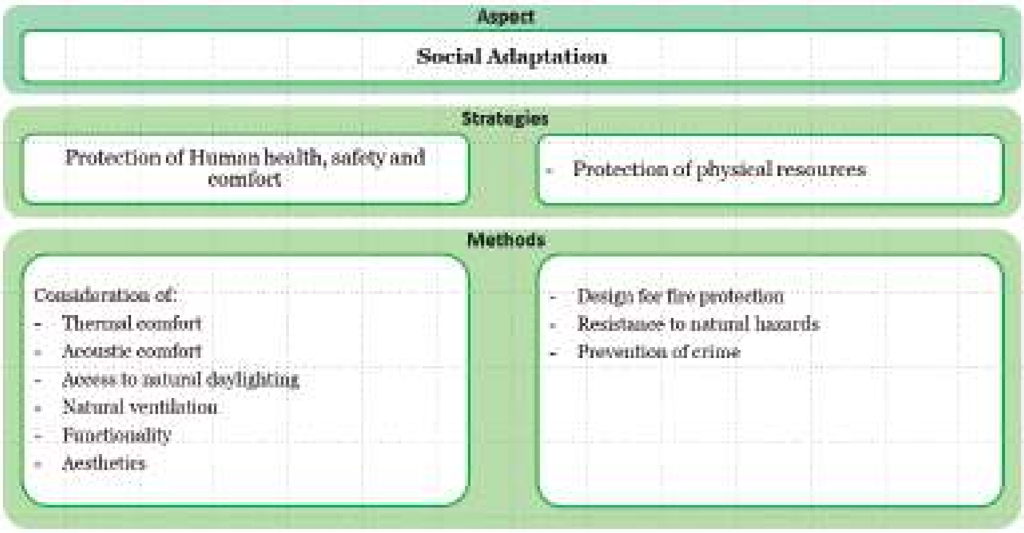


Figure 12. Framework for Sustainable Building Delivery Process (Part 3: Social Adaptation). Adapted from (Akadiri, et al., 2012).

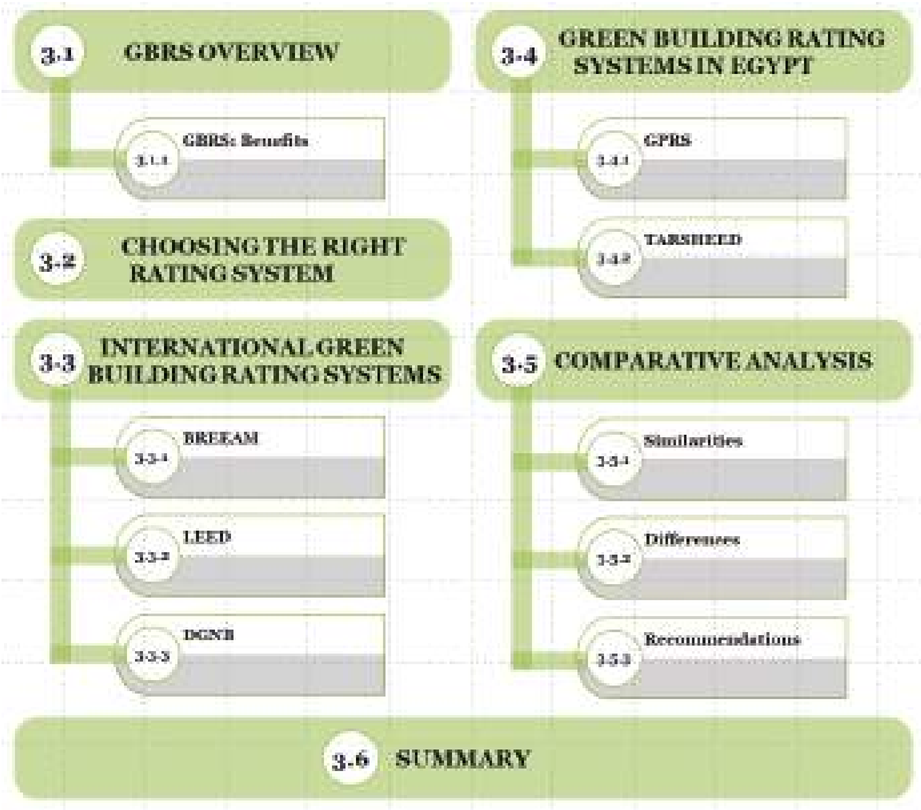


Figure 13. Chapter 3 Scheme (Author, 2019).

"A change anywhere is a change everywhere"
- Autodesk

CHAPTER 3 GREEN BUILDING RATING SYSTEMS (GBRS)

3.1 GBRS Overview

In response to the formidable impacts buildings have on our environment, a consensus among environmental-performance-committed organizations has grown in the last few decades to develop strategies and actions to direct building activities to be more sustainable (Akadiri, et al., 2012), and to clearly define, implement and measure green strategies and evaluate their outcomes (Vierra, 2019). However, constructing sustainable buildings can involve various tools and systems making the development of Environmental Assessment (EA) tools quite an important task to provide guidelines for greener designs, actions and management processes. Only then they can truly enhance decision-making as for being supported by quantitative data and verifiable indicators (Kajikawa, et al., 2011).

Worldwide, building rating and certification programs are third-party systems that provide guidance, evaluation tools, verification and recognition for buildings' efficiency or sustainability (Gin, 2018). Generally, Certification systems are used for sustainability assessment in either buildings or neighborhoods of which main goal is to reach the highest possible performance for buildings by covering all the environmental aspects related to a building's life cycle (Mohamed, 2018). They mainly include quantitative standards to measure the concept of sustainability in any region, define a set of criteria in addition to a rating system for assessing and scoring projects in different processes. The results can be quite useful for the decision-making of users such as governments, planners, designers, owners or investors (Kajikawa, et al., 2011). Identification and realization of the benefits of these standards can help in the adoption of proper strategies and the optimization of performed activities ending up with more comprehensive sustainable development achievements. (Hamedani & Huber, 2012).

3.1.1 GBRS: Benefits

Generally, the main objective of Environmental Assessment tools is to enhance the environmental performance of buildings and reduce their negative impacts. This goal can be achieved by comprehensively assessing the building performance and environmental characteristics of these building using a set of criteria to guarantee high environmental standards (Kajikawa, et al., 2011).

Nevertheless, there is a wide range of benefits that can ultimately encourage designers to go through the certification process, such as;

1. Setting a common objective (from the beginning) for the involved teams: to collaborate and integrate their aesthetical, technical, functional as well as energy performance- and building life-cycle- related expertise (Stamenov, et al., 2016).
2. Outlined green standards products: that should be included, which helps to feed the market with more 'green' options (Vierra, 2019).
3. Enhanced building performance: by implementing green building principles regarding energy and water conservation, indoor air quality improvement, better selection of building materials and driving innovation (Vierra, 2019).
4. Running cost reduction: the operation cost in certified buildings can be less by 40% as a result of the energy and water consumption re-

ductions.

5. Better market opportunities: certified buildings gain higher asset values and consequently higher rates of lease-up and return on investment would both increase up to 7% (Vierra, 2019). Certification also ensures higher value of money and lower investment risks for owners and/or investors (Stamenov, et al., 2016)

6. Verified Green nature of projects: which can be a valuable educational and marketing tool to widen creating green efficient buildings (Vierra, 2019).

7. Incentive for different stakeholder: to promote their construction practices sustainably (Vierra, 2019).

3.2 Choosing the Right Rating System

Nowadays, there are numerous green building certification programs in use around the world; of which some cover all aspects of what makes a building green, while the others focus on single attributes such as ecological or energy efficiency aspects (Gin, 2018), while some other tools include the sociocultural, occupant's health and comfort or the economic aspects so as to enhance the overall sustainability of the assessed project (Kajikawa, et al., 2011).

Green building professionals may decide to pursue one or multiple green building certifications based on the project priorities, marketability and leasing benefits, available incentives building type applicability, expectations of occupants, mandatory development requirements and cost (Kajikawa, et al., 2011).

There is a number of prominent GBRS including Building Research Establishment Environmental Assessment Methodology (BREEAM) in the UK, Leadership in Energy and Environmental Design (LEED) in the US, Green Star in Australia, German Sustainable Building Council System (DGNB System) in Germany, Estidama in the UAE and Green Pyramid Rating System (GPRS) and TARSHEED in Egypt as well. As different types of buildings have different characteristics of performance, most of the aforementioned systems have a range of subsets that could better fit building projects according to which the assessment process and the assessed criteria are defined;

Life-Cycle Stage: Conceptual Design and Planning, construction, operation, etc. (Gin, 2018).

Building status: new construction or retrofit (they need to be assessed differently due to the difference between the followed guidelines and actions);

Building type: such as schools, commercial, office buildings, residential, healthcare facilities or neighborhoods (Kajikawa, et al., 2011; Collinge, et al., 2015).

Consideration of Location and climate: some systems can be used globally (such as LEED and DGNB) while others are context-specific (like Comprehensive Assessment System for Built Environment Efficiency, CASBEE in Japan)) (Kajikawa, et al., 2011) (Gin, 2018).

This is why a single green building rating system cannot be globally convenient (Collinge, et al., 2015).

In the last few decades, these systems had a powerful positive impact in improving the designs and performance of the built environment (World Resources Institute, 2016), by creating conversion tools for high-performance buildings, credibility of a third-party verification, in addition to a competitive atmosphere among building owners (Gin, 2018).

A comparison between LEED, BREEAM, DGNB, GPRS, TARSHEED needs to be done in order to compare their features and indicate the advantages and potentials that needs to be adopted to enhance the Egyptian certification systems.

However, before comparing the above-mentioned systems, there are some important definitions to be pointed out:

- **A Rating system:** is the specific boundaries for the evaluated indicators classified by the criteria value factor and the minimum required level.
- **A Certification process:** is where the necessary measures and steps to award a certification are described.
- **A Scheme:** the type of buildings the system assesses
- **A Category:** a set of performance criteria in one area of focus
- **A Criterion:** an aspect that states the main specifications of the determined objectives.
- **An Indicator:** is measurable quantitative evaluation of the criteria, which can be described by more than one indicator.
- **Ratings:** The level of certification a project receives determined by the points acquired from meeting the requirements of each criteria/ category.

3.3 International Green Building Rating Systems

3.3.1 Building Research Establishment Environmental Assessment Method (BREEAM)

The world's first, most widely used green building rating system. BREEAM was launched in 1990 (Kajikawa, et al., 2011) and has served as a basis for many of the green building certification systems that were established afterwards such as LEED and Green Globes (Vierra, 2019). BREEAM is owned and managed by the British firm; Building Research Establishment (BRE) Global. There are more than 562,400 developments certified by BREEAM and more than 2.2 million buildings have registered for assessment from 76 different countries since its launching (Gin, 2018). BREEAM is expectedly more popular in Europe, found to have an 80 percent market share across Europe for sustainable building certification (Gin, 2018).

3.3.1.1 BREEAM Schemes

BREEAM has multiple technical standards to evaluate the sustainable performance of projects as follows;

- ***Master planning,*** for communities;
- ***Buildings,*** for new construction;
- ***In-use,*** (existing buildings and operations);
- ***Refurbishment and fit-out,*** (for interiors and renovation projects) and;
- ***Civil Engineering and public realm,*** for infrastructure (Gin, 2018).

3.3.1.2 BREEAM Categories

BREEAM offers assessment of nine categories of environmental issues (plus innovation) (Table 1), which address building-related environmental impacts, giving each a number of assigned credits (Gin, 2018).

Table 1. BREEAM, Credit categories and weightings (Kshirsagar, et al., 2015).

Point distribution based on category		
	Category	Points
1	Management	11
2	Health and Well-being	14
3	Energy	17
4	Transport	7
5	Water	6
6	Materials	11
7	Waste	7
8	Land use and Ecology	9
9	Pollution	9
10	Innovation	9
	Total	100

3.3.1.3 BREEAM Certification Process

Certification process of BREEAM (Figure 14) starts with hiring a local, independent BREEAM assessor (who is trained, qualified and licensed by BRE Global Ltd.) to register the project. They start the process by carrying out a pre-assessment then project teams collect and provide evidence documents during design and construction. Once the assessment is complete (assuring the required qualities), BRE Global Ltd. issues BREEAM certificate. This 30-year old methodology is

Figure 14. BREEAM, Certification process (Gin, 2018).

now being adopted in the U.S. under an initiative by a consulting firm named BuildingWise providing the American market with BREEAM USA (only for existing operational buildings at this time) (Gin, 2018).

3.3.1.4 BREEAM Certification Ratings

In BREEAM, projects are certified on a scale (Table 2) of pass, good, very good, excellent and outstanding, where pass reflects the minimum standard good practice of sustainable design is being used and outstanding reflects the highest-possible level of innovation. Minimum requirements must be met, although these requirements depend on the pursued certification level. This means, for instance, that a project certified as excellent-level (or higher) must meet additional minimum number of criteria compared to a pass or a good level.

Table 2. BREEAM, Certification ratings.

BREEAM Certification ratings (%score)					
Outstanding	Excellent	Very good	Good	Pass	Unclassified
≥ 85	≥ 70	≥ 55	≥ 45	≥ 30	<30

3.3.2 Leadership in Energy and Environmental Design (LEED)

LEED was created by the U.S. Green Building Council (USGBC) in 1998 (Karmany, 2016). Since then, it has been one of the most widely used green building certifications. There are now more than 90,000 projects participating in LEED in 162 different countries, in addition to the approximately 200,000 LEED credential holders. LEED rating systems are regularly updated by the USGBC while Green Business Certification Inc. (GBCI) is responsible for the project certification and credential exams (Gin, 2018).

3.3.2.1 LEED Schemes

- ***(BD+C) Building Design and Construction,*** for buildings newly constructed or going through major renovations. This rating includes adaptations of different building types, such as; New construction, Core and Shell, Schools, Retail, Hospitality, Data centers, Industrial warehouse and Distribution Centers as well as Healthcare;
- ***(ID+C) Interior Design and Construction,*** for 'complete' interior fit-out projects including Commercial Interiors, Retail and Hospitality;
- ***(O+M) Building Operations and Maintenance,*** for buildings under-going improvement works, or little-to-no construction;
- ***(ND) Neighborhood Development,*** for new land development or pre-development projects including residential, non-residential and mixed-use;
- ***(Homes),*** for single family homes, low-rise multi-story (from one to three) or mid-rise multi-story (from four to six) (Gin, 2018).

LEED introduces updated versions every three years or so as a reflection for building codes, products and technologies new improvements. Since the first pilot LEED v1.0 was launched by the USGBC in August 1998, LEED Rating System continued to evolve in versions (2), (3 known as version 2009) and the most recent (V4) (Gin, 2018).

3.3.2.2 LEED Categories

LEED credits are grouped in multiple categories in (Table 3), to focus on each aspect of what could make a building green. A LEED Checklist (a one-page document that gives a summary of the certification strategy used for this project) to identify the credits and pursued certification level along with the rating type and the version the project falls under (Gin, 2018).

Within each category, there are credits that pertain to specific sustainability strategies such as; the use of low-emitting products, reduced water consumption, energy efficiency, access to public transportation, recycled content, renewable energy and daylighting (Vierra, 2019).

Table 3. LEED, Credit categories and weightings (Kshirsagar, et al., 2015)

Point distribution based on category		
	Category	Points
1	Sustainable Sites	26
2	Water efficiency	10
3	Energy and atmosphere	35
4	Materials and resources	14
5	Indoor environmental quality	15
6	Innovation in design	6
7	Regional priority	4
	Total	100

Figure 15. LEED, Certification process (Gin, 2018).

3.3.2.3 LEED Certification Process

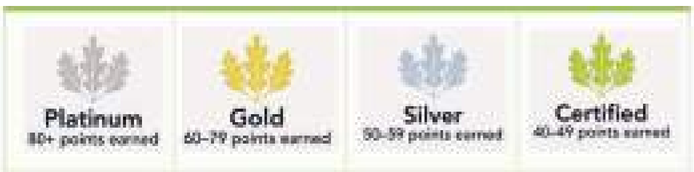
All projects pursuing LEED certification must meet the mandatory pre-requisites such as minimum energy and water-use reduction, recycling collection and smoke control (Vierra, 2019) regardless of the level of target certification. The total points are 110 points and credits may receive from 1 to 18 points depending on how influential they are on reducing negative environmental impacts (Gin, 2018).

The “online” LEED certification process (Figure 15) starts with project registration. Afterwards, the project team communicates with the GBCI using the “LEED Online” platform. As soon as the team members are assigned to credits and prerequisites, project documentation including drawings, calculations, energy model, material project data are all uploaded to be reviewed (Gin, 2018). Then it is optional to either submit design credits first and earn the construction credits at the end of the project, or to submit the documentation all at once when the project is complete. LEED certification, except for Homes, does not require any on-site assessment (Gin, 2018).

3.3.2.4 LEED Certification Ratings

There are four levels of certification as illustrated in (Table 4) (USBGC, 2019). In LEED, all projects pursuing certification have the same minimum requirements to meet regardless of the certification level (Gin, 2018).

Table 4. LEED, Certification ratings (USBGC, 2019).



3.3.3 Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB)

The German Sustainable Building Council (or Deutsche Gesellschaft für Nachhaltiges Bauen – DGNB) has developed a certification system regarding the economical, ecological and social aspects in planning, construction and operation of buildings in Germany in 2007 (Hamedani & Huber, 2012), with a main objective; to emphasize a wider view on sustainability (Hristova, 2016).

DGNB focuses on integrating Building Life-Cycle Assessment in their requirements. In the 2018 version, further steps have been taken towards promoting Life-Cycle Assessment, real sustainability and measurable improvements regarding carbon footprint and other environmental impacts (Horster, 2018; DGNB, 2018).

DGNB has been widely adopted in countries other than Germany (DGNB, 2018).

3.3.3.1 DGNB Schemes

DGNB certification system offers different schemes such as certificates for (Bernardi, 2013);

- ***Existing Buildings,*** for offices, residential buildings,Industrial buildings, commercial buildings;
- ***New Buildings,*** offices and administration, healthcare, educational facilities, hotels, retail, assembly buildings, industrial, tenant fit-out and industrial locations.
- ***New Districts,*** for Urban and business districts.

These schemes make it possible to plan, construct, operate and certify buildings on a uniform basis.

DGNB always develop and update its schemes according to the interest of the market (DGNB, 2018).

3.3.3.2 DGNB Categories

DGNB offers 6 categories (also called qualities) presented in (Table 5). The first four qualities take up to 22.5% of the total score. The quality of Process takes 10% where Site does not give any points yet has to be documented. These categories consist of subgroups (called criteria), which are given different weights with a factor. These criteria are prioritized by their significance (Hristova, 2016).

An advantage of DGNB is that none of these categories' quality can be overlooked, meaning that there is a minimum acceptable score that must be reached in order to get the building certified. This way ensures an overall high quality for all the features in the assessed building (Hristova, 2016).

Table 5. DGNB, Credit categories and weightings per each (DGNB, 2018).

Point distribution based on category		
	Category	Points
1	Ecological quality	22.5%
2	Economical quality	22.5%
3	Socio-cultural and functional quality	22.5%
4	Technical quality	22.5%
5	Process quality	10%
6	Site quality	—
	Total	100

3.3.3.3 DGNB Certification Process

To start the DGNB certification process, there are a few prerequisites need to be first met (DGNB, 2018);

1. The building needs to be classified into one of DGNB's schemes.
2. The certification of the building must occur not later than 3 years after the building is completed and commissioned.

3. There are specific minimum requirements regarding Indoor Air Quality, Design for all and Legal Requirements for Fire Safety and Sound Insulation must be achieved.

4. The submitted reports and simulation should be based on constructed buildings.

To start the certification process (Figure 16), the contractor needs to find a suitable DGNB auditor (a search function is provided on the DGNB website), who supports the contractor and supervises the whole process from registration till certification (DGNB, 2018). The auditor is also responsible for following the design work and collecting the required documents from the design team. In some cases, assessors can even offer to help the team (Hristova, 2016). The contractor enters into two contracts; one with DGNB and the other with the auditor, (there is no contractual relationship between DGNB and the auditor) to guarantee the greatest possible degree of objectivity and independence (DGNB, 2018).

Figure 16. DGNB, Certification process (DGNB, 2018).

There are a number of necessary documents that must be submitted by the design team to DGNB including; description of the building (built up area and number of floors as well as drawings of elevations, sections, floor plans, location plan and layout), specification of technical installations, description of the energy performance, the DGNB evaluation matrix, organizational chart and contract form of the project, expected time of pre-certification and handover.

Additionally, the following calculations need to be enclosed: LCA calculation, LCC calculations as well as calculations for water use (Hristova, 2016).

Fulfilment of the criteria is measured with checklist points (called tjeklistepoint or TLP) which are later converted into evaluation points (EVP) using an evaluation matrix. The final score is presented in percentages divided into three levels: Silver, Gold and Platinum. DGNB certification process can be conducted during the design phases but no later than project completion (Hristova, 2016).

3.3.3.4 DGNB Certification Ratings

The necessary documents to be delivered include: description of the building, specification of the technical installations, description of energy concept of the building, DGNB evaluation matrix, estimation of built area by floors, organizational chart and contract form for the project, information about the estimated time of precertification and handing over. The drawings required are: elevations, sections, floor plans and location plan. Also the LCA calculations as shown in (Table 6), must be attached. (Hristova, 2016).

Technology	Project Area
LCA	• Global warming potential • Ozone depletion potential • Photochemical ozone creation potential • Acidification potential • Eutrophication potential.
Environmental Risk of building materials	• To restrict the use of some substances and materials
Environmental impact of use of resources	• To use certified materials
LCA	• Total primary energy demand • Proportion of renewable primary energy (including embodied and operational energies)
Water demand	• Drinking water • Waste water volume
Land use efficiency	• Efficient use of building's land plot • Soil contamination studies

Table 6. DGNB, Documents required for LCA (Hristova, 2016),

Depending on the degree of compliance, the evaluated project is awarded with either Gold, Silver or Bronze (Table 7).

Table 7. DGNB, Certification ratings (Hristova, 2016)

Gold	Silver	Bronze
≥ 80 %	65-79.9 %	50-64.9 %

3.4 Green Building Rating Systems in Egypt

LEED is the most popular environmental policy followed for buildings in Egypt. LEED aims at saving natural resources and promoting the use of clean and renewable resources of energy. It also focuses on reducing water consumption, selection of healthier construction materials and encouraging design innovation. LEED-certified buildings have proved to save 40% of their energy consumption compared to conventional buildings as well as retaining higher property values and being qualified to receive incentives like tax rebates and zoning allowances (Khodeir & Nessim, 2017).

According to the USGBC, around 50 buildings are registered to acquire the LEED certification in Egypt, which are mostly located in Cairo and Giza regions (USBGC, 2019), most of them are owned by private sector. The first Egyptian LEED project was certified in 2010, while the first Egyptian project started the registration process in 2007.

For the first time in Egypt and North Africa, a building (Credit Agricole Egypt Head Office, Figure 17), designed by ECG, was awarded LEED Platinum certificate in 2016 with a total score 81 points out of 100 (Figure 18).

Figure 17.Credit Agricole Egypt, Headquarters. Source: (www.kemert.com.eg/)

Figure 18. Credit Agricole Egypt: LEED credit achievement Source: (gbib, 2019).

3.4.1 Green Pyramid Rating System (GPRS)

The Egyptian Green Building Council (EGBC) was established in 2009 by a group of members from national and international origins including governmental ministers, NGOs officers and others. The green building code in Egypt was first developed when the Energy Efficiency code was created. The council's main target was to establish a systematic mechanism to encourage building professionals to adopt codes satisfying concepts of energy efficiency and environmental conservation (Hanna, 2015) as well as to raise awareness of the necessity of adopting green building principles within the Egyptian context (Karmany, 2016).

3.4.1.1 GPRS Categories

The GPRS evaluates a building's performance regarding the credit categories mentioned in (Table 8), from which it can be noticed that energy and water efficiencies are the most important categories in this assessment given (50 and 70 credits respectively) (Hanna, 2015).Innovation and added value are considered as a bonus.

Point distribution based on category		
	Category	Points
1	Sustainable Site, Accessibility and Ecology	15%
2	Energy Efficiency	25%
3	Water Efficiency	30%
4	Materials and Resources	10%
5	Indoor Environmental Quality	10%
6	Management	10%
7	Innovation and added value	Bonus
	Total	100

Table 8. GPRS, Credit categories and weightings per each (Karmany, 2016).

3.4.1.2 GPRS Certification Process

The assessment process evaluates a project using a spreadsheet as follows (Figure 19);

1. The number of awarded credits is calculated for each category then determined by a green pyramid.
2. The credits achieved are calculated for each green pyramid.
3. The section score is calculated by multiplying the archived credits by the percentages of the corresponding weightings.
4. All the scores are added to give the total green pyramid rating.

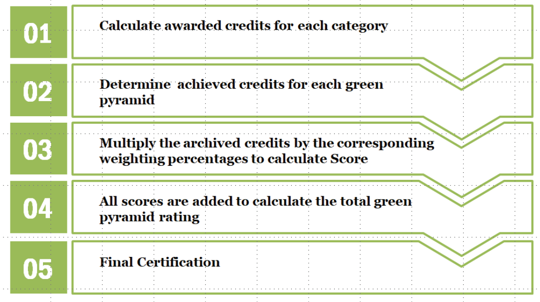


Figure 19. GPRS, Certification process (Hanna, 2015).

3.4.1.3 GPRS Certification Rating

A project must satisfy all the mandatory minimum requirements with more credit points (gained by meeting certain criteria) to earn the Pyramid certification. The rating credits are as follows (Table 9):

GPRS certified (40 – 49 credits), Silver pyramid (50 – 59 credits), Gold Pyramid (60-79 credits) and Green Pyramid (80 credits and above). While projects with less than 40 credits are classified as "uncertified" (Hanna, 2015).

Table 9. GPRS, Certification ratings (Hanna, 2015).

Green	Gold	Silver	Certified	Uncertified
≥ 80	60-79	50-59	40-49	‹40

3.4.2 TARSHEED

TARSHEED is the Arabic word for 'Rationalization'. It is a new rating system developed by Egypt Green Building Council (EGGBC) after studying a number of green building assessment systems such as BREEAM, LEED, ESTID-

AMA and EDGE. The main goal is to achieve savings that exceed the conventional design according to a set of credits under each category (Karmany, 2016).

3.4.2.1 TARSHEED Schemes

TARSHEED offers different schemes to certify (Egypt Green Building Council, 2015);

- ***Residential*** (Basic, advanced), ***Commercial*** and ***Community***.

3.4.2.2 TARSHEED Criteria

- ***Integrative Process:*** ensures collaboration between the diverse team members during the pre-design phase (no credit);
- ***Indoor Environmental Quality:*** focuses on promoting indoor air quality, daylight access and natural views;
- ***Neighborhood Pattern & Design:*** emphasizes on creating compact, walkable, vibrant and mixed-use neighborhoods with good connections to neighboring communities;
- ***Sustainable Sites:*** focuses on how to reduce negative impacts on ecosystems and water resources;
- ***Green Infrastructure & Buildings:*** emphasizes on reducing the environmental consequences resulted from either the construction or the operation of buildings and infrastructure;
- ***Innovation:*** design measures that are not covered under the other TARSHEED credit categories (Table 10).

3.4.2.3 TARSHEED Certification Process

A project can be TARSHEED certified when a minimum of 20% reduction in energy, water and habitat is achieved. The assessment happens in two stages:

- Preliminary assessment (at the design stage), and;
- Final assessment during construction and handover.

Table 10. TARSHEED Point Distribution based on category (Karmany, 2016).

TARSHEED Point distribution based on category			
Category			Points
1	Energy		33.3%
2	Water		33.3%
3	Habitat	Outdoor (42%) Material (34%) Indoor (24%)	33.3%
Total			100%

3.5 Comparative Analysis between BREEAM, LEED, DGNB, GPRS and TARSHEED

Understanding the similarities and differences between the rating systems can help to find more green building solutions context-suitable for each assessed project, widening the limits professionals can meet when obliged to a single green building framework.

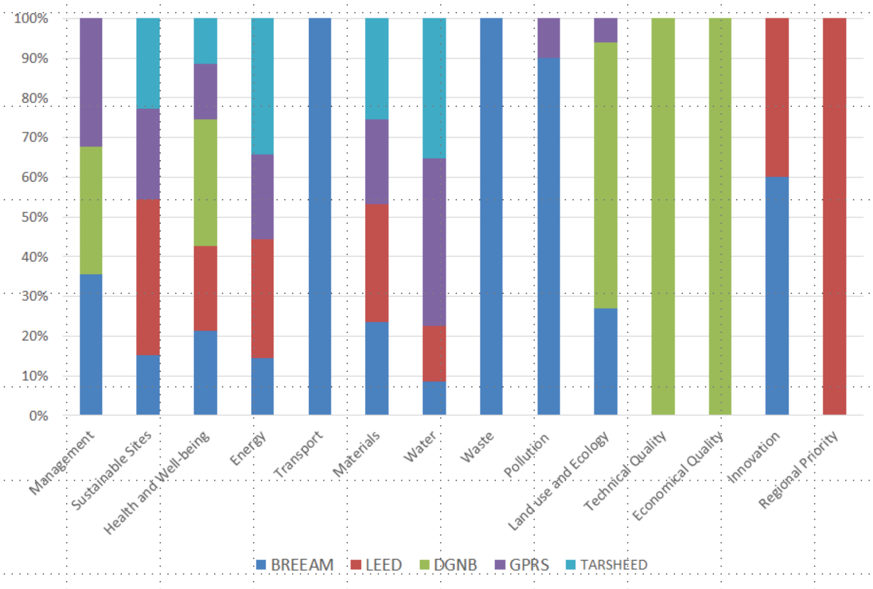


Figure 20. Graphical Illustration for the comparison between BREEAM, LEED, DGNB, GPRS and TARSHEED Criteria (Author, 2019).

3.5.1 Similarities

From the comparison (Figure 20), there are common characteristics between the mentioned GBRS, as they all focus on mutual aspects such as; Site Design, Land and Transportation, Energy efficiency, Water Efficiency, Materials and Resources as well as Indoor Environmental Quality.

In addition, there are no fundamental differences between the certification tools regarding the steps required for the process. They all begin with: 1) project registration; 2) completion and submission of assessment documents to the certification institute; 3) examination of criteria; 4) rating and; 5) issuance of certificate.

Also, the assessment method, which is performed by a third-party, is usually similar except that in LEED, GPRS and TARSHEED it is not necessary that a trained professional should be examining or submitting the project's documents. However, it is considered as an extra merit for the project's accreditation when dealt by a LEED Accredited Professional (AP) (Hamedani & Huber, 2012).

3.5.2 Differences

Yet, the major differences noticed between the certification systems are as follows;

- **Criteria:** each certification system gives attention to specific subjects more than the others (Hamedani & Huber, 2012) as follows;
    - BREEAM addresses Management, Transportation and efficient use of resources, life-cycle costs, service life planning and responsible construction practices (Gin, 2018). BREEAM also is the most dependent on environmental conditions and characteristics of the assessed projects (Hamedani & Huber, 2012);
    - LEED gives more attention to Location of new and existing communities and Design and Planning;
    - DGNB focuses on more Life-cycle phases, technical, economical, process and construction management qualities. DGNB also targets the cohesion of sustainable development aspects (e.g. environmental, economic and social) (Hamedani & Huber, 2012).

Even the categories common between the different GBRS differ in scope and content according to local needs and priorities (Karmany, 2016).

- **Weight:** which defines the significance of each category based on the local needs and environment of the issuing country (Karmany, 2016). For instance, DGNB has 5 main groups each with a weight of 22.5%, except for the process quality which only weighs 10%. While in BREEAM, criteria have different weights (Hamedani & Huber, 2012), giving Energy the highest priority (Karmany, 2016). LEED (followed by GPRS) is mostly similar to BREEAM in this regard, that each criterion has different weight based on its importance (Hamedani & Huber, 2012).

- **LCA inclusion:** Most of the mentioned GBRS take into account the design and construction phases of the project. Only DGNB additionally evaluates the operation and Maintenance phases of the assessed building's lifecycle (Collinge, et al., 2015).
- **Simplicity of practice:** LEED (as for being the most compatible with common plans and elements of urban planning) and TARSHEED use simpler rating system compared to the other certification systems, BREEAM comes next (using the pre-weighted categories method and its criteria for achieving credits) and finally DGNB (Hamedani & Huber, 2012).
- **Flexibility:** BREEAM and LEED have the largest number of certified buildings globally due to their flexibility. Countries other than the UK and the US can adopt their local standards instead of the international standards in the two assessments to evaluate green criteria (Doan, et al., 2017).
- **Minimum accepted score:** In LEED, this is defined as the pre-requirements (mandatory credits in BREEAM), meaning that some criteria are critically necessary. In DGNB, the minimum score is considered individually in each main group. Thereby, the final rating of the project depends on both the total score as well as this factor. This guarantees a minimum quality level for all the elements of the project (Hamedani & Huber, 2012). In GPRS, there is a minimum credit points mandatory for each category (like BREEAM).

- **Rating levels:** each of the certification tools applies a different rating system. DGNB found to be the strictest, then comes LEED, BREEAM and finally GPRS and TARSHEED. Nevertheless, BREEAM has a wider range of labels for certification where the rank “outstanding” needs very special requirements and it is much more difficult to get compared to the highest rankings in the other certification systems (Hamedani & Huber, 2012).
- **Context adaptability:** DGNB is being adapted for 9 countries not only in Europe but also in Asia and South America. There are 13 countries that are applying the international version of the assessment. BREEAM targets the European market, where 7 countries adapted the assessment. LEED has been adapted for 5 countries.
- **Transparency:** LEED calculates the final results in a more transparent rating approach.

Table 11. Comparison between BREEAM, LEED, DGNB, GPRS and TARSHEED (1/3). Adapted from (Hamedani & Huber, 2012; Kshirsagar, et al., 2015; Karmany, 2016).

	BREEAM	LEED	DGNB	GPRS	TARSHEED
Title	Building Research Establishment Environmental Assessment Method	Leadership in Energy and Environmental Design	Deutsche Gesellschaft für Nachhaltiges Bauen	Green Pyramid Rating System	TARSHEED
Developer	Building Research Establishment (BRE) Global	U.S. Green Building Council	German Sustainable Building Council	Egyptian Green Building Council	Egyptian Green Building Council
Country of Origin	United Kingdom	United States of America	Germany	Egypt	Egypt
Launched in	1990	1998	2007	2010	2015
Certification process	Refer to 3.3.1.3	Refer to 3.3.2.3	Refer to 3.3.3.3	Refer to 3.4.1.1	Refer to 3.4.2.3
Rating levels	Table (2)	Table (4)	Table (6)	Table (9)	Table (10)
Certification institute	Building Research Establishment (BRE) Global	Green Building Certification Institute (GBCI)	German Sustainable Building Council	Egyptian Green Building Council	Egyptian Green Building Council
No. of certified projects	568,609 certificates (2019)	80,000 buildings (2016), 18 in Egypt	2200 certificates (2017)	Not indicated	6 projects, 2 ongoing (2018)
Customized Versions adapted for different Countries	9	6	15	1	1
Website	www.breeam.org	www.usgbc.org	www.dgnb-system.de	http://egypt-gbc.org/	http://[illegible]/index.html#

Table 12. Comparison between BREEAM, LEED, DGNB, GPRS and TARSHEED (2/3). Adapted from (Hamedani & Huber, 2012; Kshirsagar, et al., 2015; Karmany, 2016).

CREDIT CATEGORIES	BREEAM	LEED	DGNB	GPRS	TARSHEED
Management/ process quality	12%	0%	10%	10%	Integrative process (no credit)
Site quality	10%	26%	Rated independently	15%	15%
Water	6%	35%		30%	25%
Energy	19%	10%		22%	40%
Materials	12.5%	14%		10%	12%
Indoor Environmental quality	15%	15%		10%	8%
Waste	7.5%	0%		0%	0%
Pollution	10%	0%		1%	0%
Transport and Accessibility	8%	0%			
Technical/ functional quality	0%		22.5%		
Ecological quality	0%		22.5%	2%	
Socio-Culture and Economy	0%	0%	22.5%+22.5%	0%	0%
Innovation	+10%	+4%		Innovation and Added value	0%
Rating Approach	Pre-weighted categories	Additive credits (with mandatory prerequisites)	Total performance index	Additive points (with mandatory requirements)	20% savings compared to the base case

Table 13. Comparison between BREEAM, LEED, DGNB, GPRS and TARSHEED (3/3). Adapted from (Hamedani & Huber, 2012; Kshirsagar, et al., 2015; Karmany, 2016).

	BREEAM	LEED	DGNB	GPRS	TARSHEED
Life-Cycle stages coverage	Pre-design		Pre-design		
	Design	Design	Design	Design	Design
	Construction	Construction	Construction	Construction	Construction
	Post Construction Review	Post Construction Review	Post Construction Review		
			Operation – in use		
			Refurbishment and Maintenance		
Cost of Assessment	$ 4450	$ 5120	Depends on project area and DGNB membership status (starts from $4380)	Not stated	$ 1533

3.5.3 Recommendations

In general, there are some measures that need to be addressed to improve GPRS and TARSHEED as the national rating systems in Egypt;

- Including the life-cycle phases of operation, renovation, demolition and recycling/ reusing and disposal of building waste as well as life-cycle cost assessment (Karmany, 2016);
- Adding schemes for all project types and buildings (Karmany, 2016);
- Considering the special heritage, cultural and regional variations in the Egyptian context;
- Paying attention to economic and social aspects as much as the environmental performance;
- Including categories and credits for reduction of pollution and waste (Akadiri, et al., 2012);
- Considering regional priority and transport (Kshirsagar, et al., 2015);
- Giving more attention to management and maintenance (Kshirsagar, et al., 2015);
- Accepting construction and architectural professionals (in GPRS) to become members of The Egyptian Green Building Council;
- Specifying credits for categories such as; Management, innovation, building aesthetics as well as socio-cultural and heritage aspects (Karmany, 2016);
- Including credits that encourage the selection of green materials (proved with Environmental Product Declaration (EPD));
- Allowing the users to understand the intent behind each requirement so as to promote innovation and savings application (Karmany, 2016);

- Involvement of assessors or accredited professionals at the design stage, as it becomes very beneficial to the process in terms of the comprehensive inclusion of sustainable design criteria and the final certification (Kajikawa, et al., 2011).

3.6 Summary

The chapter focused on presenting five GBRSs; BREEAM, LEED, DGNB as well as GPRS and TARSHEED. An overview along with the schemes, categories, certification process and ratings have been explained in detail. The comparative analysis provided a clear understanding of the metric of each system and helped to point out the similarities and differences between the selected systems.

Through the reviewed literature, DGNB has proved to be a good model for the purpose of the research for the following reasons:

- DGNB assesses a wide range of schemes;
- DGNB is claimed to have the most holistic perspective on sustainability by offering a complete framework, where the widest range of fields are assessed. (Hristova, 2016). This definition has a great influence on architects' and contractors' awareness, understanding and knowledge of sustainable design (Hristova, 2016).
- DGNB provides an operative definition of sustainability that brings the designers' and owners' attention to further sustainability concepts that they already had considered but not explicitly documented or announced within their profiles (Hristova, 2016; Miranda, 2013).
- It largely considers the Life-Cycle of buildings which leads to more transparent and well-defined processes resulting in minimized construction, operation, renovation and removal risks (Miranda, 2013);

- DGNB has been adapted for the largest number of countries compared to BREEAM and LEED in different regions of the world, which shows the applicability of DGNB in different contexts;
- DGNB demonstrates the positive effects of the assessed buildings on both the environment and society, considering economic and functional aspects too (Miranda, 2013). In addition, none of the assessed categories' qualities can be overlooked, as for instance, the economic dimension is given the same weight as the environmental and social aspects (all evaluated with 22.5%) (Hristova, 2016).;
- DGNB helps to promote collaboration between the stakeholders including the client, architects and contractors gaining an improved and mutual understanding of the project goals thanks to DGNB target levels (Hristova, 2016).
- DGNB gives the architects and contractors the chance to form a common language and discussion on sustainable building design, which was not often practiced (Hristova, 2016);
- DGNB stimulates innovation as for setting functional requirements for a building's performance. This requirement offers designers more opportunities to make alternative solutions and encourages creativity (Hristova, 2016).
- DGNB assesses every project uniquely, both quantitatively and qualitatively, as the assessors tolerate the specificity of each building while considering various types of documentation (Hristova, 2016).
- DGNB does not only assess individual measures, but it is concerned about the overall performance of the assessed building, which ensures a

holistic sustainable product (DGNB, 2018).

- In general, compared to other green building rating certifications, the requirements of DGNB are usually higher. This serves as a powerful motivation for building professionals to cover more than the minimum requirements. While for building owners, the motive would be the increased sales value of the building (the certification can serve as a guarantee for the building's quality which increases the sales price of the asset) as well as guaranteeing less expenses on the long term (Hristova, 2016).
- The flexible update of the certificate so it can be adapted to technical, social and international developments (Miranda, 2013).
- The certification process ensures a high degree of certainty that the sought sustainability-performance can be achieved at the time of completion (Miranda, 2013).
-

However, there is still a need for a balanced rating system that is simple, straight forward and complete in coverage that can be specially tailored for the Egyptian context, so as to assess the sustainable design of projects that meets national laws and codes and at the same time suits the local needs and strategies and enhances the common technical knowledge.

This would significantly improve the picture of the "too complex" environmental assessments amongst the stakeholders involved in the AEC industry which would relatively speed up the adoption of sustainable practices.

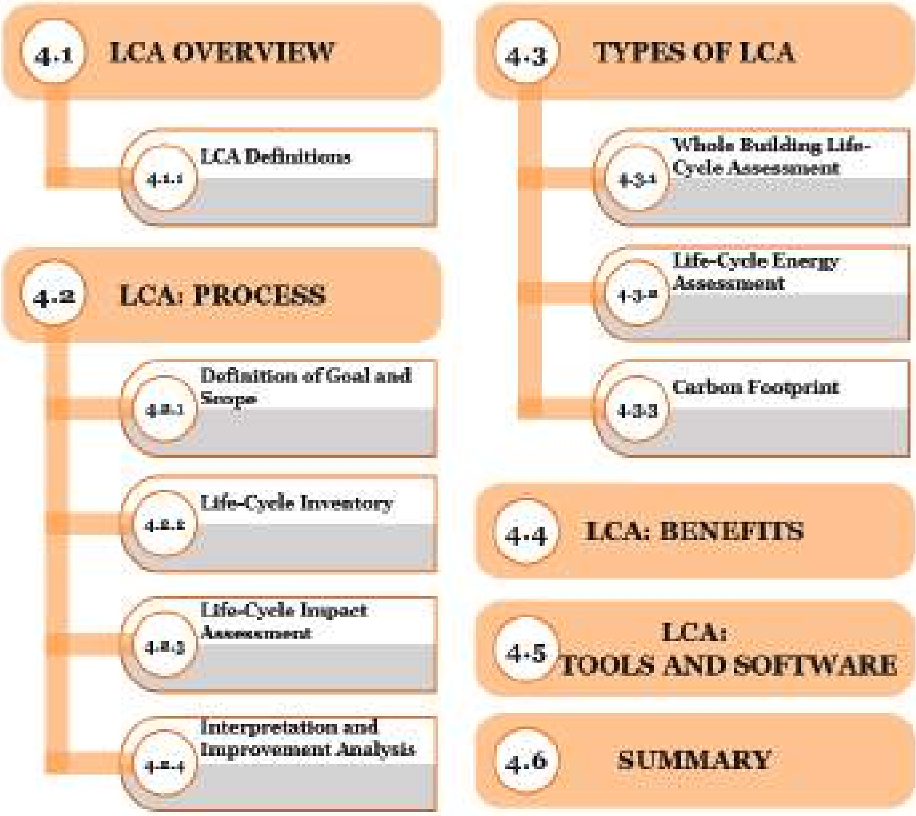


Figure 21. Chapter 4 Scheme (Author, 2019).

"When we build, let us think that we build forever".
- John Ruskin

CHAPTER 4 LIFE-CYCLE ASSESSMENT (LCA)

4.1 LCA Overview

As the building sector has been developed severally in the last two decades, also methods seeking environmental assessment of 'human activity' have been developed, such as Environmental Risk Assessment, Material Flow Accounting, Input-Output Analysis and Life-Cycle Analysis (LCA) (Berardi, 2011). These new methods were reflecting the concepts of meeting present needs without compromising the future generations' needs and in consequence the urgency to evaluate the occurring impacts from an environment, social and economic perspectives (Collinge, et al., 2015).

4.1.1 LCA: Definitions

LCA is the most commonly used system among the above-mentioned systems (Berardi, 2011). It can be defined as 'a systematic tool for evaluating the "cradle-to-grave" environmental performance aspects (Rodriguez, et al., 2019) and related impacts where the material and energy flows of a system, product or process are quantified and evaluated through all its life-cycle stages' (Ramesh, et al., 2010) (Chhatwani, 2015). A Life-cycle of a building (Figure 22) consists of the consecutive phases that building passes through its life time starting from raw material extraction, manufacturing of building materials, project design process, assembly of construction materials on-site, occupation or operation, maintenance and repair and eventually demolition and disposal or re-use. (Wong & Zhou, 2015).

Studies regarding life cycle energy use of the building are of a great importance, as they are mainly used to evaluate the inputs of resources such as energy, water and materials and the outputs similar to CO_2 emissions, solid and

Figure 22. Life-cycle of a building. Source: www.greenbuilding.saint-gobain.com

liquid wastes of a process (Chau, et al., 2015). Subsequently, environmental impacts such as global warming, ozone depletion, eutrophication and acidification are then analyzed, quantified and evaluated regarding energy consumption and waste generation. Therefore, it has been used as a method to improve the construction industry from a sustainability point of view (Ramesh, et al., 2010).

Relatively, making a building "energy efficient" requires the selection of appropriate actions and technologies in each stage of a building's lifecycle to determine how these efficiency options work. Therefore, definition of LCA system boundaries, description of the physical characteristics of the building can significantly affect the found results (World Resources Institute, 2016).

4.2 LCA: Process

As shown in (Figure 23), International Organization for Standardization (ISO) in ISO 14040 and 14044 describes the four major phases an LCA mainly follows:

Figure 23. Graphical representation of LCA stages (Ormazabal, et al., 2014)

4.2.1 Definition of Goal and scope

- Where the objectives (or purposes) of the LCA whether product comparison, improvement-oriented (or other) and description of the physical characteristics of the building as well as system boundaries and the established functional units are all defined (Rodriguez, et al., 2019) (Collinge, et al., 2015).

4.2.1.1 Functional unit

Definition of the functional unit is a key step of an LCA. A functional unit is a quantified measure of the performance of the functional outputs of a product's system (Ghattas, et al., 2013) (Michalski, 2015). It is essential to compare between two or more aspects regarding one constant unit (Ghattas, et al., 2013).

4.2.1.2 Lifetime

Similarly, determination of the lifetime of a building is a key consideration for performing an LCA. It usually varies from 30-50 years according to the literature reviewed (Ghattas, et al., 2013).

4.2.1.3 System boundaries

It is necessary to clearly define the included and excluded activities in an LCA study, as life-cycle of even the simplest products can become quite complex. This applies on the life cycle phases which will be included in the assessment, such as; 'cradle-to-site[1]' , use phase, or 'cradle-to-grave[2]' . In addition, graphical boundaries are a key differentiator between studies, which affects many aspects regarding locally available energy and material resources and climatic zones. Also, location is a key factor as it directly affects transportation during construction and use phases of the building (Ghattas, et al., 2013).

4.2.1.4 Considered materials

As such, the materials (or combination of materials) selected to be considered in an LCA assessment depend on the goal of the study and the audience to whom it will be addressed (Ghattas, et al., 2013).

4.2.2 Life-Cycle Inventory (LCI)

- Where input, processes, emission and resource use relative-data are collected from literature or life-cycle databases. Then, calculations to quantify material, energy inputs and system outputs are performed so as to evaluate the significance of potential environmental impacts based on the LCI (Ramesh, et al., 2010). Collection of inventories differs according to the system boundaries. This second phase is critical phase as the whole results of LCA process relies on the quality of the data in the inventory (Collinge, et al., 2015);

2 *Assessment of environmental impacts of a product or system from the materials extraction and manufacturing through the completion of the building construction.*

3 *Assessment of environmental impacts of a product or system from extraction and manufacturing until the building's end-of-life or eventual disposal.*

4.2.3 Life-Cycle Impact Assessment LCIA

- This is where the LCA data presents the assessed environmental impacts in comprehensive and quantifiable terms based on the inventory analysis. This phase is conducted in three steps which are; impact category definition, classification and characterization. The results can be normalized, grouped, weighed and analyzed to improve their relevance (Collinge, et al., 2015);

There are mandatory and optional elements within the Impact Assessment phase, as shown in (Figure 24) (Chau, et al., 2015).

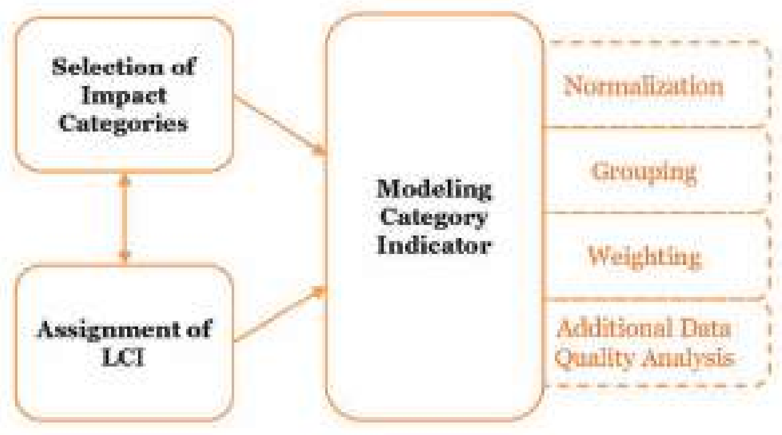


Figure 24. Mandatory vs. Optional elements in the Impact Assessment Phase. (Chau, et al., 2015).

The main purpose of this phase- which is to evaluate the potential environmental impacts and estimate the used resources in the studied system- can be fulfilled in three main steps (Chau, et al., 2015).

4.2.3.1 Selection of Impact categories

There are various impact modelling approaches, but the most commonly used are midpoint and end point. While midpoint modelling is comprehensive and well defined, endpoint (sometimes called damage impact) lack these features.

However, endpoint is popular as for being directly relevant to decision-making by dealing directly with the “endpoint” impact (Ghattas, et al., 2013).

Once the impact categories are established, an indicator and model can be utilized to assess data (Michalski, 2015).

4.2.3.2 Assignment of LCI (Life-Cycle Inventory) results (or classification)

LCI results are classified into emissions, wastes and used resources where each is assigned to the chosen impact categories. Then, the converted LCI results are all aggregated into one indicator result, which represents the final point of the mandatory part of an LCA (Chau, et al., 2015).

4.2.3.3 Modeling of category indicators (or Characterization)

To quantify environmental impacts, there are two characterization approaches can be applied: the problem-oriented (mid-point) and the damage-oriented (endpoints). In the mid-point approach, the used values are either at the beginning or middle of the environmental mechanism. Impacts are classified by environmental themes similar to global warming, acidification and ozone depletion potentials. This method helps to generate a more comprehensive picture of the ecological impacts yet to interpret the results, this requires a good knowledge of LCA. While in the end-point approach, impacts are grouped into categories of general issues such as human health, natural environment and resources, which can be later calculated into a single score. This method is easier to understand but can be less transparent. It is also worth mentioning that mid-point approach needs fewer modelling assumptions as well as reflecting more on societal consensus (Chau, et al., 2015).

The optional steps are: Normalization, Grouping, Weighting and Additional data quality. Normalization helps to understand the relative importance of different impact categories within the LCA by calculating the magnitude of category indicator results that are relative to some reference information. Grouping is to aggregate impact categories into one or more sets. Weighting is to rephrase the resulted indicators of different impact categories into global issues of more concern or in some cases into a single score using numerical factors. These factors are derived from value-choices (based on policy targets), monetization or panel weighting. The chosen weighting schemes can affect the conclusions significantly meaning that there is no preferred or satisfactory approach regarding the weighing step.

In general, LCA should consider all the environmental impacts including resource inputs as well as emissions and wastes outputs of a building during its whole life-cycle (Chau, et al., 2015).

4.2.4 Interpretation and Improvement Analysis

- The results are refined into meaningful information that could be used for better decision-making and improvement recommendations (Collinge, et al., 2015; Chau, et al., 2015).

4.3 Types of LCA

4.3.1 Whole Building Life-Cycle Assessment (WBLCA)

The proliferation of WBLCA studies, which is currently a predominant method used to quantify environmental impacts of buildings, have triggered the development of LCA tools especially the ones targeted to AEC practices (Rodriguez, et al., 2019).

In WBLCA, there are taxonomies[3] that serve the purpose of organizing construction entities in a standardized way by describing these entities in a subclass hierarchy through an "is-a" relationship to standardize terms and eventually enable comparison. Some of the well-known taxonomies in the AEC fields are OmniClass Construction Classification System, MasterFormat and UniFormat.

4.3.2 Life-Cycle Energy Assessment (LCEA)

LCEA can be described as a simplified version of LCA that mainly considers the evaluation of energy inputs for the different phases of a building's life-cycle (Ramesh, et al., 2010). The total energy consumed during the whole life cycle of a building would be calculated by adding the Energies consumed in the phases of extraction, manufacture, onsite, operation demolition, recycling and disposal. (Chau, et al., 2015).

The analysis of LCEA can be performed using primary (energy extracted from nature like coal) or secondary energy (the energy actually consumed such as electricity) but it is important to specify the form of energy under focus to facilitate the later comparison. (Chau, et al., 2015).

4.3.3 Carbon Footprint

Carbon Footprint (CF) has recently gained much attention as a main reason for the ever-growing issue of global warming. However, it is still important to understand that a smaller carbon footprint does not always mean superior environmental performance. This is where LCA is different than CF, and

1 3 Taxonomy, in general, is defined as the branch of science concerned with classification, especially of organisms; systematics.

this highlights the importance of defining the goal and scope of what the user is looking for and then determine which tool would best cover their requirements (Ormazabal, et al., 2014).

4.4 LCA: Benefits

The benefits of the using LCA (Figure 25) can be summarized as follows;

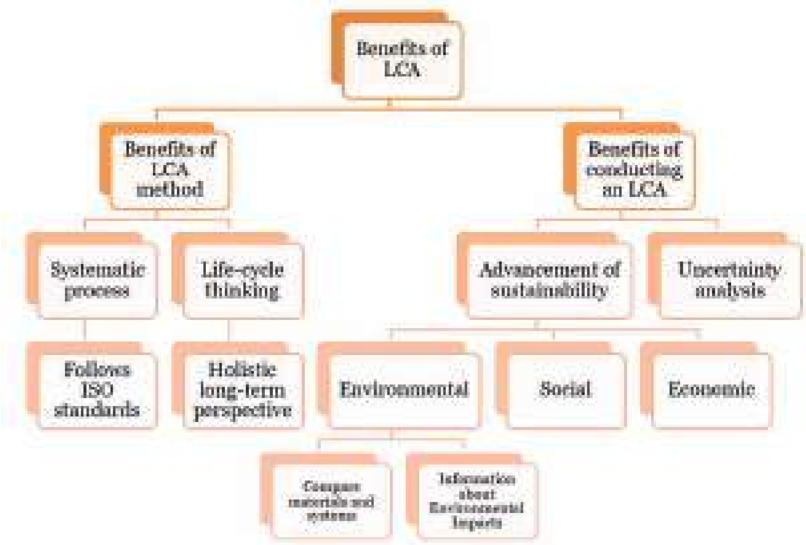


Figure 25. Benefits of using LCA. Adopted from (Saunders, et al., 2013).

1. The potentials of life-cycle thinking and systematic four-step process (compared to other sustainability building related metrics) (Saunders, et al., 2013). Like the Whole Building Life-Cycle Assessment (WBLCA), that entirely considers the building project which helps the building's designers to reduce the environmental impacts of their design (Rodriguez, et al., 2019).
2. The advancement of sustainability within the building sector (Saunders, et al., 2013).

3. LCA views products from a life-cycle perspective which is useful to minimize problems shifting from one life-cycle phase to the other (Rodriguez, et al., 2019).

4. The provision of uncertainty analysis (through Monte Carlo analysis[4]) .

4.5 LCA: Tools and Software

There have been several LCA tools and software recently developed for buildings. These tools usually require mapping and exportation of the bill of materials for the ones having database available within the used software (Yang & Wang, 2013).

The basic function of any LCA software package is to determine the balances of energy and mass on a model then allocate the resulting emissions and energy uses, to facilitate the calculations associated with the later stages of inventory and impact assessment. In a study carried out by (Ormazabal, et al., 2014), the team developed a list of the best known LCA software packages and found out that the most commonly used were; ATHENA, LEGEP, SimaPro, GaBi, Earthster 2 Turbo and OpenLCA. These tools were usually selected as for offering a variety of characteristics.

- ***ATHENA Impact Estimator***, a user-friendly tool providing users in North America with practical database for building assembly which makes it easier to give a comprehensive description of the building and a more accurate estimation of the expected impacts (Yang & Wang, 2013). Moreover, it is connected to the US Life-Cycle Inventory (US LCI) database which is free and open access with a good amount of database for

1 4 *The most common method of uncertainty analysis among LCA software tools.*

construction materials and supported assemblies.

- ***LEGEP,*** (in Germany), an effective tool that performs integrated LCA and Life-Cycle Costing (LCC). It can calculate environmental impacts of the building while considering the economic factors all in the same framework (Yang & Wang, 2013).
- ***SimaPro,*** considers every aspect of cradle-to-grave analysis and it includes processes from harvesting of materials till the reuse and disposal. It accepts EcoInvent databases (Yang & Wang, 2013).
- ***GaBi,*** which provides its own construction-industry database (by think-step and PE international) (Chhatwani, 2015).
- ***Earthster 2 Turbo,*** an example of Software as Service (SaaS), whose main objective is to provide designers, manufacturers, suppliers and environmental experts with updated available data. It also has the capability to include social impacts into the calculation.
- ***OpenLCA,*** a widely known, easy-to-handle software tool that allows users to calculate all LCA-associated stages. It provides users with the possibility of working with various databases like the ones used by GaBi and many others. It was initially designed to calculate environmental impacts of products and processes, but now developed to include economic aspects too (Ormazabal, et al., 2014).
- ***One Click LCA,*** it offers a wide range of services such as; Early stage LCA calculation and design optimization, circularity assessment, Carbon foot-printing and Life-cycle Costing.

4.6 Summary

Integrating the Life-cycle Assessment in the design process could be vital to enhancing Efficient Building Design practices in the Egyptian AEC industry. Buildings have been found to generate numerous negative impacts to the environment (Figure 26), which require a cautious attention to the buildings produced everyday.

LCA mainly focuses on Materials and Resources to assess the Environmental Impacts resulting from their manufacturing, use and disposal.

Although LCA methodology is well-defined, LCA for buildings is still seen as complex to handle and hard to understand. This can be due to the huge amount of information needed for carrying the assessment out (which sometimes

Figure 26. Life-Cycle Stages and the corresponding environmental aspects to be assessed (Carre & Crossin, 2015).

is either not available or not fully accurate), and the lack of sector-specific standardization and use. In addition, the dissimilarity of the currently performed LCAs (as for being based upon different scopes and boundaries) makes the comparison between them and the amount of concluded useful data very limited.

One Click LCA has been found the most appropriate LCA tool for the current research as for being compatible with the DGNB rating system. Also, it

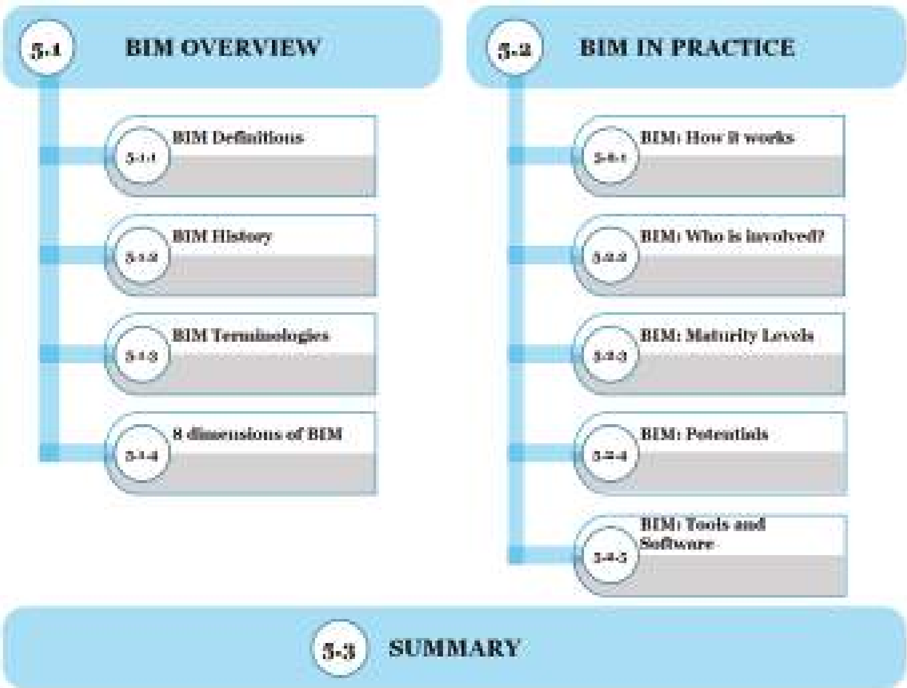


Figure 27. Chapter 5 Scheme (Author, 2019).

"A Catalyst for Change"
- Bernstein (2005)

CHAPTER 5 BUILDING INFORMATION MODELING (BIM)

5.1 BIM Overview

BIM is one of the newly deployed technologies in the Architectural, Engineering and Construction (AEC) as well as facility management fields (Elyamany, 2016). BIM, mainly, generates a digital representation of the physical and functional characteristics of a facility (WBDG, 2018) to facilitate ‘digital’ information exchange and interoperability. BIM applications have been tremendously developed from a three-dimensional design tool into a set of tools used for model analysis, clash detection, material and product selection and even the conceptualization of the whole project (Elyamany, 2017).

5.1.1 BIM: Definitions

There is no single agreed upon definition of BIM whether it is a product or a process. Therefore, the definitions mentioned hereby will be the ones serving the objectives of the research. BIM is basically "a systematic process for creating, managing and disseminating the information generated during a building’s design development and operation" (Gerrish, et al., 2017). The Associated General Contractors of America (AGC) states that: A building information model is “a data-rich, object-oriented, intelligent and parametric digital representation of a project (Shoubi, et al., 2015), including all the physical and functional characteristics, giving access to the digital description of every aspect of the built asset" (Shawky, 2018). Whereas Aranda (2008) defines BIM as "a new approach for practicing the design profession that can be effective only when new policies, contracts and relationships among the involved stakeholders are implemented" (El Barbary, 2018). In the glossary of the BIM handbook by (Eastman, et al., 2011), it has been defined as “the tools, processes or technologies operated by digital ‘machine-readable’ information about a building’s design, planning, construction as well as operation and performance” (Khodeir & Nessim, 2017). While Construction Project Information Committee (CPIC) defines BIM as a "digital representation of physical and functional characteristics of a project creating a shared information resource (Çavuşoğlu & Çağdaş, 2018), which decision-making can be reliably based on during its life-cycle, form the earliest concept till its end-of-life" (El Barbary, 2018).

Accordingly, different views and data can be extracted from a BIM model and analyzed related to the various needs of users which can significantly improve the whole delivery process of the project (Jung, et al., 2013) (Shoubi, et al., 2015).

This object-based, integrated, intelligent and virtual model provides an environment to obtain abstract forms of representations, time schedules, analyses and simulations that enables the creation, generation, coordination and management of numeric and non-numeric data collaboratively, comprehensively, and in a computable yet user-friendly way. BIM has the capabilities to improve the design process tremendously, as it allows for multi-disciplinary collaboration between the involved parties (via digital media). Furthermore. the three dimensional (or more) object-oriented model gives access to information regarding material types, properties, quantities, energy performance, lighting and site disturbance which are usable for analyses, evaluations and assessments (Çavuşoğlu & Çağdaş, 2018).

A BIM model needs to: be object-oriented, three-dimensional, embed discipline-specific information for the modeled objects and the interwoven relations and hierarchies between them, as well as to include a detailed graphical and non-graphical description of the building (El Barbary, 2018).

5.1.2 BIM: History

Although BIM was developed in the mid-1980s, only in the last ten years it began to gain a noticeable popularity among architectural, engineering and construction (AEC) professionals (El Barbary, 2018). In 1986, ArchiCAD was first introduced as a revolutionary software for Information Technology for Construction (ITC) that could create virtual 3D models of projects instead of the 2D Computer Aided Design (CAD) representations used at that time. Obviously, this was quite important as only then architects, designers, planners and engineers were not able to store large amount of data using 'datasets' embedded within the 3D model. These data included geometrical, special properties and quantities of the components in the model (Shoubi, et al., 2015). Currently, USA is considered the biggest producer and consumer of BIM products, directing the largest flow of BIM knowledge towards developing countries. While Finland is the world's leader in BIM implementation, followed by the UK, Hong Kong, Singapore and Australia which are seeking for BIM endorsement on their national levels (Elyamany, 2016).

It is worth mentioning that BIM is not an advanced (CAD) tool as it can give a completely different set of services for being a 3D virtual reality of the objects and assemblies present in the model, rather than two-dimensional CAD representations (Mohamed, 2018).

BIM has been developed over the years to improve the flow of data through building processes and therefore improve their efficiency. In order that BIM can meet the required appropriate structure of design information, its standards have gradually been matured in order to work better for construction practices (Marty, R., 2014).

BIM can be a single model or a set of assembled models representing several separate databases that by interoperability communicate their information (El Barbary, 2018).

5.1.2 BIM: Terminologies

There is a set of basic terminologies that are central to understanding BIM and differentiating it from conventional 3D modeling on which the research can be based. The following list can be a starting point for this understanding:

- ***Parametric objects:*** 3D objects that have associated data and rules, that are non- redundantly integrated and allowing for no inconsistencies. Their associated geometry is automatically modified when associated objects are changed. Different levels of aggregation can be defined for objects and their related subcomponents. Violations of object feasibility regarding size and manufacturability can be spotted when changes are applied. These objects also can link to or receive and export other attributes like materials and energy data (Eastman, et al., 2011).
- ***Integrated Project Delivery (IPD):*** is a Project Delivery Method that (PDM) that starts the collaboration between owners and design team from the early beginning. This method incorporates the different actors with exchanging information and design practices into one system, where all the involved parties provide their insights and expertise

for the mutual objective of the project. This method can significantly increase efficiency as well as reduce time and cost (Stamenov, et al., 2016; El Barbary, 2018).

- ***Level of Detail and Development (LOD):*** is a reference to describe the progression of the project from conceptual to the detailed assembly (Table 14). The level of detail can be described as the inputs to the element, while the level of development is the reliable inputs (El Barbary, 2018).

Table 14. Level of Development progression specifications (Mohamed, 2018).

LOD	100	200	300	400	500
Model concept	Conceptual	Approximate geometry	Precise geometry	fabrication	As-built
Design & coordination (function /form/behavior)	Non-geometric data or line work, areas, volumes, zones etc.	Generic elements shown in three dimensions • maximum size • purpose	Specific elements Confirmed 3D Object geometry • dimension • capacities •connections	Shop drawing/fabrication • purchase • manufacture • install • specified	As-built • actual

- ***Collaboration:*** the ability to coordinate and communicate between people regarding values, intent, context and procedures (Eastman, et al., 2011).
- ***Assemblies:*** multiple building elements combined into a single assembly that can be independently scheduled, tagged, and filtered.

Figure 28. BIM collaboration between stakeholders' value chain. Source: (www.Buildingincloud.net)

- ***BIM Execution Plan (BEP):*** is an essential document for the successful development of a BIM project (Figure 29). It contains all project information from the model details (of technical specifications, documentation, visualizations, etc.) to the details of contact employees alomg with their role and responsibilities through the collaborative process. In order to ensure the optimal development of all the involved parties, the BEP needs to be available, updated, with accessible information to allow the team to face any unforeseen in any phase of the project . (Zigurat Global Institute of Technology, 2018).

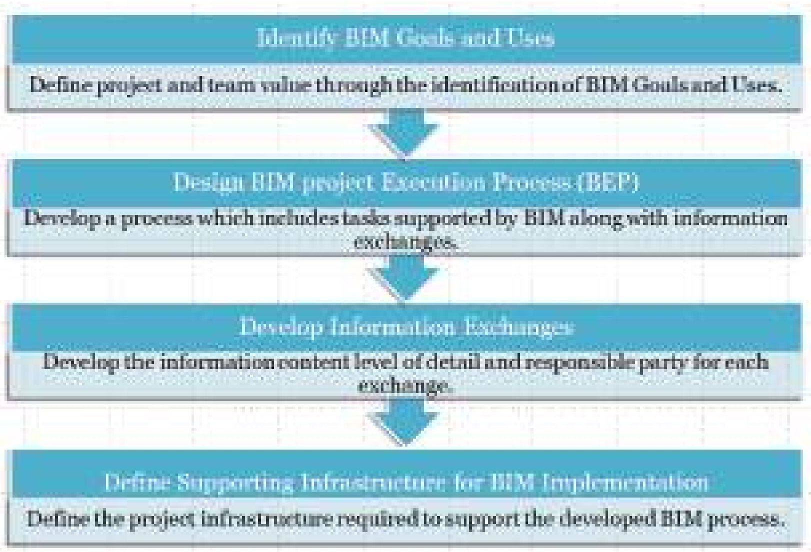


Figure 29. BIM Project Execution Planning procedures. Adapted from (The University of British Columbia and École de Technologie Supérieure, 2011).

- ***Integrated Project Delivery (IPD):*** IPD is a project delivery approach that seeks to integrate people, systems, business structures and practices into a single process and collaboratively harness the talents and insights of all participants on a particular construction project in order to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction.

5.1.3 8 Dimensions of BIM

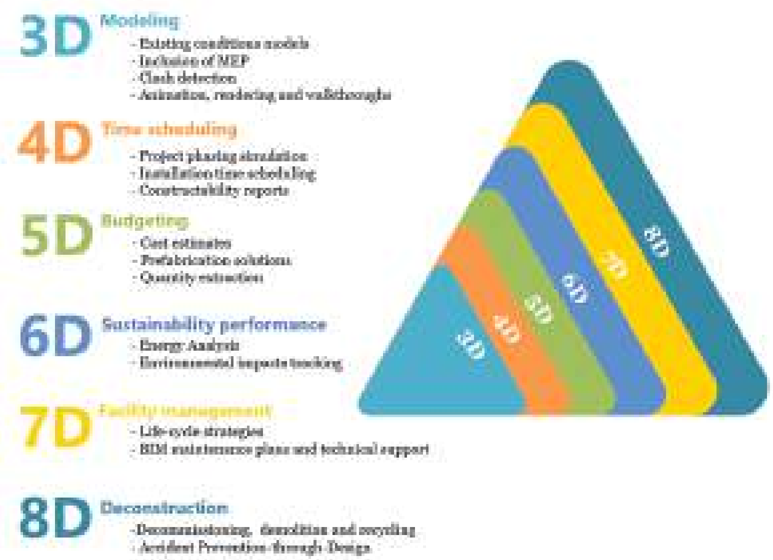


Figure 30. Different dimensions of BIM. Adapted from (El Barbary, 2018).

In the last few years, BIM has vastly developed to include the information of several dimensions, going beyond the simple 3D model. Linking extra dimensions of information to the model allows for further potentials and better understanding of the project regarding delivery, cost and later maintenance. The following part explains what type of information can be embedded within the BIM model (Figure 30), and how this can significantly affect decision making and consequently more efficient buildings (McPartland, 2014).

- ***3D Modeling:*** While the third dimension is normally used during the design process for graphical and non-graphical information visualization and better understanding of the project, the associated data facilitated the coordination of all involved teams until the data is handed over to the client at completion (McPartland, 2014). This compactly-packed information models help to mark clashes, resolve conflicts and keep track of construction progression (El Barbary, 2018).
- ***4D Scheduling:*** this include adding the information of time management as well as linking model elements and data with construction sequence and scheduling. These details can be used to obtain visualizations of how the project programme will develop, the time needed for components to be installed or constructed and become operational and sequentially dependencies of other areas in the project (McPartland, 2014).
- ***5D Budgeting:*** linking BIM model elements and assemblies with automatic counting of quantities and cost estimations including capital costs, running costs and the cost of renewal or replacement when needed, helps tracking predicted and actual spend over and budgeting of the project (McPartland, 2014). This feature makes decision-making more effective and helps to track budget throughout the construction phase (El Barbary, 2018).
- ***6D Sustainability Performance:*** taking the other two sustainability pillars (economic and social aspects) into consideration to allow comparisons between the proposed designs with required budgets and resulted social impacts (El Barbary, 2018). This dimension included

adding energy performance modeling and consumption analyses, which results in more accurate energy estimates in the early design stage along with sustainability element tracking and possible GBRS evaluation (McPartland, 2014).

- ***7D Facility management:*** linking model attributes and data (by providing a database for ongoing tracking) to support management and operation of the building, equipment and structure. This offers a better understanding of the whole life-cycle of the asset in terms of cost and performance, which helps in making better decisions later (McPartland, 2014), providing action plans for logistics, facility management and real-time collaboration (El Barbary, 2018), which all add significant asset values when it is handed over to the end-user (McPartland, 2014).
- ***8D Deconstruction:*** related to the 'afterlife' of buildings, regarding decommissioning, demolition and recycling of the building or its structure. BIM can help to find the best way to deconstruct a building using Accident Prevention-through-Design (PtD) to deal with possible hazards and expected risks, including the quantities and description of the produced materials. This tool helps designers, who are not equipped to do thorough risk assessment of each design component due to their limited knowledge about safety during construction, to perform hazard audits using BIM models and produce hazard profiles for elements regarding their severity (critical, moderate and low) and get suggestions of design revision for elements rated critical (Kamardeen, 2010).

5.2 BIM in Practice

5.2.1 BIM: What should a model contain?

The contents of a BIM model depends on the phase and purpose of the model itself. The content should include;

- Geometric and spatial data;
- Object proprietary data;
- Object construction data (how assemblies are broken down);
- Cost and object parameters schedules.

In BIM, even objects that not to be modeled their associated data can still be defined and mentioned as properties of other objects (CRC Construction Innovation , 2009).

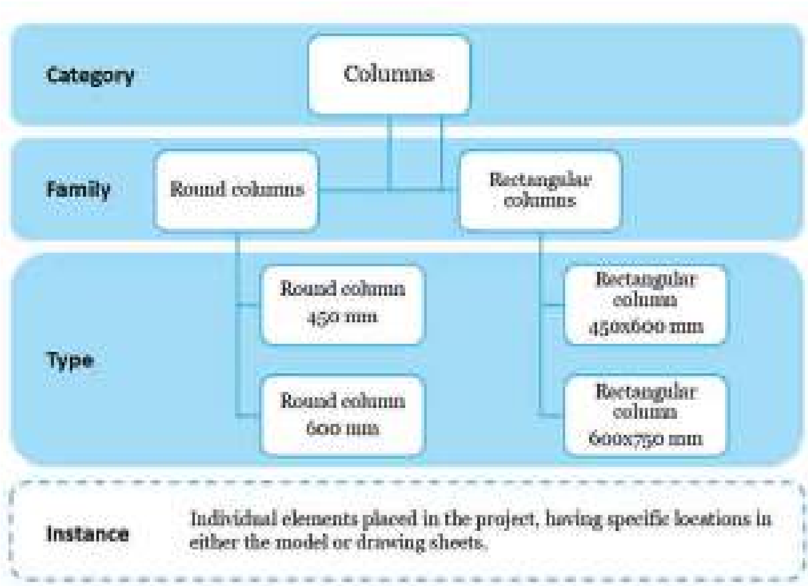


Figure 31. Classifications of elements in Revit (Knittle, N.D).

In Revit Autodesk, a building's components are grouped by categories, families and types (Figure 31) (Knittle, N.D).

- ***A Category:*** controls the organization, visibility, graphical representations, and scheduling options of Families within a project.
- ***A Family:*** is a group of 2D and/or 3D information that serves to represent an individual building element in the model. It defines the parametric, graphical, and documentation requirements.
- ***A Type:*** is a specific group in a Family with distinct parametric, graphical and documentation characteristics that makes it unique from the other Types in the same Family.
- ***An Instance:*** is a representation of a Type which has unique parametric, graphical and documentation characteristics that makes it unique from the other Instances in the same Type.
- ***Elements*** are everything in a Revit's model. Elements are classified into distinct groups of classes and subclasses.

5.2.2 Who is involved?

The BIM player groups can be categorized in three fields (Figure 32), Policy, Process and Technology as follows;

- The **Technology Field** players specialize in developing software, hardware, equipment and networking systems necessary to increase efficiency, productivity and profitability of AECO sectors.
- The **Process Field** players procure, design, construct, manufacture, use, manage and maintain structures. These include facility owners, architects, engineers, contractors, facility managers and all other AECO industry bodies.
- The **Policy Field** players' responsibility include; preparing practition-

ers, delivering research, distributing benefits, allocating risks and minimising conflicts within the AECO industry. These involve organisations — like insurance companies, research centres, educational institutions and regulatory bodies — which play a pivotal preparatory, regulatory and contractual roles in the design, construction and operations process.

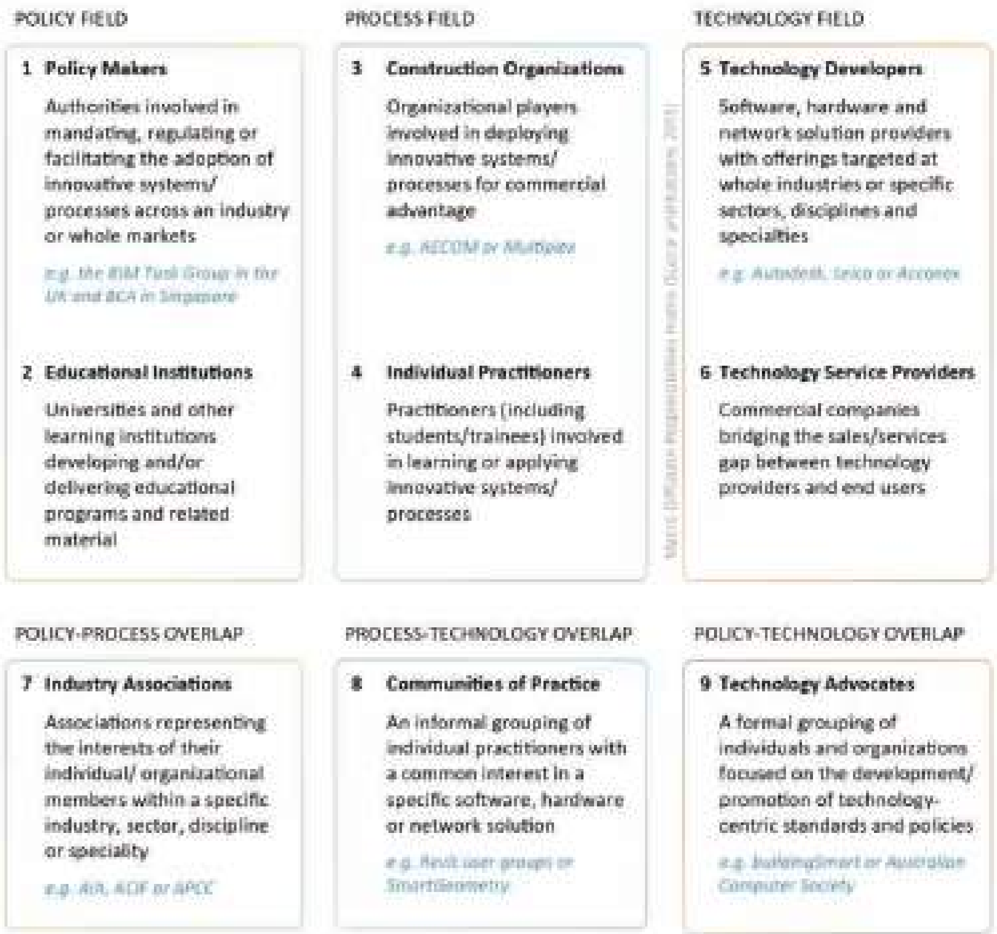


Figure 32. Stakeholders involved in BIM Design Process and their responsibilities (Succar, 2017).

5.2.3 Information Exchange

BIM data flows are variable, as they can include the transfer of structured/ computable (e.g. databases), semi-structured (e.g. spreadsheets) or non-structured/non-computable data (e.g. images) between different systems.

BIM data flows can either be data ‘exchanges’ or data ‘interchanges’, as follows;

A BIM data exchange: is when a BIM player exports or imports data that is neither structured nor computable, like exporting 2D CAD drawings out of 3D object-based models.

A BIM data interchange: is when a BIM player exports and imports data that is structured and computable by another application. Interchanges assume ‘adequate interoperability’ between the sender and receiver systems that may occur in many technical ways like the exchange of proprietary (RVT and DGN), open-proprietary (like DWF and many eXtensible Markup Languages) or non-proprietary file formats (ex: IFC and CIS/2).

5.2.3.1 Interoperability

Interoperability is the ability of different information systems, tools or applications to be connected within prepared organizational boundaries to access, exchange and use data among the involved stakeholders to enhance work flows and facilitate process automation (Eastman, et al., 2011).

5.2.3.2 Common Data Environment (CDE)

A CDE is an assigned single source of information used to collect, manage, share information and disseminate documentation as well as to extract graphical and non-graphical data for a BIM project, accessible by the whole team. CDE can allow for high levels of coordination and is essential to accordingly deliver quality renovation, repair, maintenance information within time and budget frames.

There are many online collaboration platforms (such as Viewpoint, Asite and Conject) which all facilitate a CDE for project information sharing and exchange among the different teams working on the same project (Moscardi, 2016).

5.2.3.3 Industry Foundation Classes (IFC) *(The most advanced non-proprietary data exchange format for construction)*

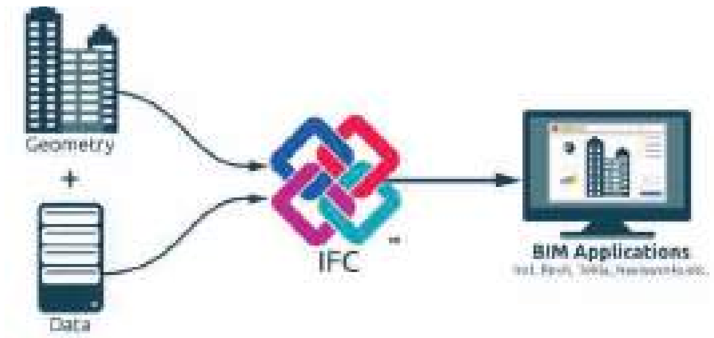


Figure 33. Sharing Information using IFC. Source:(www.blazethread.com, 2017).

As a result of having many BIM software platforms, there was an urgent need for a single domain or a hub where all the BIM software can be integrated fully when needed. This is why Industry Foundation Classes (IFC) was developed by the Alliance for Interoperability (IAI) to facilitate open online interoperability between different software in the construction industry (Mohamed, 2018). IFC is defined as "an extensible object-oriented data model where the base entities can be elaborated and specialized by sub-typing to make any number of sub-entities" (Idra, 2017). IFC consist of a library of object and property definitions that can be used to represent a project while supporting the use of the available building information for particular purposes (Eastman, et al., 2011).

IFC has neutral and open specification which is not controlled by one or a group of vendors. IFC is registered by the International Organization for standardization as an international standard data model ISO/IS 16739 (Mohamed, 2018).

5.2.3.3.1 IFC uses

IFC format can be beneficial for several uses (all free, well documented and can be used by many other BIM tools and applications) (BIM Community, 2018);

- The design visualization and clash detection;
- Import data from one application to another (Figure 33 and Figure 34);
- IFC model contains both building geometry and building data as well as the information held in native BIM files.

Figure 34. Uses of IFC Data Exchange. Adapted from (Stumpf et al., 2011).

5.2.3.4 COBie (Construction to Operations Building information exchange) *(The standard exchange protocol of BIM)*

Historically, information transmittals for a building under construction have been done on paper. This resulted in a significant portion of information loss once the building is completed, in addition to the quantity of data redundancy. The Construction Operations Building information exchange (COBie) is the information base used in the United Kingdom's building information modeling (BIM) implementation that keeps information about the building in a usable format for everyone to access throughout the building's life cycle (Mohamed, 2018).

COBie is considered as a standardized method to collect information during the design and construction processes, as a part of the package delivered to the owner during commissioning and handover (Eastman, et al., 2011). This can significantly help to avoid redundancies and waste of time in collecting useless data. It is also convenient in economic terms and easy in use: it is a spreadsheet, (Figure 35), operable by common interfaces as Microsoft Excel, and for the same property it is machine-readable. It could be also integrated by Computer Maintenance and Management Systems (CMMS), as well as in many other design and facility management software (Mohamed, 2018).

The IFC format is used to record data of a building that can be exchanged between different software, meaning that it is designed for software-to-software exchange. While having a spreadsheet form of COBie has the real benefit of allowing human-to-human understanding of the exchanged information (Mohamed, 2018).

The primary benefit of COBie is that it enables information to flow from the design phase onward, allows information to be added anytime and is available to transfer the information to the facility manager upon completion.

COBie is a performance-based specification where two main types of assets are included; equipment and spaces. In simple words a COBie spreadsheet makes it possible to know which object (with its characteristics) is where. This is fundamental for the decision-making stage (in the preliminary project’s phases) or in the execution of the maintenance plan (for the operative phase). COBie, then, helps the project's team both within construction as well as operation and maintenance (O & M) stages without asking for additional effort. Moreover, COBie data can be imported directly into asset management software, again at no cost. Project Documents and building information model files that accompany COBie are exported in a way that they can be easily accessed through the office server. In general, COBie does not generate any significant change in the design and construction processes, but makes them more linear and lighter, reducing useless passages and redundancies optimizing the "paper-process". Information in COBie are not an end onto themselves but can be re-used through the project. Today, COBie has been included in design and construction contracts in the United States, United Kingdom, and Singapore, but it is going to have a very fast adoption, this is due to its simplicity in use and convenience in economic terms: when a computer is available with excel installed, the work can be done in a precise and automatic way (Idra, 2017).

In short, COBie does not generate significant changes in design and construction processes, it only makes them more linear to reduce useless redundancies and optimize paperwork (Idra, 2017).

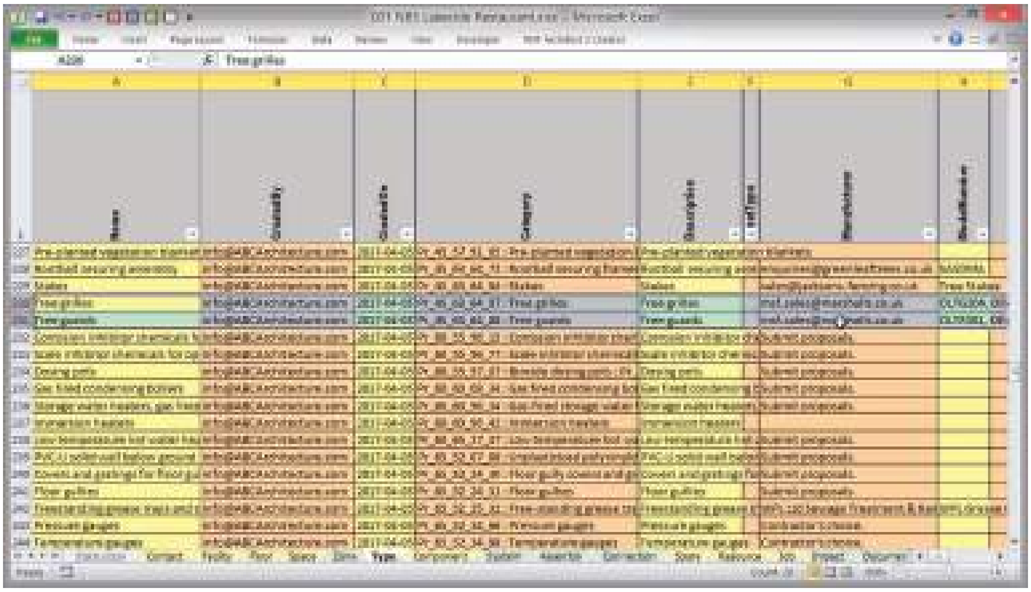


Figure 35. *Example for data inside a COBie Spreadsheet (Stephan, 2018).*

5.2.3.5 Green Building eXtensible Markup Language (gbXML)

gbXML is another interoperability schema that transfers the building data needed for preliminary environmental analysis of building envelopes, zones and mechanical equipment simulation from CAD or BIM applications to (specially energy) software (Mohamed, 2018) (Eastman, et al., 2011). It is an open data scheme whose main scope is to provide data for the analysis of operational energy consumption such as; thermal properties of construction materials or HVAC installation (Mohamed, 2018).

5.2.4 BIM: Maturity Levels

‘BIM maturity' essentially means the supply chain’s ability to exchange information digitally (McPartland, 2014). The maturity wedge diagram, (Figure 36), shows the BIM levels (within the range from 0 to 3) as pre-defined distinct and recognizable milestones;

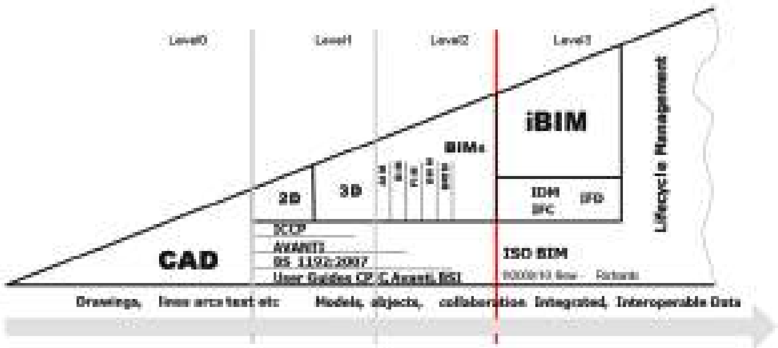


Figure 36. The UK BIM Maturity Model (from Computer-Aided Design to building Life-Cycle Management ((GCCG, 2011)).

Level 0 BIM: only 2D CAD crafting is utilized for Production Information, with no effective collaboration. Outputs and exchange are in paper forms and electronic prints.

Level 1 BIM: a mixture of 2D CAD for drafting of statutory approval documentation and Production Information and 3D CAD for conceptual work. Data could be shared ‘electronically’ from a (CDE), usually managed by the contractor. To achieve this level, minimum requirements should be met; 1) Roles and responsibilities should be agreed upon; 2) Naming conventions should be adopted; 3) create and maintain the project’s specific codes and special coordination; 4) allow information exchange between all team members using a (CDE) or ‘Electronic Document Management System’ (EDMS); 5) agree upon a suitable information hierarchy to support the concepts of CDE and document repository (McPartland, 2014).

Level 2 BIM: tends to focus on collaborative working, requiring for an information exchange protocol specifically for the project and well-coordinated between the different involved systems and project participants. Accordingly, the used software should be capable of exporting information in one of the common file formats such as IFC (Industry Foundation Class) or COBie (Construction Operations Building information exchange). The UK government has set this level as minimum for all public-sector works (McPartland, 2014).

Level 3 BIM: has not been fully defined. Yet, it has been found to benefit the users in creating less waste, delivering in shorter time and producing more efficient outputs while maintaining convenient profit margins. This is due that the shared data is not converted and sent between the multi-users via one established source, stored on the cloud and accessible by all the project teams. BIM level 3 can be highly effective regarding building life-cycle management as data is transacted for construction, fabrication and facility management.

5.2.5 BIM: Framework

The BIM Framework identifies BIM maturity within organisations, projects and industry as a series of stages that need to be gradually and consecutively implemented by stakeholders. BIM maturity includes TPP (technology, process and policy) components and is subdivided into three transformational stages each of which is subdivided into further incremental steps (Succar, 2009).

BIM stages are (Figure 37):

- BIM Stage 1: Object-based modelling
- BIM Stage 2: Model-based collaboration
- BIM Stage 3: Network-based integration

Figure 37. *BIM Maturity Progression Stages (Succar, 2009)*

5.2.6 BIM: Benefits

Generally, BIM can be said to have plenty of potentials and added values when adopted in the construction industry (Khodeir & Nessim, 2017) especially when implementing sustainability criteria within.

Moreover, these potentials can be widely enhanced if proposed using the LCA methodology (Antón & Díaz, 2014). The Benefits of utilizing BIM can be described as follows (Figure 38);

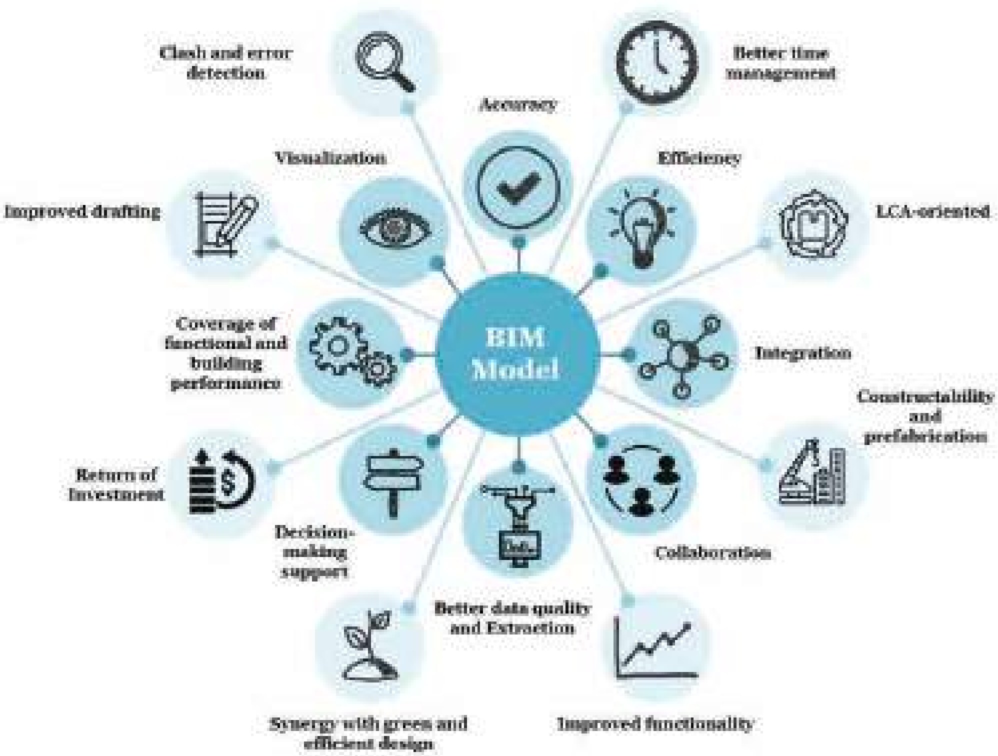


Figure 38. *Benefits of BIM for the AEC industry. Adapted from (http://new.siemens.com/).*

1. **3D Visualization vs. 2D Representation:** BIM allows users to create immerse visualizations for the project which enhances the quality of design and document deliverables (Khodeir & Nessim, 2017). The user also gets more insights into the modelled design with the add-ins analysis tools (Autodesk, 2019);
2. **Accuracy vs. Estimation:** the virtual construction of the building before the actual in situ action ensures the accuracy of quantities and qualities of the proposed design while keeping the estimated factor minimal (Antón & Díaz, 2014) and financial risks at the lowest (Mohamed, 2018). The methodology of association between the 3D model and information makes huge improvements in design quality and reductions of errors, construction time and costs (Shoubi, et al., 2015);
3. **Efficiency vs. Redundancy:** user-input minimization as objects and data in BIM only need to be drawn and/or changed once then the central database updates all changes of the object with all the relative parameters in the same time (Khodeir & Nessim, 2017);
4. **Integration vs. Separation:** the simulation aspect allows a direct access of the project related costs estimation, project management and structural analysis, providing the involved stakeholders with more efficient and smarter decision-making (Mohamed, 2018). Researchers claim that the current BIM practices are quickly evolving, transforming the design process from a traditional sequential (linear) into a circular, interdisciplinary one (Stamenov, et al., 2016);
5. **Collaboration vs Division:** the capability of multiple team members from different disciplines to access and work together on the

same project with the use of cloud-based BIM tools supports concurrent BIM authoring, regardless of location (Idra, 2017) (Autodesk, 2019). For instance, using BIM helped the UK government to reduce waste in construction by 20%, which was caused by the discrepancies, mistakes and inefficiencies in the conventional information supply chain. This reduction was achieved by maintaining the collaborative working environment provided by BIM (McPartland, 2014);

6. **Data Extraction:** for the purpose of analysis or coordination in the format of charts, diagrams or tables as well as 2D and 3D presentations, schedules and construction drawings all become more efficient yet less costly and time saving (Mohamed, 2018). BIM can superimpose information allowing multi-discipline data exchange within the same model (Shoubi, et al., 2015) (Stamenov, et al., 2016). In addition, that information of properties and quantities of building materials, energy performance, lighting and equipment types can be extracted (Stamenov, et al., 2016). This feature creates a great opportunity for sustainability mitigations and performance analyses to be performed (Shoubi, et al., 2015);

7. **Improved Drafting:** as the design team is allowed to 'virtually' construct project, while sections, elevations, plans and 3D views are created and edited concurrently without the need to check plots. In addition, all the revealed documentation becomes a short and by-product without extra cost or orders (El Barbary, 2018);

8. **Better Time Management:** less time is advanced for production, while more time is provided for design and creative solutions (El

Barbary, 2018);

9. **Decision-making Support Tool:** the ability to evaluate and compare the feasibility of the design alternatives. This improves collision/ clash detection (Shawky, 2018) while giving the opportunity to compare different architectural designs, environmental variables with the access to full calculation of resource, time and cost all visualized in 3D environment (Khodeir & Nessim, 2017) (Antón & Díaz, 2014);

10. **Coverage of Functional and Building Performance Aspects:** such as structural integrity, temperature and acoustics control, ventilation and airflows, lighting, pedestrian circulation, energy and water consumptions (Eastman, et al., 2011). Additionally, using BIM to manage building performance information is a potential end-goal for post-construction phases. This gives the building's end user the benefits of error reduction, minimization of lead times and cost (Gerrish, et al., 2017);

11. **Improved Business Functionality:** as by using BIM; the collection, use and maintenance of a facility's information becomes a part of the business done by the authoritative source and not a separate activity (WBDG, 2018);

12. **Clash detection and error minimization:** the feature of overlapping and integration of different platforms in one single model provides the possibility to identify, inspect and report system interferences (El Barbary, 2018);

13. **Possibility of Synergy with Green and Energy Efficient Design:** utilizing BIM would help to encourage the sustainable ap-

proach in construction processes making it neither complicated nor expensive but on the contrary a holistic integrated process. On one hand, this integrated design sees all the components of a project holistically rather than individually. On the other hand, this integration can understand the other social, economic and environmental aspects of these components (Antón & Díaz, 2014). Recently, AEC professionals have started to recognize the capabilities of BIM that can be used to meet sustainability demands (Stamenov, et al., 2016). By using BIM, the environmental performance of an entire building can be quantified and compared to standard baselines. This gives designers a wide spectrum of alternative solutions for the building design, implemented systems and suggested materials where they get the chance to select the best suitable for the targeted performance (Stamenov, et al., 2016). Relatively, there have been a lot of BIM tools targeting sustainable construction. For example, Ecotect, introduced by Autodesk, Inc., is "a complete building design and environmental analysis tool that covers simulation and the analysis functions needed to truly understand how to operate a building's design process". This program introduced capabilities of energy, thermal and lighting/shading analyses (Shoubi, et al., 2015). All of these goals are all strengthen by the reliability, consistency and usability of the information extracted from the BIM model which supports complete and accurate energy estimates, improved life-cycle analyses, increased opportunities for measurement and verification during the occupation phase (GSA, 2018);

14. **LCA-Oriented:** In many countries, BIM is now being increasingly used in not only conceiving, designing and constructing a building but also in facility management as well as operation and Maintenance (O & M) (Shawky, 2018). It creates concurrent information (Khodeir & Nessim, 2017) and serves as a shared knowledge resource for information of life-cycle performance of the asset (Khodeir & Nessim, 2017), forming a reliable basis for decisions from inception onward (WBDG, 2018);

15. **Constructibility and Prefabrication:** 3D BIM models provide the level of accuracy (with the needed specifications, sequence, finishes and 3D visual for each component) required for prefabrication and constructibility analysis;

16. **Return of Investment (ROI):** the shift to BIM may need principle costs for training and software purchases, yet BIM reduces both the time and money spent on production, use of paper documents as well as providing the accurate information to minimize conflicts and errors and maximize productivity (El Barbary, 2018).

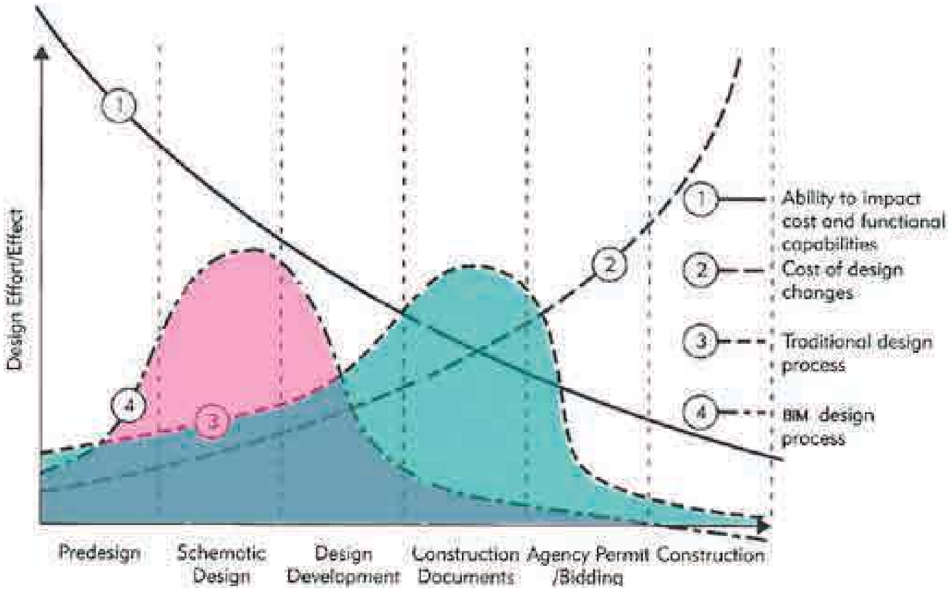


Figure 39. Cost Benefit Analysis of Building Information Modeling Implementation in building projects (Lu, et al., 2014).

5.2.7 BIM: Tools and Software

Many software facilitates the developing and maturity of BIM, such as (just to name a few) (Table 15);

Table 15. BIM applications per project area. Adapted from (Eastman, et al., 2011;The University of British Columbia and École de Technologie Supérieure, 2011)

Technology	Project Area		Software	Improvements in
3D Laser Scanning	• As-built information • As constructed information			
3D Sketching	• Design • Modeling		• Sketchup • Rhino • BonZai	
3D Geometric Models	• Site • Architecture • Structural	• MEP • Fabrication/ Construction • Tolerance	• Revit • Tekla • ArchiCAD • Navisworks	
Design and Construction Coordination	• Coordination between disciplines	• Clash detection	• Revit • Tekla • ArchiCAD • Navisworks	• Quality • Accuracy • Coordination • Efficiency
4D / 5D Models	• Project Phasing • Tenant phasing	• Construction sequencing • Traffic studies	• Assemble Systems • VICO office	
BIM Models	• Site • Architectural ○ Space ○ Zone/ circulation	• Structural • Mechanical • Equipment information • Maintenance schedules	• GT-STRUDL • **Structural:** Revit Structures and Bentley	
BIM Analysis Applications	• Program/ Asset Management • GIS • Energy analysis • CFD Analysis	• Acoustic • Cost Estimating • Equipment Inventory • Facility Management (FM)	• **Energy Analysis:** DOE-2 and EnergyPlus • **Lighting Simulation:** Radiance • **Cost estimation:** Autodesk's QTO and VICO Takeoff Manager	

5.3 Summary

BIM has proved to be a major change for the building industry. It facilitates the move from drawing-based technologies to digitally readable models that can generate drawings, schedules and data throughout a life-cycle of a project. Although BIM facilitates the design and management of large and complex 3D data-models, it imposes a style of technology that most users are still foreign to. Fortunately, a large number of firms are now investing to learn and make the maximum use of such a new mindset.

Despite the fact that the full potentials of BIM capabilities are not yet fully known, BIM is still able to resolve many fundamental representational issues in AEC practices allowing for quick pay-offs for those transitioning to it.

Pay-offs include; error reduction, consistency, improved productivity and facilitated communication among stakeholders.

The need for explicit exchange standards is becoming recognized and urgent, as such standards become the base of project-scale business practices definition. The trend to IFC is expected to grow to provide the not-well-supported work flows. However, there is still a need to gain help in managing heterogeneous data coming from diverse platforms (specially in complex and sustainable projects). Also, the development of BIM servers is now more required as for allowing for different proprietary and manual exchanges which are main steps in projects' work flow (Eastman, et al., 2011).

It is worth mentioning that the most critical aspect need to be solved in order to enhance BIM implementation is; the engagement of all stakeholders with a well-established understanding of the detailed process of BIM hosting.

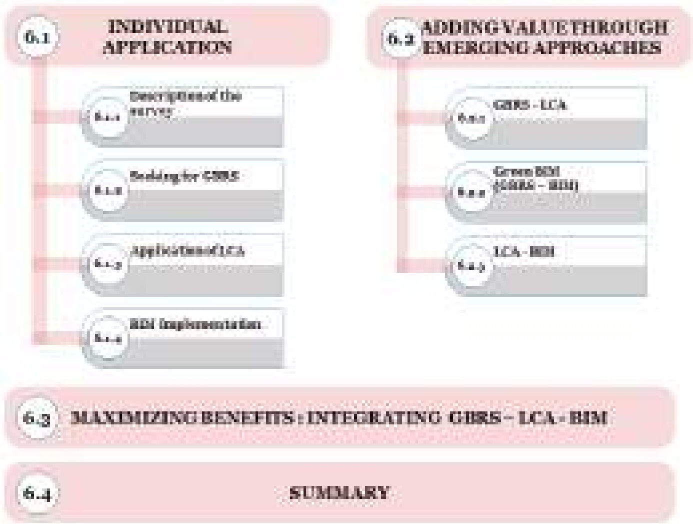


Figure 40. Chapter 6 Scheme (Author, 2019).

"Keep up to date with technology, acquire it and use it for your advance".
(yba-architects.com, 2019)

CHAPTER 6 APPLICATION AND PRACTICE

This chapter is subdivided as illustrated in (Figure 40) as follows;

The first segment analyzes the use of GBRS, LCA and BIM individually. In addition, an online survey targeting GBRS, LCA and BIM practicing professionals in Egypt was conducted based on the insights collected from the literature review. Then, a second segment focusing on examples of developed integrated methodologies of GBRS and LCA, LCA and BIM as well as GBRS and BIM will be reviewed. Finally, a third segment will consider full integrated approaches, so as to benefit from their potentials and shortcomings in developing the framework in Chapter 7.

6.1 Individual Application

In order to achieve the objective of this research, the author conducted three online surveys targeting a group of Architectural professionals that have been involved in projects using Green Building Rating Systems, Life-Cycle Assessments and Building Information Modeling in Egypt and the MENA Region. The purpose was to find out more about users' experience regarding the potentials of each, the challenges that hinder their wider adoption and the opportunities, actions and measures suggested to enhance their implementation.

6.1.1 Description of the survey

The survey was developed based on the information gathered through literature review, to consist of the following;

In [*Investigating the efficiency/ influence of Green Building Rating Systems principles application on the Construction Industry in the MENA Region*], the participant is asked about the GBRS they are mostly using in addition to the benefits and challenges of their usage and actions suggested to widen their adoption.

Whereas in [*Investigating the application of Life-Cycle Assessment approach within construction practices in Egypt*], the participant is asked about their awareness of LCA, the barriers that hinders its adoption and how they can be overcome.

Finally in [*Enhancing BIM adoption in the Construction Industry*], participants are mainly asked about the benefits of using BIM compared to CAD, the types of BIM software they are aware of and how data is exchanged between them, whether they have used BIM in sustainable building design and the difficulties they encountered.

6.1.2 Seeking for GBRS

6.1.2.1 GBRS Survey

The survey was answered by 4 GBRS experts with an experience ranging from 2-11 years of experience in the sustainability field of whom some are LEED Associate Practitioners and others are Green Associates. Some of them work in academic institutions while others are professional architects. The findings can be summarized as follows;

1. LEED was found to be the most popular rating system for green buildings used in the Egyptian market (Khodeir & Nessim, 2017), as it offers context adaptations and workarounds (considered in the Regional priority credits) to overcome any inconveniences to help achieve the main goal of sustainability. According to the interview; LEED has defined and specific goals all in a cohesive and integrated system. They also claim that LEED offers the most user-friendly and clear certification process.
2. The majority of the interviewees did not use the Egyptian GPRS, and the rest used it only for research purposes. Their answers also show that GPRS can be found used in cases of economical restrictions.

6.1.2.2 Triggers

The triggers behind sustainability assessment and certification of buildings, as collected from both literature review and the online survey are summarized in ();

Table 16. Triggers for Adopting GBRS. Adapted by (Author, 2019).

Triggers for Adopting GBRS
Enhanced building performance.
The possibility of using renewable energy resources and recycled materials as well as conserving natural resources.
Higher reductions of energy, carbon, water consumptions and waste generations.
Operational costs savings on the long term.
Higher lease-up rates.
Certification verifies the green nature of projects.
Works as an incentive to promote sustainable construction practices.
Encourages the market to purchase greener and recycled products.
Advancement of the project's triple bottom line (Saunders, et al., 2013).
Enhances occupants' productivity, health and comfort as a result of better indoor environmental quality, natural daylighting and usage of healthier materials and products.

6.1.2.3 Obstacles

However, the full adoption of GBRS principles in Egypt has faced a number of obstacles regarding the following aspects;

Table 17. Obstacles for Adopting GBRS. Adapted by (Author, 2019).

Aspects	Obstacles
Practice	• The different understanding each of the involved teams has regarding sustainability and the sustainability goals the project is targeting. • The limited communication and collaboration between project teams. • Some GBRS certification rating process can be quite un clear (sometimes complex). • The lack of documentation tools which raise information loss risks. • Performing the certification in the later stages of the design process, limits the opportunities to apply design optimizations and requires more time, effort and cost and affects the level of targeted sustainability for the designed projects.
Awareness	• The limited knowledge of contractors and labor regarding the technicalities of some 'sustainability-related' tasks. • The unavailability of some of the required 'sustainable' equipment. The limited utilization of green building materials as well as the unavailability of (EPDs) and the full environmental data sheets for the materials manufacturing process.
Neglected Aspects	• Neglecting construction waste management (recycling, reusing and disposal), as one of the main green construction principles. • Some GPRS do not give full attention to whole life perspective of projects to cover the construction, operation and sometimes the dismantling phases.
Regarding Egyptian GPRS	• The absence of a step-by-step certification process in addition to the requirement of local-code application (which are sometimes more stringent than international GBRS).
Economic barriers	• The benefits of GBRS certification and the expected long-term paybacks are not fully understood by the project's owners/managers that they would not invest in the initial cost required for certification. • The absence of governmental incentives.

6.1.3 Application of LCA

6.1.3.1 LCA Survey

Due to the limitation to survey LCA experts, the status of LCA application, triggers and obstacles that LCA method faces was concluded through further literature and case study review, as follows;

6.1.3.2 Triggers

The major triggers for conducting an LCA are (summarized in Table 18);

Table 18. Triggers for conducting LCA. Adapted by (Author, 2019).

Triggers for conducting LCA
Promotion of Green market Products and optimization of construction materials selection by considering their environmental impacts.
Promotion of innovative building practices to generate less environmental impacts.
Software as Service (SaS) applications, which offers the LCA service without purchasing the software license, allowing to reduce the costs to perform LCA calculations.
Provision of Environmental Impact (EI) information.
Comparison between alternative materials "form a sustainable point of view".
Enhancement of long-term and holistic perspective of design choices
The recent consideration of graphical interfaces in LCA tools which facilitates users' ability to operate data and results and enhances the visualization of results (diagram and flow charts)
Availability of new tools which allow for comparisons of changing products with different parameter values.
The possibility to export graphical and in-tables data to text editors like MS- Word or Excel which facilitates information exchange with other tools.

6.1.3.3 Obstacles

Despite that LCA is one of the most suitable methods of environmental impact assessment[1] that can be applied on the construction industry, yet the use of whole building LCAs haven't gained as much momentum and still face some drawbacks to be used as decision support tools (Chau, et al., 2015). Obstacles and the issues lying under each are categorized here below (Table 19);

Table 19. Obstacles for conducting LCA. Adapted by (Author, 2019).

Aspects	Obstacles
Practice	• Lacking for uncomplicated procedures and methods. • Claimed to be not design-oriented, not catering for quality or aesthetics. • Complexity of LCA for buildings (for the comparatively long-life and , the incredible number of components they might include and the changes they undergo along their life-cycles. • Difficulty to mandate LCA for buildings due to the lack of benchmarks. • Varying ways for conducting the assessments • Limited availability for allocation information. • The gap between urban planners and building designers. • Most of the conducted LCAs are carried out in developed countries, so there is no cases from Africa to use for reference. • Limitation of application due to the wide range of building materials • Limited accessibility to environmental impact information and lack of well-defined environmental impact information in early design phases
Software	• Closed codes and high-price licenses • Software is quite complex to use and requires considerable time to master hindering the conduction of in-depth comparisons • Umberto software is quite complex with no significant innovation and same price range (compared to other LCA tools).
Awareness	• The "no-commitment' of the top management to LCA. • The limited availability of proper knowledge needed to make allocation (which is the proper distribution of environmental issues generated by a product or a process). • Many companies have not yet reached the same stage of maturity in terms of environmental management.

1 *As stated by the American Institute of Architects in 2010.*

6.1.4 BIM Implementation

Recently, there have been many efforts to adopt BIM in Egypt. In January 2018, the first Egypt BIM day took place, where BIM experts working for a wide range of AEC firms shared their experience about BIM implementation and how beneficial it was for quality enhancement as well as cost, time an effort reduction. Furthermore, Autodesk, as one of the leading BIM technology providers, showed their marketing strategies and presented the sale plans they offer to encourage small and medium-scale firms to purchase licensed products. This conference is planned to be held annually so as to have the chance to show how BIM adoption in Egypt is progressing (Mohamed, 2018).

6.1.4.1 BIM Survey

The survey was answered by BIM experts with (4-11) years of experience working in different Architecture Design and Consultancy firms in Egypt. Half of the interviewees had the chance to utilize BIM on green buildings (2 hospitals in KSA and 1 school in UAE) seeking for LEED certification (gold and silver).

6.1.4.2 Triggers

In the conducted survey, the participants explained the triggers of implementing BIM as follows (Table 20);

Table 20. Triggers for BIM Implementation. Adapted by (Author, 2019).

Triggers for BIM Implementation
The shift of working process from one-perspective oriented towards an integrated approach and the enhanced integration between design process phases
BIM helps to achieve higher productivity, time efficiency as well as enhanced quality of visualization and documentation
Better collaboration, coordination and communication between the different involved parties
Clarified and unified project's goals for all the involved parties
Supportive decision-making tools
Project cost reductions throughout design, construction and operation phases
Better management: through clash detection, time and resource saving
The potentials BIM has to offer for sustainable and large-scale projects even with large amounts of information and stakeholders

6.1.4.3 Obstacles

In order to find out how to improve the implementation of BIM in Egypt, it is first needed to define and understand the obstacles that hinder the spreading of BIM usage in AEC activities;

Table 21. Obstacles for BIM Implementation. Adapted by (Author, 2019).

Aspects	Obstacles
Resistance to shift	• Some researchers propose that clients are the main driver for BIM adoption, while others see it is still the designer's responsibility to share how BIM is developed and how its further utilization is driven. • The limited coordination between the design and operation to define how data is provided for operational managers. • The sustainability certification is not being mandatory, which make some users believe BIM is not necessarily required. • BIM suffers from the inconsistent requirements, lack of standards and several changes of existing processes. • The resistance to change workflow and the mindset of clients and contractors
Hindered improvement	• Implementing BIM as a performance management tool has not been widely adopted beyond research which results in numerous barriers regarding BIM application . • The uncertainty of who should develop and operate the BIM models
Software	• Some software is developed only to address certain quantitative aspects and not the whole process . • The interoperability of information among different software and platforms and the need of well-developed practical strategies and tools to transform and export files in different formats which might, sometimes, cause loss of data.
Economic barriers	• Relatively high cost of BIM licenses purchases which result in a limited number of professionals implementing the BIM technology. • The equipment upgrade that might be needed to operate BIM software efficiently requires high-end specifications, which costs more. • A large sector of the Egyptian market is not fully aware of the ROI study, which could be quite essential to show the effectiveness of moving their firms to be BIM-adapted. • The need for additional cost for staff training and sometimes the convenience of training can discourage the shift to BIM.
Knowledge and Technicalities	• Limited availability of skilled staff, as for needing special training and technical expertise • The need for well-defined transactional models for the construction process which would effectively eliminate issues of data interoperability. • The limited access for drafting standards and content libraries . • The requirement of computable digital design data. • The lack of BIM documents instructing the application, use, standardization of the implementation guidelines and the establishment of model contract documents of BIM in construction practices . • The difference between the high building design standard and the falling behind information management standards Making the best use of BIM tools is hindered by the division between research and practice of BIM implementation in the real world. • The absence of detailed guideline of the best practice (in a form which can be replicated) of BIM to support ongoing building performance optimization . • Some companies had to develop their own protocol and standards, based on BIM forum standards. Others used British standards which all highlight the problem of not having a national BIM standard in Egypt. • The usage of BIM is generally limited to the building's design (including architectural, structural, Mechanical and Plumbing (MEP) aspects and Bill of Quantities) but rarely used for the other dimensions of scheduling and cost estimation. • limited legal guidance regarding the authorization of the ownership of information within the BIM model and uncertain determination of the owner's information requirements

6.1.4.4 Recommended Improvements

These barriers could be overcome by following the listed-below actions (see Table 22,Table 23 and Table 24) regarding GBRS, LCA and BIM respectively:

Table 22. Recommended Improvements for GBRS Adoption. Adapted by (Author, 2019).

- Spread the awareness of GBRS potentials.
- Mandate GBRS certification for new projects, and establish globally-recognized baselines into governmental/ national regulations to specify minimum requirements and sustainability rating.
- Form a common 'efficient building' design language.
- Provide a holistic definition of sustainability.
- Tie use phase energy consumption into LCA of products within GBRS to attract a wider range of building stakeholders by aligning, as much as possible, the environmental and financial implications of products.
- Evaluate the energy saving associated with materials choices to effectively increase the merits behind GBRS credits.
- Involve more development for LCA indicators and impact categories in GBRS, giving special attention to the whole life perspective of projects to cover the construction, operation and sometimes the dismantling phases.
- Enhance the collaboration between the involved stakeholders gives a better chance to exchange opinions, knowledge and invent more efficient design solutions.
- Provide an operative holistic definition of sustainability, which brings designers' attention to further sustainability concepts
- Promote integrative planning and incorporating multi-stakeholders can be an effective tool.
- Form a common language and discussion on green efficient building design
- Allow for better innovation within design practices for all the involved parties
- Raise the awareness and provision of proper education of the environ-

mental issues we are facing and the potentials of GBRS in counteracting against them along with the benefits of less operating costs, healthier environment, reduction of negative environmental impacts as well as saving energy and water. Also, it is highly recommended to spread the knowledge about Life-Cycle approach.

- Understand the importance of the other pillars of sustainability especially the social aspects, which are mostly overseen.
- Get involved with other 'successful' international associations to inherit some of the guidelines, standards and processes they follow.
- The cooperation between academia and the private sector with governmental institutions to include GBRS within educational programs as well as maximizing benefits from the performed research efforts.

Table 23. Recommended Improvements for LCA Application. Adapted by (Author, 2019).

- Enhance the data quality as for affecting all four stages of LCA assessment process.
- Increasing the consistency across reports by providing analyses of common parameters in existing tools that will provide guidance on how to carry out the LCA process.
- Propose an international 'taxonomy' of Goal and Scope definition to list the minimum necessary parameters.
- Offer simplifications to conduct LCAs by including proliferation of methods and tools, which would significantly reduce the most time-consuming part; LCIA phase.
- Broadly redefine LCA tools as for being; 'any systematic means that deals with environmental issues during a product's development process'.
- Lead efforts in harmonizing database development and LCA reporting.
- Spread the implementation of quality guidelines (such Ecoinvent LCI database) in order to ensure coherent data acquisition and reporting.
- Carry out data validation and sensitivity checks to eliminate making assumptions.
- Improve documentation of acquired data and data assumptions to enhance transparency.
- Mandate inclusion of social and economic aspects as for their important influence on an LCA comprehensiveness.

- Follow the after-mentioned criteria respectively; physical properties (like mass, economic value or the number of subsequent uses of recycled materials), to solve the allocation problem.
- Standardize LCA inventory and impact datasets and develop model bases to aid the LCA industry by alleviating persistent problems with data availability and quality.
- Model environmental impacts of extraction and pollution geometrically (when possible), to improve the sophistication of LCA.
- Link the indoor environmental quality with the surrounding area to get a good picture of a 'holistic' environmental performance of the built environment.
- Establish new ways to enhance the communicability between assessments.
- Consider site adaptations, local aspects and priorities needed to fit in cases of contextual differences.
- Study the social and economic aspects without increasing the complexity of the LCA process.
- Performing LCA assessment throughout the early stages of the design process (aligning with the material selection phase) can make the design process a lot smoother and time efficient.

Table 24. Recommended Improvements for BIM Implementation. Adapted by (Author, 2019).

- Mandate the use of BIM for projects of certain sizes. This can happen gradually in new construction projects; starting with public, then publicly-funded and private projects later.
- Communicate with governmental bodies and authorities to form a vision of BIM implementation in construction industry.
- Cooperate with the private sector and industry leaders to assist in visioning and being involved in the roadmap.
- Include academia to share their knowledge and research background to assist in proper implementation scheduling.
- Offer incentives for AEC companies to implement the integrated approach such as tax reduction or loan provision.
- Create 'Open Data' standards

- Establish a cooperative learning environment for users.
- Establish a BIM best practice platform, for evaluating and sharing and pilot projects case studies
- Expose to international markets.
- Seek for organizations which generate software solutions and equipment of direct and indirect applicability to the design, construction and operation of facilities, to develop software with better accessibility and compatibility with the Egyptian AEC industry needs.
- Establish national standards, guides and protocols for BIM implementation in Egypt.
- Spread the knowledge of Integrated Project Delivery (IPD).
- Increase the level of maturity gradually.
- Provide BIM basics courses for the professionals working in Governmental positions who need to evaluate submitted projects.
- Providing BIM formal and informal education as well as training support to educate potential service providers by cooperating with standards organizations and universities.
- Spread knowledge and awareness of BIM potentials among AEC professionals and owners, so they would be more willing to implement BIM tools into their building practices.
- Automate 3D scanning process and developing the inference between scanned objects can highly facilitate existing building renovations.
- BIM should increase its capacity to effectively integrate with environmental analysis and improve interoperability.

6.2 Adding Value through Emerging Approaches

6.2.1 GBRS - LCA

Over the last few years, there has been a shift from the perspective approach of sustainable design towards the scientific evaluation of the actual performance throughout Life-Cycle Assessments (LCA). LCAs are not “yet” a consistent requirement in all green building rating systems and codes but there are growing trends requiring LCAs and many methods attempting to improve their implementation (Vierra, 2019).

The integration of LCA and GBRS can be quite beneficial as LCA gives the quantitative perspective of manufacturing and in-use environmental impacts of products while GBRS focuses on the qualitative perspective of how these selections would affect the environmental, social and economic qualities of the designed buildings.

6.2.1.1 Case study (1)

In a study performed by (Collinge, et al., 2015) titled "Integrating life cycle assessment with green building and product rating systems", the team studied the integration between LCA and GBRS to examine and compare alternatives for two building products, to achieve LEED certification. The first experiment (Figure 41) compared a conventional carpet with three other RED List free or compliant carpets. The results show that not only the components of the chosen products make the difference, but also the combination of materials can have the most environmental impacts.

The second experiment (Figure 42) was assessing alternative building materials for two roof scenarios for an existing commercial building and how the energy consumption was affected during the in-use phase. The study found that selection of one material can help in achieving LEED credit points (for Urban Heat Island (UHI) reduction as a result for cooling energy conservation) while LCA finds the other alternative is a better choice (as for having less toxic content and its manufacturing generates less waste).

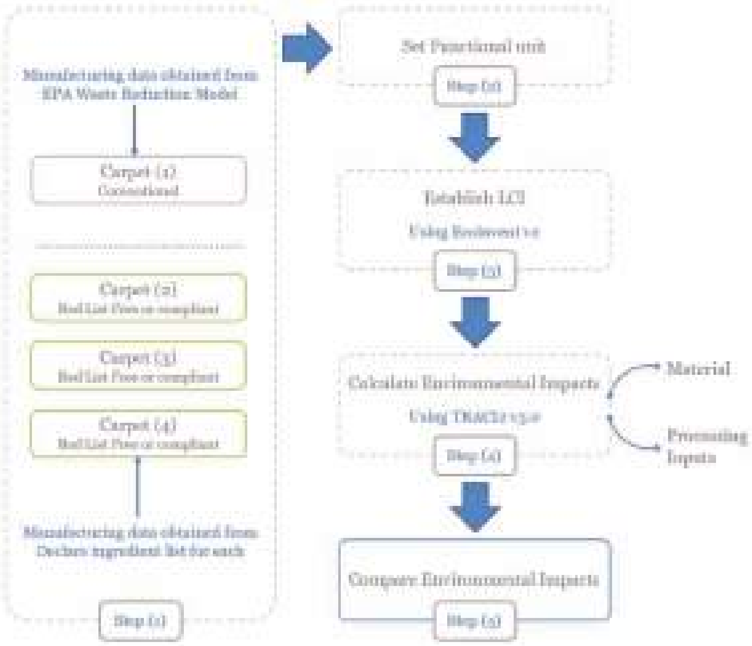


Figure 41. Case study (1) - First experiment: Comparison between building products using an integrated LEED and LCA process. Adopted from

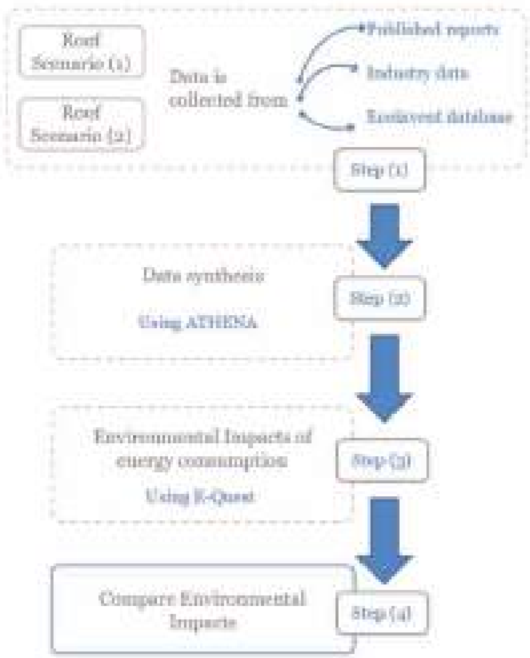


Figure 42. Case study (1) - Second experiment: Comparison between two roof building products using an integrated LEED and LCA process. Adopted from (Collinge, et al., 2015).

6.2.1.2 Case study (2)

(Vierra, 2019) supports the same opinion that green building rating systems still require an integrated design process throughout the building's life-cycle from siting to design, construction, operation, maintenance renovation and demolition to create projects that are truly environmental responsible and resource-efficient.

This was proved in a study done by (Collinge, et al., 2015), where optimizing the building envelope design as part of fulfilling GBRS criteria has resulted in significant energy savings, less payback periods and more life-cycle savings.

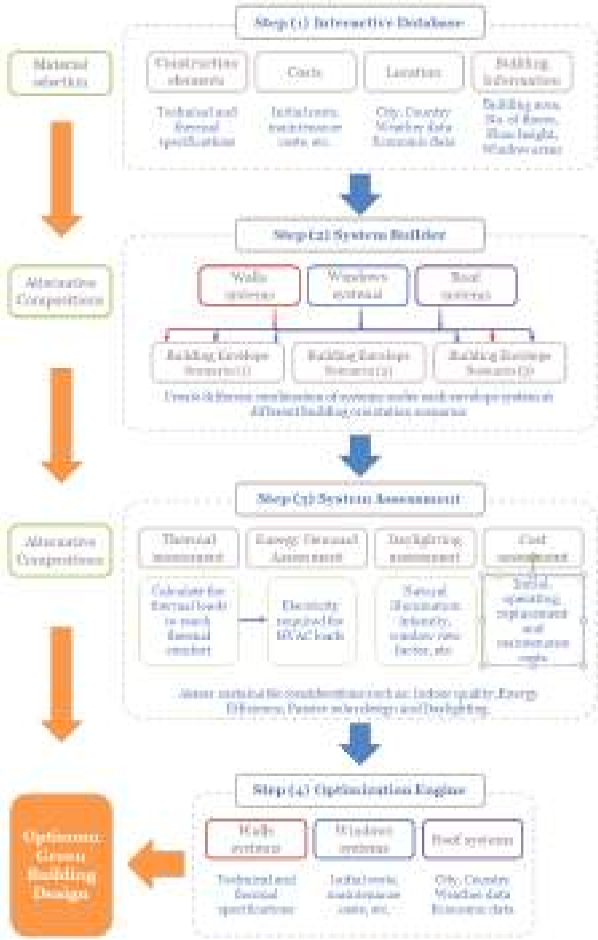


Figure 43. Case study (2) - Second experiment: Comparison between building products using an integrated LEED and LCA process. Adopted from (Collinge, et al., 2015).

6.2.2 Green BIM (GBRS - BIM)

BIM-related researches usually center their attention particularly on geometrical information. It has been suggested by (Idra, 2017) to direct some focus on semantic data to avoid the creation of the graphical model to save time and resources.

However, before BIM, an engineer traditionally would assign a perimeter and a core to do analyses for a building. This is where the attempts to integrate sustainability considerations with the design process lacked the feature of activities sequence as well as reasoning of decisions. The problem is even exacerbated, when the information needs of design disciplines vary, resulting in difficulties to make optimal design decisions (Zanni, et al., 2017).

BIM is considered as 'Green' when BIM tools are used in a project to achieve environmentally-improved building performances or sustainability objectives. 'Green BIM' can be defined as a model-based process that generates and manages coordinated and consistent project's data during its lifecycle while enhancing energy-efficiency performance and facilitating the accomplishment of established sustainability goals (Wong & Zhou, 2015).

6.2.2.1 Case study (3)

Combining LEED rating system with BIM tools can create more sustainable out-comes in buildings. LEED experts see that BIM tools can effectively support some of the green building practices and strategies promoted by the LEED rating system.

According to (Figure 44), (Wu & Issa, 2014) used BIM to achieve LEED certification as per the following integrated process;

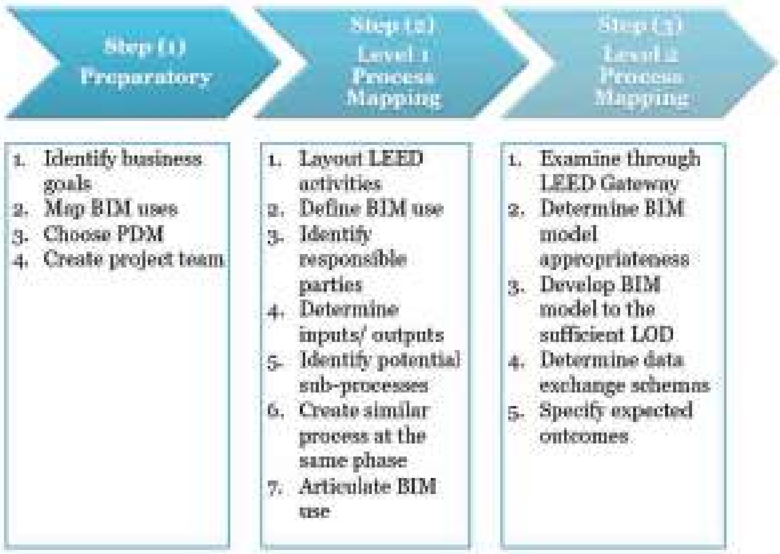


Figure 44. Case study (3): Integrated Framework of using BIM for LEED Certification . Adopted from (Wu & Issa,2014).

Step 1: Preparatory

1. Determine the feasibility of achieving the required certification LEED level (primary business goal) based on the accumulated LEED credit points (secondary business goal).

2. Map BIM uses for each of the sought LEED credits using a LEED strategy (a checklist that represents the project compliance path with LEED certification by linking the LEED activities (tasks essentially needed in order to score LEED points) to a particu-lar functionality of BIM to conduct the desired analysis to confirm that the design meets the LEED credit requirement).

3. Choose Project Method Delivery (PMD) like Integrated Project Delivery (IPD), which facilitates BIM use amongst multiple parties, en-courages the early involvement of stakeholders and enhances collabo-ration.

4. Identify stakeholders and create project team, which includes; the owner, architects, engineers, contractors, commissioning agent (CxA), consultants (including LEED instructor) and suppliers.

Step 2: Level 1 Process Mapping

5. Layout LEED activity (e.g. carry out energy analysis) for a specific LEED goal (optimized energy performance);

6. Define BIM use (e.g. energy analysis);

7. Identify responsible parties (e.g. consultant);

8. Determine inputs/ outputs;

9. Identify potential sub-processes;

10. Create similar processes at the same phase;

11. Articulate BIM use for non-green (which does not address LEED activities) processes. See (Figure 45).

Figure 45. Example for Level 1 process Mapping (Wu & Issa, 2014).

Step 3: Level 2 Process Mapping

12. Examine through LEED Gateway (a process control of business decision-making, driven by LEED strategies or standards, to identify the compliance path needs to be taken to meet the credit requirement (e.g. whole building energy simulation is needed to optimize energy performance);

13. Determine whether the BIM model is appropriately developed for energy simulation as regulated by standards (e.g. elements like walls,

roofs and shading devices, specified thermal zones and space boundaries are modeled);

14. Develop BIM model to the sufficient LOD compliant with energy analysis needs;

15. Determine proprietary and open source data schemas to streamline information export from BIM to BEM (Building Energy Model). (See Figure 46).

16. Specify expected outcomes.

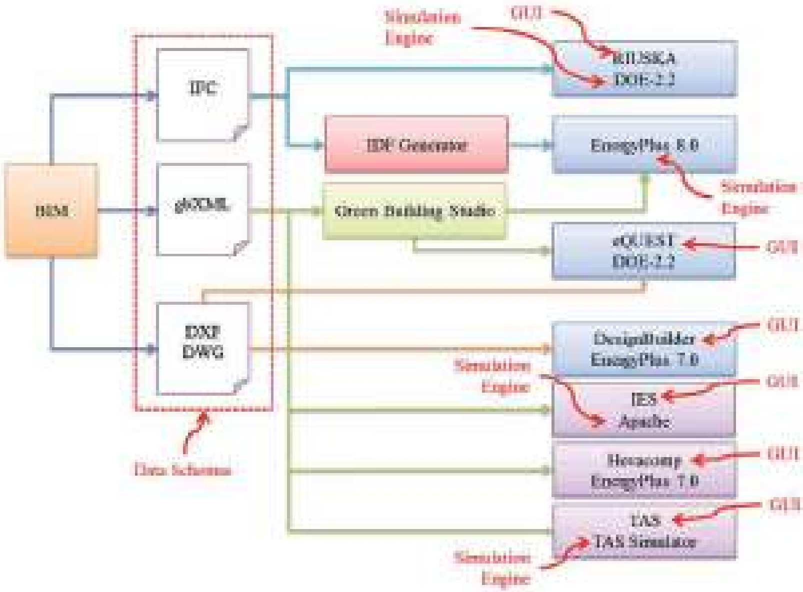


Figure 46. Information Exchange for BIM-based Energy Simulation (Wu & Issa, 2014).

6.2.3 LCA - BIM

Recent global sustainability research has focused on how to manage and minimize energy consumption and carbon emissions over the entire life-cycle of buildings (Antón & Díaz, 2014). BIM as a Construction Information Technology has gained a special attention due to its possible contributions to building sustainability and lifetime performance enhancement (Wong & Zhou, 2015).

Usually in a conventional LCA, most of the information regarding the building construction process is lost during the calculation procedures which makes the optimization of the architectural design (after the assessment) rather difficult. In this regard, setting (assembly-approach) BIM-LCA framework can be much more efficient (Yang & Wang, 2013).

6.2.3.1 Case study (4)

A study performed by (Shoubi, et al., 2015) to investigate BIM potentials in assessing the effects of material compositions alternative on reducing the building's annual operational energy use. As illustrated in Figure 52, first the plan drawings and material specifications of the building were provided, then it was simulated in Revit software. Afterwards, for Energy modeling in Ecotect Analysis software, the various parts of the building need to be separately zoned (to model the energy of various spaces and export the file to Ecotect software). Therefore, the file is exported in gbXML format, to make sure that all the building's specifications defined in Revit are exported to Ecotect. How-ever, some basic assumptions still need to be established (such as location and type of building). In Ecotect, further assumptions need to be established like activity, type of system and thermal comfort temperature). Finally, the building annual operational energy is then calculated, while examining alternative materials to find out the most convenient materials in achieving the highest energy efficient performance.

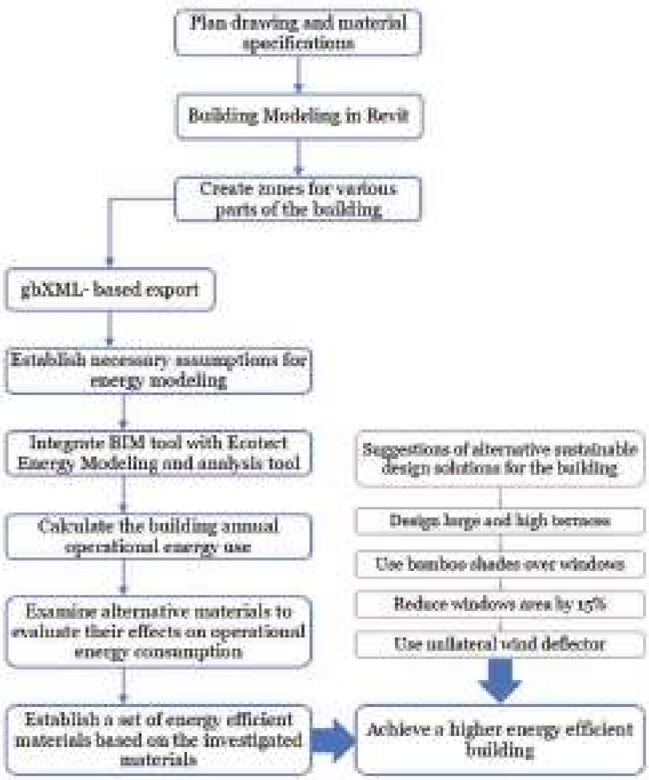


Figure 47. Case study (4) Framework integrating LCA and BIM (Shoubi, et al., 2015).

6.2.3.2 Case study (5)

(Yang & Wang, 2013), have integrated LCA and BIM, as shown in Figure 53, to calculate the environmental impacts of a high-rise residential building in Tianjin, China. The results showed that the operational phase was accounted for almost 90% of the total energy usage basically because of; the large area of the building and the low-intensity building materials used for construction. By comparing these results to low-energy buildings in Europe, they concluded that if the building's envelope could be optimized (specially with regards to insulation) significant improvements can be achieved. Hence, lowering energy demands in the operational phase of a building can be achieved by the appropriation of construction materials selection (Yang & Wang, 2013). In this study, they have suggested some alterations for the LCA process, such as; to perform the LCA on assembly-based rather than material-based approach to make the assessment results more accurate.

Therefore, this approach can be applied using BIM as for being object-based which can include the information of assembly details for all the included components in a building. Furthermore, using this BIM-LCA framework can involve not only the parametric information (from building assemblies databases) and construction materials data (specially energy efficiency related information), but can also add the dimension of material cost (retrieved from cost data inventories) (Yang & Wang, 2013).

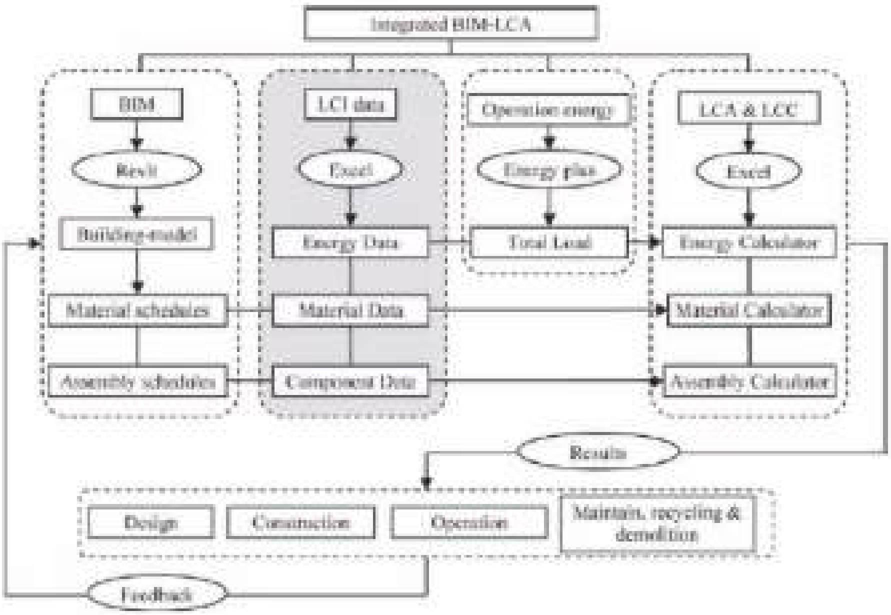


Figure 48. Case study (5) Integrated BIM and LCA framework (Yang & Wang, 2013).

6.3 Maximizing Benefits: Integrating GBRS - LCA - BIM

Performance analysis tools have been utilized extensively in order to predict and quantify aspects of environmental impacts and sustainability to ameliorate quality and cost throughout the building's life-cycle. As a sequence, the workload of these assessments can be significantly saturated with information compared to traditional project delivery especially at the early design stages. Furthermore, the contribution of design participants and accuracy of the provided information are crucial for a successful delivery. Therefore, the hardest challenge in the whole process is communication and coordination across the involved multidisciplinary, and this is what the design process usually suffers from. This is where the sustainable outcome is difficult to achieve as a result of the absence of the appropriate information exchange when critical decisions are supposed to be made (Zanni, et al., 2017).

On one hand, the Life-cycle assessment and Green Building Certification when performed apart from BIM (using separate software tools), this turned the whole assessment into a complex process that is subjected to many drawbacks such as; data re-entry, work duplication; increased initial costs and complex interoperability issues.

On the other hand, despite the several benefits of integrating LCA and BIM, the process still lacks the guidelines of how they could be used as decision-making tools (Stella, 2018). These guidelines can be inherited from GBRS design criteria and requirements.

6.3.1 Case study (6)

(Lu, et al., 2017) developed what they called a "BIM green building nexus"; a triangle showing the support BIM can offer to a green building throughout its whole life-cycle. The triangle, in Figure 54, consists of;

1) Project Phase: defining the phase perspective of the project's life-cycle whether it is design, construction, operation and maintenance or demolition;

2) Green Attributes: where sustainability considerations like energy and water saving, indoor air quality, sustainable material selection, opportunities for daylighting and natural ventilation and acoustics analysis are included;

3) BIM Attributes: which shows the contributions of BIM technology with regards to visualization, analysis and simulation, documentation management as well as collaboration.

They found out that BIM have many potentials to support green building in both the life-cycle analysis (LCA) of green buildings and the green building assessment of projects (Mohamed, 2018).

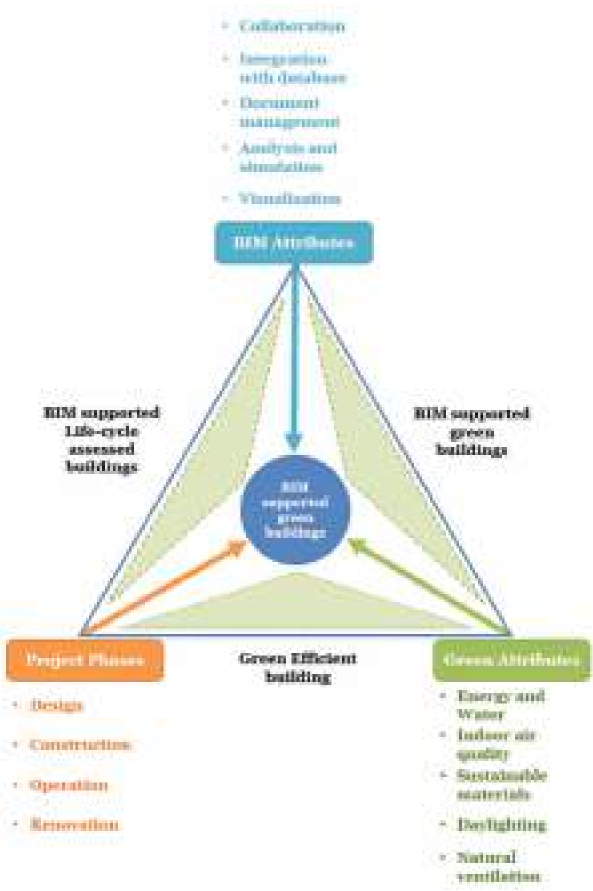


Figure 49. Case study (6): Integrated LCA-BIM framework for Green efficient building design. Adapted from (Lu, et al., 2017).

6.3.2 Case study (7)

In a study performed by (Jalaei & Jrade, 2013), the authors' aim was to develop an automated way to accomplish 3D sustainable design and relate the model with the earned certification points and the associated costs.

The methodology integrated several applications in the following framework;

1. **Phase 1:** a relational database for the model to design sustainable buildings;
2. **Phase 2:** 3D BIM Revit modeling to create families and keynotes for the new elements and building's components;
3. **Phase 3:** Design an LCA module to evaluate the environmental impacts of the design;
4. **Phase 4:** Incorporate a module for the sought green certification to calculate the potential earned points and the associated costs.

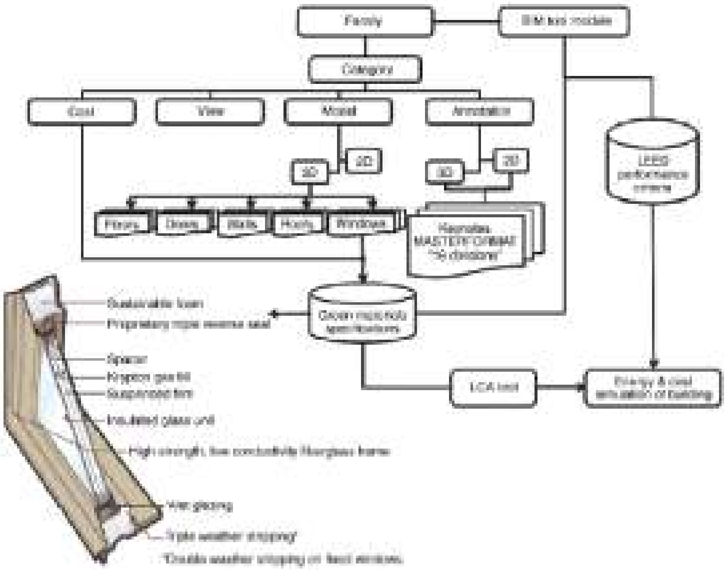


Figure 50. Case study (7): Workflow in an Integrated LEED -LCA -BIM framework (Jalaei & Jrade, 2013).

6.4 Summary

BIM is found to be a helpful tool with regards to improving sustainable outcomes and achievement of green objectives. Moreover, BIM helps to enhance the integration of sustainable components in building design industry, especially the application of energy efficiency in the life-cycle of buildings (Wong & Zhou, 2015).

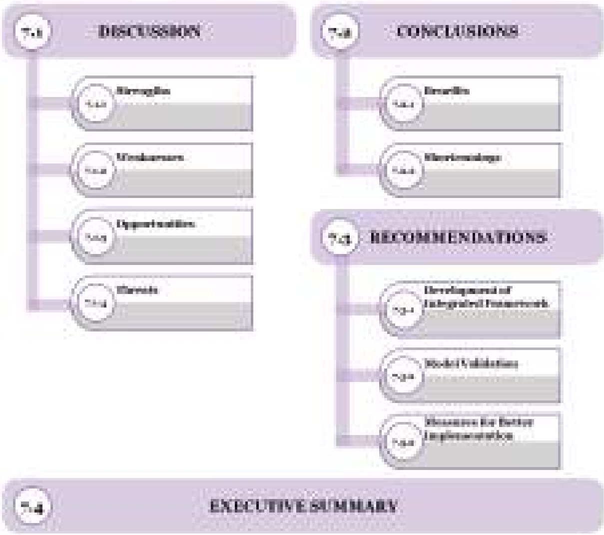


Figure 51. Chapter 7 Scheme (Author, 2019).

CHAPTER 7 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

"BIM can deliver tremendous benefits, but doing so requires a departure from traditional ways of working."
(Arayici et al., 2009)

7.1 Discussion

The models reviewed in the previous chapter gave a clear image of the position of GBRS, LCA and BIM regarding their implementation in AEC activities. A SWOT analysis is being presented to illustrate the Strengths, Weaknesses, Opportunities and Threats of including each of GBRS, LCA and BIM in integrated frameworks to achieve effective decision-making in the field of efficient buildings.

7.1.1Strengths

Table 25. SWOT Analysis: Strengths of each of GBRS, LCA and BIM Methodologies. Adapted by (Author, 2019).

GBRS	LCA	BIM
• Unified goal for all the involved stakeholders • Enhanced building performance • Higher reductions of energy, carbon, water and waste • Running cost reduction • Higher lease-up rates • Certification verifies the green nature of projects • Works as an incentive to promote sustainable construction practices • Encourages the market to purchase greener and recycled products • Higher occupants' productivity, health and comfort	• Inclusion of all phases of buildings' life-cycle • LCA provides information about environmental impacts • 'Sustainably' compares between alternative products • Understands the long-term holistic perspective of design choices • promotes 'green-ability' of market products • New available software tools	• Faster and controllable design process allowing for easier environmental assessment • increased effectiveness, efficiency • Less time consumption • No need for manual data re-entry • Improved exchange and management of information • enhanced collaboration between the involved parties. • Better accessibility to information starting from the early design stages • Possibility to compare design alternatives and the resulting environmental performance
• Higher capacity for accommodating the three pillars of sustainability (Holism). • Improved effectiveness of environmental assessment as for being performed starting from early design stages • Recognizing (in real time 3D model) the impact of every design choice on the ecological, economical and socio-cultural resources of local and global environments.		

7.1.2 Weaknesses

Table 26. SWOT Analysis: Weaknesses of each of GBRS, LCA and BIM Methodologies. Adapted by (Author, 2019).

GBRS	LCA	BIM
• Neglecting cost efficiency, carbon footprint. • Not involving phases of maintenance, repair, recycle/ reuse of existing materials or components and demolition • Economic barriers (unawareness of long-term benefits) • Limited knowledge of 'sustainability-related' tasks • Lack of incentives • Limited availability of 'sustainable' equipment • Unclear (sometimes complex) certification process	• Lack of standardized ways for performing and presenting LCAs not for the same type of buildings or the same geographic regions. • Limited availability of environmental data required to carry out LCAs • Uncertainty caused by the assumptions done in cases of data unavailability • Complexity and user unfriendliness • Limited research on renovating existing housing within energy efficiency measures.	• The training required for stakeholders to know-how to include environmental criteria to their assessments • Costly transition • Limited knowledge and technicalities • Limited availability of skilled staff, as for needing special training and technical expertise • Resistance to shift • Relatively high cost of BIM licenses • Lack of standards and local protocols • Limited access to best practices • Improvement is hindered by the division between research and practice
• There is still further development needed to enhance interoperability between GBRS, LCA and BIM tools		

7.1.3 Opportunities

Table 27. SWOT Analysis: Opportunities for each of GBRS, LCA and BIM Methodologies. Adapted by (Author, 2019).

<table>
<tr><th>GBRS</th><th>LCA</th><th>BIM</th></tr>
<tr>
<td>• Provide a holistic definition of sustainability
• Promote collaboration between stakeholders
• Form a common ‘efficient building’ design language
• Allow for innovation
• Spread the awareness of GBRS potentials
• Mandate GBRS certification for new projects
• Maximize benefits from academic research</td>
<td>• Integration of LCA in the planning process
• Some LCA online tools are currently working on including DGNB 2018 reporting within the assessment.
• Enhancement of data quality
• Propose an international ‘taxonomy’ for the minimum necessary parameters
• Data validation and sensitivity checks
• Improve documentation
• Mandate inclusion of social and economic aspects
• Standardize LCA inventory
• Geometrically model environmental impacts (when possible)</td>
<td>• Import data from Lite BIM tools to professional ones so that owners can easily build their design and transfer them to professionals
• Movement from desktop apps to internet-based apps
• Using BIM tools to support complex systems such as HVAC equipment
• Mandating the use of BIM for projects of certain sizes
• Create ‘Open Data’ standards
• Establish a cooperative learning environment for users
• Exposure to international markets
•</td>
</tr>
<tr><td colspan="3">• Integrating GBRS (in some cases), can overcome the limited knowledge of sustainability aspects when performing LCA
• Greater incorporation of LCA in GBRS can significantly enhance quantitative comparisons between alternatives.
• LCA becomes valuable within BIM, when combining construction technologies, process and policies.</td></tr>
</table>

7.1.4 Threats

Table 28. SWOT Analysis: Threats for each of GBRS, LCA and BIM Methodologies. Adapted by (Author, 2019).

<table>
<tr><th>GBRS</th><th>LCA</th><th>BIM</th></tr>
<tr>
<td>• Neglecting involving GBRS within the building regulations by the national authorizing bodies.
• The need for special expertise to implement the design criteria and certification process.</td>
<td>• Neglecting involving LCA within the building regulations by the national authorizing bodies.
• The need for special expertise to perform the assessments.</td>
<td>• AEC practitioners' resistance to shift because their perception of BIM potentials regarding relevancy, compatibility with project sizes and ROI.
• Neglecting involving BIM within the building regulations by the national authorizing bodies.
• The lack for a National BIM protocol and standardization regulations.</td>
</tr>
<tr>
<td colspan="3">• Limited Client demand
• The limited collaboration between the stakeholders involved in the AEC industry.
• The limited awareness of the significance of efficient building practices regarding their environmental, economic and social benefits.
• Improvement is hindered by the division between research and practice.
• The absence of well-defined transactional model and processes for the implementation of each.</td>
</tr>
</table>

7.2 Conclusions

From the previous analysis along with the case studies reviewed in Chapter 6, the concept of full integration between GBRS, LCA and BIM was found to have a wide variety of potentials. Yet, the development of this concept still suffers from a number of issues. The benefits and issues are briefed in the next part, and are followed by the recommendations to maximize the benefits and overcome the challenges.

7.2.1 Benefits of Full Integration

The integration of GBRS, LCA and BIM in one holistic approach has a wide range of benefits, such as;

- Targeting a wide range of users (Zanni, et al., 2017);
- Sharing the environmental-friendly sustainable point of view with all the stakeholders involved in the AEC process (Zanni, et al., 2017);
- Supporting decision-making in early design stages (Stella, 2018);
- Taking off the quantities from Revit to perform LCA saves much time and effort (Stella, 2018);
- Early integration of LCA within BIM provides the benefit of assessing the environmental impacts of the materials and systems used in the architectural design, structural, MEP and HVAC disciplines (which are mostly concerned about the cost and safety and not the environmental aspects of their choices) (Stella, 2018);
- Guaranteeing the inclusion of social and economic points of view besides the ecological aspect.

7.2.2 Shortcomings

- The implementation of integrated GBRS, LCA and BIM within one holistic approach still has many shortcomings, such as;
- In BIM-enabled sustainable design process, organizational aspects have not been yet sufficiently addressed (Zanni, et al., 2017).
- The limited coordination among people, tools, deliverables and required information, which hinders effective interactions between stakeholders. This keeps BIM only at maturity level 1 instead of the collaborative BIM maturity level 2 (Zanni, et al., 2017).
- The lack of a comprehensive structured process that enables the harnessing of intellectual inputs of all the involved disciplines that eventually would assist professionals in planning and delivering green building design from the early stages (Zanni, et al., 2017).
- The need for a level of detailed information within the BIM model in order to perform the LCA, that would be very advanced to make changes (Stella, 2018).
- Inclusion of such an amount of information (specially for large-scale projects) makes Revit files too large to run (Stella, 2018).
- In some cases, objects in the Revit model do not correspond to the real products, making it hard to get the exact amount of used materials (Stella, 2018).

7.3 Recommendations

This section divides the recommended improvements needed to be considered to enhance the Sustainable Building Design process in two parts; first by developing a framework, integrating GBRS, LCA and BIM in one holistic approach. Besides the second part which illustrates the measures required to support the application of the proposed framework and the parties responsible for each.

7.3.1 Development of Integrated Framework

This part aims at developing a conceptual framework to integrate GBRS, LCA and BIM in one holistic approach.

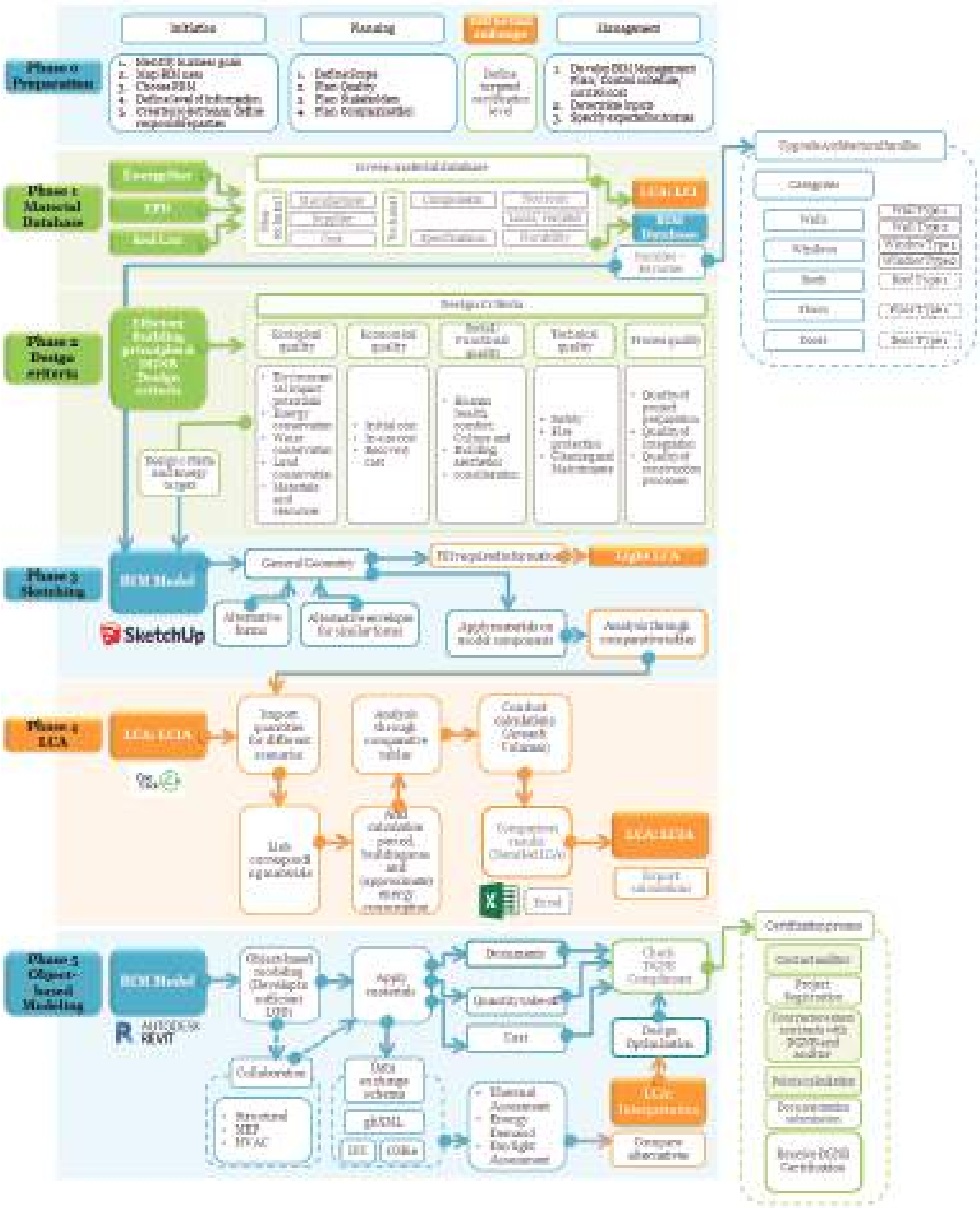


Figure 52. Proposed frame work for integrated DGNB - LCA - BIM Design Approach (Author, 2019).

This framework can be applied as a decision-making support tool throughout the initiation, planning, management and design stages, to enhance the environmental performance of the SBD performed using BIM.

7.1.1.1 Phase (0) Preparation

This phase is intended for integration process preparation as follows;

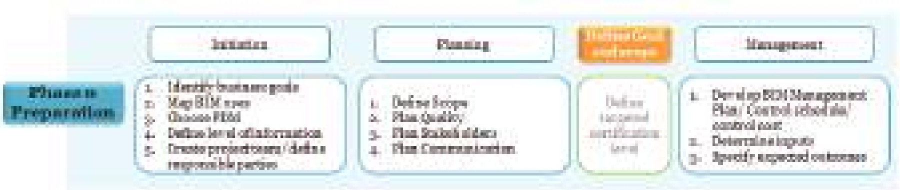


Figure 53. Phase (0) Preparation (Author, 2019).

7.1.1.1.1 Initiation

- **Identify business goals:** Determine the feasibility of achieving the required DGNB certification.
- **Map BIM uses:** for each of the sought criteria/ credits (project compliance path) by linking each of the DGNB activities/ tasks to particular BIM functionality to define the analyses needed to confirm meeting DGNB design requirements.
- **Choose PDM:** like IPD that facilitates the use of BIM amongst multiple parties, encourages the early involvement of stakeholders and enhances collaboration.
- **Indicate Level of information:** and overall geometric expression of the modeled objects in each phase.
- **Create project team/ define responsible parties:** Project team should normally involve the owner, architects/ designers, structural, MEP and HVAC Engineers, Contractors and Commissioning Agents. In

the proposed framework, it is suggested to involve the DGNB assessor and LCA experts from the early stages of the design process.

7.1.1.1.2 Planning

- **Define Scope:** articulate BIM uses for green and non-green processes
- **Plan Quality**
- **Plan Stakeholders/ Responsible parties:** (e.g. Consultant)
- **Plan Communication**
- **Define LCA Goal and Scope:** Goal (assessment goal and background information for the assessment) and scope (minimum required information, functional unit choice, study period reference, system boundaries definition).
- **Define targeted DGNB certification level:** either Gold, Silver or Bronze

7.1.1.1.3 Management

- **Develop BIM Management Plan/ Control schedule/ control cost**
- **Determine inputs:** (Figure 54)
- **Specify expected outcomes** (Figure 54)

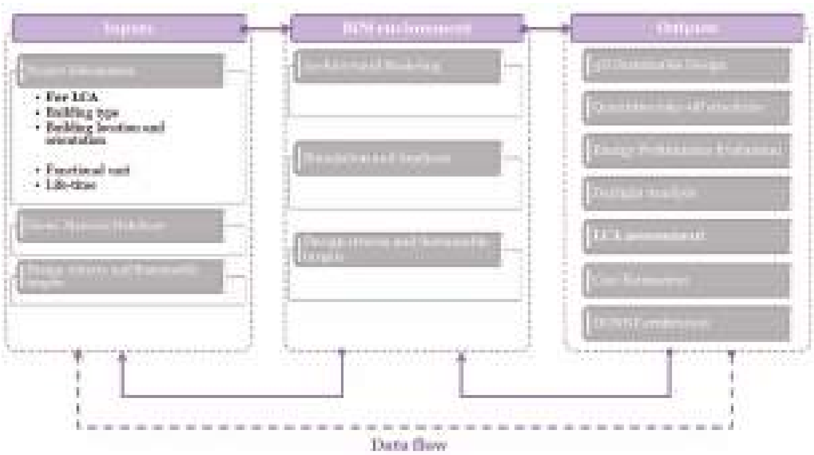


Figure 54. Inputs/ outputs of the proposed framework process. Adapted by (Author, 2019)

7.1.1.2 Phase (1) Material Database

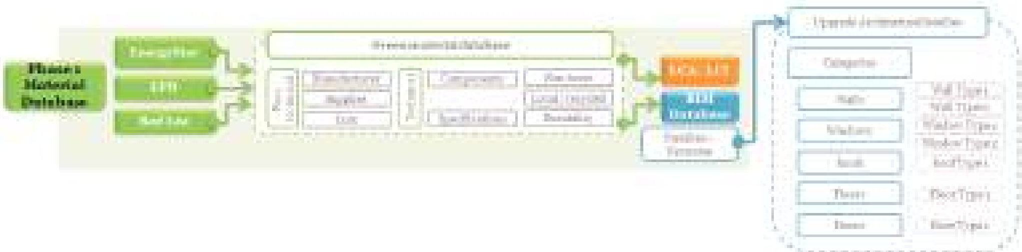


Figure 55. Phase (1) Material Database (Author, 2019).

Establish a green material database by;

- **Include the information:** of environmental product declarations, the material Red List sourcing of raw materials, and material ingredients, as determined by third party verification adhering to ISO standards 14025, 14040, 14044, 21930, and 26000 (Collinge, et al., 2015). See example in (Table 29).
- **Collect further data:** about the technical and non technical specifications for the listed materials as well as manufacturers, suppliers information.

Table 29. Example for the functional, technical and financial specification of sustainable materials collected in the Green Material Database (Jalaei & Jrade, 2014).

Green families used in the BIM's sustainable model	Windows	Roofing systems	Floor	Wall	Door
Functional criteria	-Recyclable packaging materials -Products are certified by Scientific Certification Systems (SCS) to contain pre-consumer recycled content, which includes glass cullet and wood fiber in Fibrex® material -The recycled content certified to retain Forest Stewardship Council (FSC) Chain-of-Custody certification (SCS-COC-001337) for pine wood-based components	-To divert construction and demolition debris from landfills and incineration facilities -Redirect recyclable resources back into the manufacturing process -Redirect reusable materials to appropriate sites -Use materials with recycled content such that post-consumer plus ½ pre-consumer is at least 10% or 20% -Use building materials or products that have been extracted, harvested or recovered, as well as manufactured, within 500 miles of the site for a minimum of 10% or 20% -Use rapidly renewable building materials and products for 2.5% of the total value of all building materials -Patented Fibrex® material provides the strength of wood, low cost of vinyl	-Resource reuse -Recycled content -Regional materials -Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year cycle or shorter) for 5% of the total value of all building materials and products used in the project	-Framing, off-site fabrication of the structural systems -Utilize proprietary fabrication techniques for limiting waste in a controlled factory environment -Enables resource efficiencies that can often eliminate on-site waste -Reduced assembly time and smaller construction crew -Environmental preferable products -All EPS utilized is Green Guard® certified and therefore have lower emissions of VOCs, which helps reduce a home's contribution to smog compared to earlier EPS foam products -Reduce a home's contribution to smog compared to earlier EPS foam products -Reduction in assembly time and call backs and the predictability and adherence to project scheduling provided by indoor fabrication	-No added urea formaldehyde requirement -Constructed of recycled-content materials and contain insulating core material that does not contribute to ozone depletion -Factory applied finishing is applied based on control of volatile organic compounds (VOC) emissions -Regional manufacturing (500 miles) -Rapidly renewable (bamboo veneer)
Technical specifications	-Exposure category: 2000 (Pa) -Air permeability: not more than 3(m³/h·m) joint: 300 (Pa) -Water tightness: no leakage: 200 (Pa) -Wind resistance: no damage & only permissible deflection: 2000(Pa) -Design testing, manufacture and installation carried out under Quality Management Systems certified to BS EN ISO 9001	-Asphalt shingles, thermoplastic polyolefin (TPO) and Poly-Vinyl Chloride (PVC) membranes, Ethylene Propylene Diene Monomer (EPDM) membranes, poly iso insulation, extruded or expanded polystyrene insulation, gypsum board, mineral fiber board, ballast, metal flashings, metal roof panels, and clean wood -Reuse or salvage of ballast, Energy Guard™ roof insulation, and membrane -Material diverted from the waste stream during the manufacturing process -Materials considered being an agricultural product, both fiber and animal, that takes 10 years or less to grow or raise, and to harvest in an ongoing and sustainable fashion -Low E glass for energy efficient performance -Folding hardware won't interfere with window treatments	-Maintain 100% of shell/structure and 50% in addition to Non-Shell/Non-Structure Green Floors can redye your old carpet making it look like new. We can also refurbish your carpet floor tiles -Divert 50% from Landfill Green Floors specialists can analyze the carpet in the building -10% (post-consumer + 1/2 post-industrial) -20% manufactured regionally	-The system allows for construction waste per home built being less than 2.5 pounds (or 0.006 cubic yards) or less of net waste per square foot of conditioned floor area -Contain recycled content at a minimum of 25% postconsumer and 50% post-industrial for at least 90% of the building component	-Rigid foam plastics and fiberglass are typically used as insulation core -Interior doors are typically constructed of wood products (veneer, core materials, and styles) and synthetic wood products (plastics)
Financial investments	Minimize disturbance of the existing structure and internal finishes to a minimum, thereby reducing the cost of making good	This roof was selected because of its engineered cooling attributes for a cooler roof and a projected cooling cost saving of 20%	Lowers maintenance costs a minimum of 10% (based on cost) of the total material value	Benefits accrue well beyond the design and construction budget through energy savings, a reduction in the contributory costs of the built environment to global warming	The cost is higher than for conventional doors. Such cost increases are dependent on the sustainable features specified

- **Build corresponding families and related keynotes:** for the building elements (Walls, windows, roofs, floors and doors, etc.) using the selected materials (Figure 57).
- **Export elements** (with the same functional unit) to LCA tool and establish Life-Cycle Inventory.

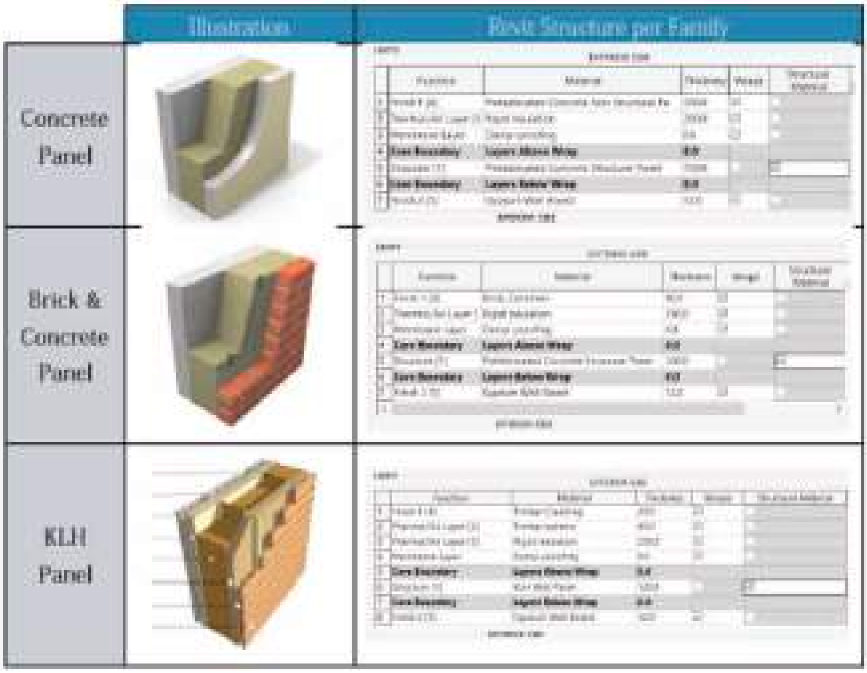


Figure 57. Example for the comparison between alternative materials for wall components (Stella, 2018).

7.1.1.3 Phase (2) Design Criteria

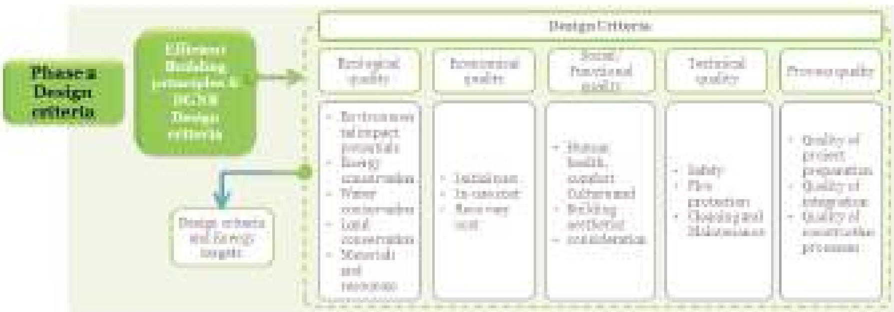


Figure 56. Phase (2) Design Criteria (Author, 2019).

- **Efficient building principles and DGNB Design criteria:** Adopt the sustainable design criteria (regarding the qualities of DGNB system) that need to be considered in the proposed designs, in order to maximize the certification possibilities and points. Also, expected energy targets need to be estimated.

7.1.1.4 Phase (3) 3D Sketching:

Figure 58. Phase (3) Sketching(Author, 2019).

- **General Geometry:** Start with simple geometrical representation of forms (including parts crucial for the design such as; external surfaces and floors) using Sketchup and suggest different solutions and building envelopes.

Figure 59. Generic objects with approximate sizes, dimensions, position and orientation (Stella, 2018).

- **Apply materials:** for a quick estimation
- **Fill the rest of the required fields** in LCA tool
- **Light LCA:** to only facilitate the comparison between the alternative geometrical forms and their corresponding environmental impacts.

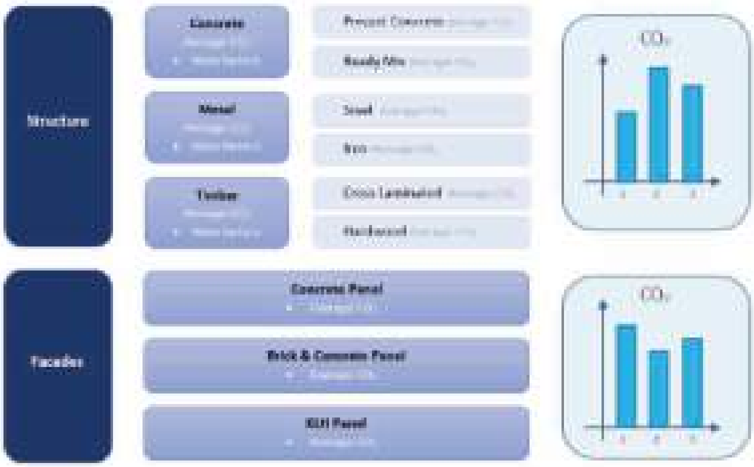


Figure 61. Example for the comparison between the environmental impacts of material alternatives in Light LCA (Stella, 2018).

7.1.1.5 Phase (4) LCA

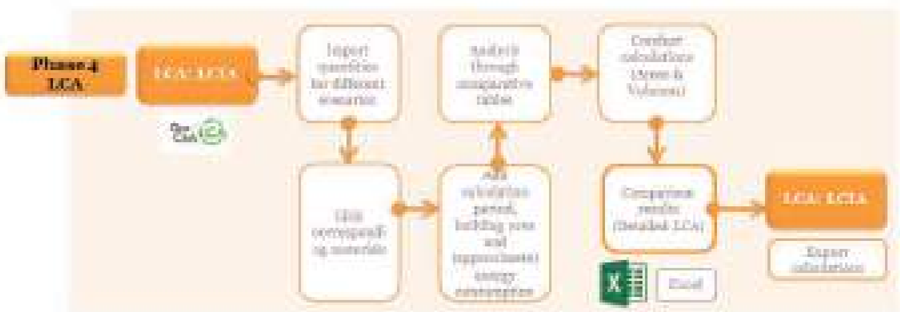


Figure 60. Phase (4) Life-Cycle Assessment (Author, 2019).

- **Import quantities for different scenarios:** using Excel
- **Link corresponding materials:** from the LCI inventory
- **Add the needed information requirements** such as; calculation period, building area and approximate energy consumption.
- **Analyze through comparative tables:** see example in (Table 30).

Table 30. Example for Comparative tables of Materials per class in Revit and One Click LCA per class (Stella, 2014).

Family	Material	Count		Volume	
		Revit	One Click LCA	Revit	One Click LCA
Basic Wall	BPS_INSULATION_BATT	[illegible]	[illegible]	[illegible]	[illegible]
	BPS_PLASTER	[illegible]	[illegible]	[illegible]	[illegible]
	Default Air layer	2	2	[illegible]	[illegible]
	Wood SAE	[illegible]	[illegible]	[illegible]	[illegible]
	Gypsum board	[illegible]	[illegible]	[illegible]	[illegible]
Floor	BPS_CONCRETE_GROUT	[illegible]	[illegible]	[illegible]	[illegible]
Roof	BPS_INSULATION_BATT	[illegible]	[illegible]	[illegible]	[illegible]
	BPS_WOOD_CONSTRUCTION	[illegible]	[illegible]	[illegible]	[illegible]
	Default Flooring	7	7	[illegible]	[illegible]
	Gypsum board	[illegible]	[illegible]	[illegible]	[illegible]
	Roof Material	[illegible]	[illegible]	[illegible]	[illegible]
	Trapezoidal Steel Plates	[illegible]	[illegible]	[illegible]	[illegible]
Doors	A-RPF Dørplade	[illegible]	[illegible]	[illegible]	[illegible]
	External Frame	[illegible]	[illegible]	[illegible]	[illegible]
	Glass	[illegible]	[illegible]	[illegible]	[illegible]
	Internal Frame	[illegible]	[illegible]	[illegible]	[illegible]
Windows	Aluminium Colour NCS [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	External Frame	[illegible]	[illegible]	[illegible]	[illegible]
	Glass	[illegible]	[illegible]	[illegible]	[illegible]
	Internal Frame	[illegible]	[illegible]	[illegible]	[illegible]
	Polyurethane colour NCS [illegible]	[illegible]	-	[illegible]	-
	Standard extra solar gain	[illegible]	[illegible]	[illegible]	[illegible]

- **Conduct Calculations:** with accurate areas and volumes exported from BIM Model
- **Compare between results:** of Environmental impacts of the alternative materials
- **Life-Cycle Impact Assessment**
- **Export calculations**: and documents required for DGNB certification

7.1.1.6 Phase (5) Object-based Modeling

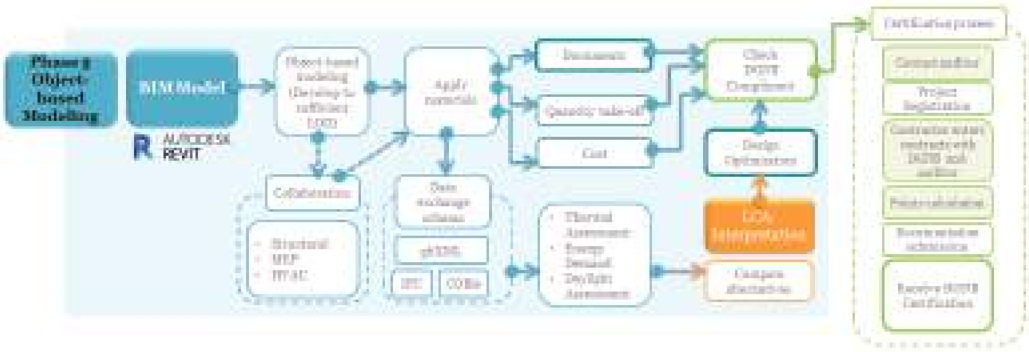


Figure 62. Phase (5) Object-based Modeling (Author, 2019).

Figure 63. Definition of final functional, performance and material contexts in BIM model (Stella, 2018).

- **BIM model:** representing a well-co-ordinated proposal of the building. The objects have specific dimensions, areas, volumes, positions and functions.
- **Develop the modeled object** to the sufficient LOD, compliant with the required analyses' needs as regulated by standards (e.g. elements like walls, roofs and shading devices, specified thermal zones and space boundaries are modeled);
- **Apply materials:** with detailed specification including manufacturing, purchasing and use details such as cost and maintenance parameters.
- **Collaborate:** the architectural design with other disciplines.
- **Export the modeled building:** proprietary and open source data schemas to streamline information export to perform Thermal, Energy Demand and Daylight analyses.

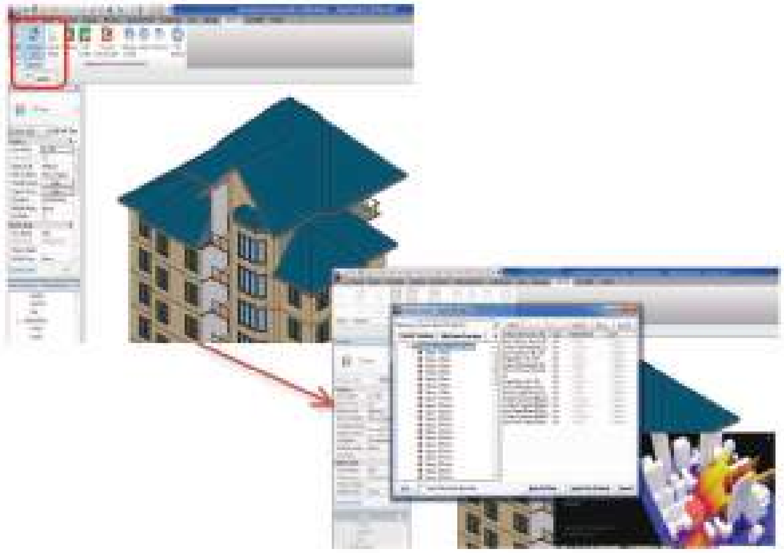


Figure 64. Information Exchange from BIM Model to building energy simulation tools (Jalaei & Jrade, 2014).

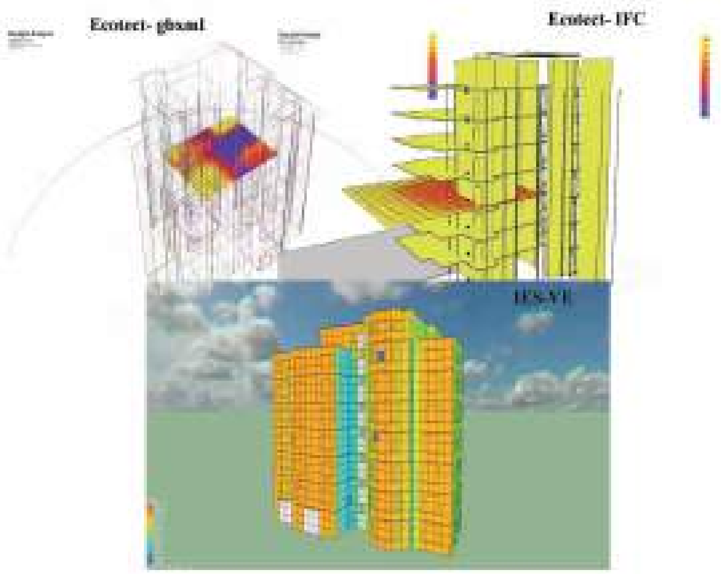


Figure 65. Example of Day lighting simulation in Ecotect and IES-VE (Jalaei & Jrade, 2014).

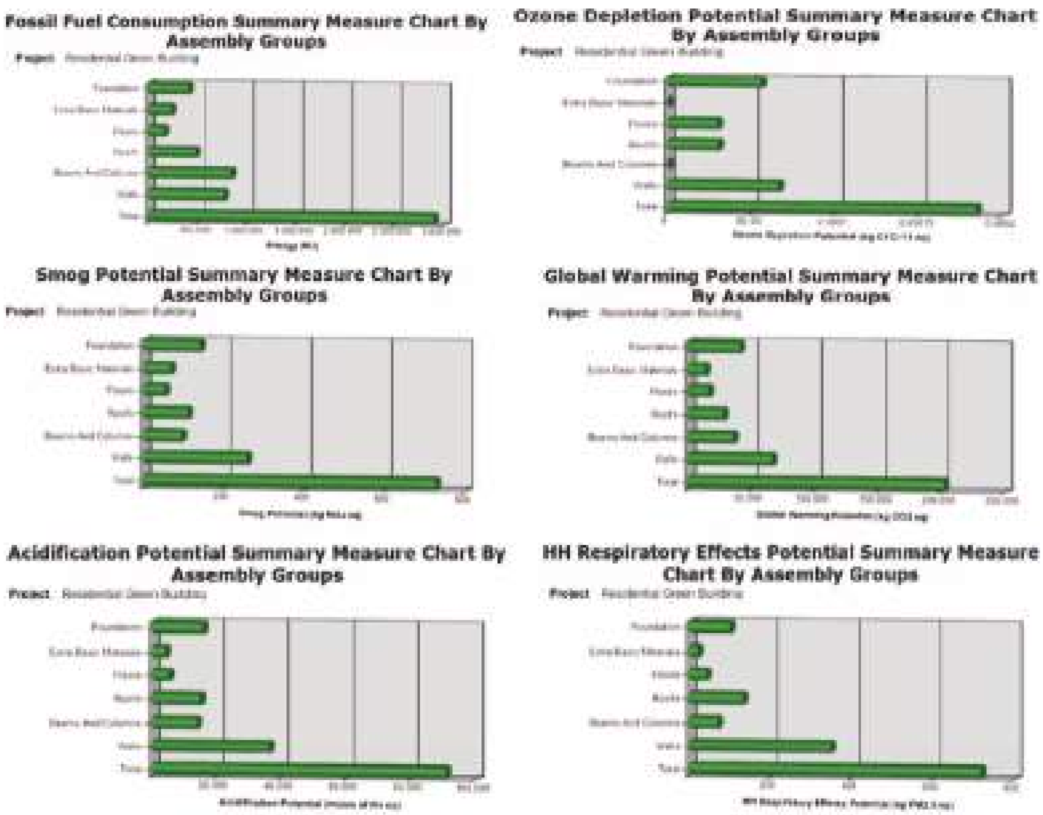


Figure 66. Example of the results of Life-Cycle Assessment Report (Jalaei & Jrade, 2014).

- **Perform LCA Interpretation,** as per the illustrated example in (Figure 66)
- **Apply design optimization** if needed (as per concluded from LCA)
- **Produce:** Documents, Quantity take-off schedule and associated costs.
- **Check** for DGNB Requirements compliance.
- **Proceed in DGNB Certification Process.**

Table 32. Example of the Quatity take-off schedule for each class (Stella, 2018).

CLASS	REVIT ELEMENT NAME	IFCMATERIAL	QUANTITY
EXTERNAL WALL	YV træ - 360 mm_RDK	BIPS_INSULATION_BATT	227.831
EXTERNAL WALL	YV træ - 360 mm_RDK	BIPS_PLASTER	33.782
EXTERNAL WALL	YV træ uisoleret - 150 mm_RDK 2	Default Air layer	2.027
EXTERNAL WALL	YV træ - 360 mm_RDK	Wood SAU	8.078
EXTERNAL WALL	WAL_Generic - 50 mm_RDK	Gypsumboard	3.258
SLAB	FLO_CON (In-Place) - 180 mm_RDK	BIPS_CONCRETE_GROUT	143.357
ROOF	Tag 02_550 mm	BIPS_INSULATION_BATT	375.853
ROOF	Tag 02_550 mm	BIPS_WOOD-CONSTRUCTIOI	91.709
ROOF	Tag 02_550 mm	Gypsumboard	11.861
ROOF	Tag 02_550 mm	Trapezoidal Steel Plates	23.057
ROOF	Tag 02_550 mm	Default Planting	44.425
ROOF	Tag 02 ikke sedum_550 mm	Roof Material	0.815
DOOR	9M	A-KPF-Dørplade	1.935
DOOR	9M	Internal Frame	1.797
DOOR	Glass_0972 x 2200	Glass	1.820
DOOR	Glass_0972 x 2200	External Frame	0.599
WINDOW	GPL-GPU - Top-hung roof window 2	Aluminium, Color NCS 7500-N	1.341
WINDOW	1512 x 1500	External Frame	2.248
WINDOW	1512 x 1500	Glass	6.822
WINDOW	Fixed -900 x900	Internal Frame	0.622
WINDOW	GPL-GPU - Top-hung roof window 2	Standard, extra solar gain	1.261

Table 31. Example of the Associated cost estimation of the selected components (Jalaei & Jrade, 2014).

Description	Unit	Quantity	Material ($)	Labor ($)	Total unit cost ($)	Total Sum cost ($)
Windows						
Windows, vinyl double hung, grids, low-E, 1 lite, 37" × 60", including grill, 1 finish, low-E, extension jambs	Ea.	5	262.00	44.0	306.00	1530
Windows, wood, casement, vinyl clad, premium, double insulated glass, multiple leaf units, double unit, 5'-4" × 5'-0" high, incl. frame, screens and grilles	Ea.	18	431.00	58.0	489.00	8802
Windows, wood, casement, vinyl clad, premium, double insulated glass, 2'-0" × 4'-0" high, incl. frame, screens and grilles	Ea.	6	375.00	44.0	419.00	2514
Roof						
Wood shingles, white cedar, 3/4" thick × 16" long, 5" exposure on roof	Sq.	27.41	154.00	147.0	301.00	8250
Floor						
Resilient flooring, cork tile, standard finish, 5/16" thick	S.F.	18 820	8.60	1.04	9.64	181 425
Doors						
Doors, wood, residential, exterior, combination storm and screen, pine, cross buck, 7'-1" × 3'-0" wide	Ea.	1	330.00	78.5	408.5	408.5
Doors, wood, residential, entrance, flush, birch, solid core, 1'-3/4" × 7'-0" × 2'-6" wide	Ea.	30	111.00	44.0	155.00	4650
Column						
Column, structural, mild steel scrollwork, flat, stock unit, plain, painted, 6" W, shop fabricated	V.L.F.	870	9.96	9.90	19.86	17 278
Railing & stairs						
Railing, ornamental, bronze or stainless, 3'-6" high, posts @ 6' O.C., hand-forged, plain	L.F.	907.1	101.00	33.0	134.00	121 539

7.3.2 Model Validation

In order to prove the applicability of the proposed model an interview (see Appendix Q) has been conducted for preliminary validation and expert opinion collection with 3 participants of whom; one has been involved in the research field of BIM Development and the other two are BIM practitioners who implemented BIM in projects seeking for GBRS certification.

The participants reviewed the proposed model, gave feedback and provided some recommendations to enhance the applicability of the framework (to be considered in further versions) as follows;

- The model is quite promising as a concept, but it is quite complex.
- A key should be provided so it can be easily comprehended.
- The Phasing of the proposed model can be very effective in terms of application; meaning that companies seeking for Developing their SBD system using BIM can slowly implement the phases one at a time especially for the phases intended for material data collection and database preparation.
- Companies in Egypt, in order to overcome the problem of not having a national BIM protocol, had to inherit protocols from the UK or sometimes developed in-house BIM standards. Similarly, this can be done in preparing the material database and building Revit families and keynotes specifically for the ,materials available in the Egyptian market.
- It would be very beneficial to find/ establish a BIM forum or platform, where the best practices can be shared among BIM users.
- One major factor that might affect the implementation of the proposed framework is the current environment in terms of processes and poli-

cies, which to change need a real desire for development from both individuals and organizations.

- The phasing of the framework should be linked to either the American or British BIM system as per the standard followed in the organization.

7.3.3 Measures for Better Implementation

The success of the implementation of (GBRS -LCA - BIM) integration

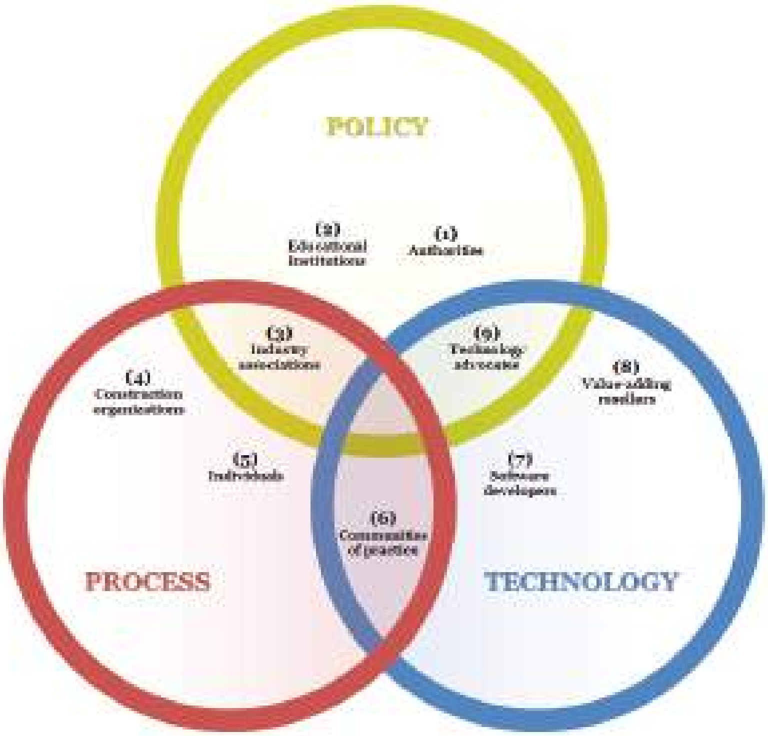


Figure 67. Involved Player groups. Adapted from (Succar, 2017)

rely on responsibility diffusion between Policy, Process and Technology (Figure 67), for which the following measures[1] need to be considered;

7.3.4 Policy

7.3.4.1 Authorities

Governments need to;

- Upgrade local mandatory codes and enforce sustainability practices at least in public buildings.

1 *Actions may occur sequentially or concurrently, or sometimes will reiterate.*

- Establish policies that mandate BIM adoption for all major projects. This can happen gradually in new construction projects; starting with public, then publicly-funded and private projects later.
- Collaborate with academia and private sector to set a road map and time frame for BIM adoption. Develop BIM standards and guidelines for
- Provide BIM basics courses for the professionals working in Governmental positions who need to evaluate submitted projects.
- Offer incentives for AEC companies to implement the integrated approach such as tax reduction or loan provision.
- Mandate a minimum level of GBRS certification gradually for new construction projects; starting with public, then publicly-funded and private projects later.
- Require the submission of GHG emission accounts (for both public and private sector projects) as part of their international commitment.

7.3.4.2 Educational and Research Institutions

There is a need of a cultural shift to bring researchers closer to the industry, by;

- Raising sustainable awareness and education in schools and colleges as well as within the construction market's key players (such as Owners, consultants, contractors, manufacturers...) Promoting for the feasibility and economic, social and environmental benefits of green projects to owners and landlords is an important step to start upgrading the construction market.
- Provide BIM formal and informal education as well as training support

to educate potential service providers by cooperating with standards organizations and universities. These teachings can be more beneficial if included the concept of collaboration between different disciplines in shared projects as well as sustainable construction and life-cycle.

- Researchers, in order to train HQP, need to build a new GBRS, LCA and BIM body of knowledge from the practical and application lessons learned in the industry.

7.3.4.3 Industry associations

- The industry needs highly qualified personnel (HQP) to help them navigate in this new business environment.

7.3.5 Process

7.3.5.1 Construction organizations

- Establish an official qualified independent authority for quality and environmental control. This authority can be then responsible to collect and verify data sheets (from Environmental Product Declaration and Materials Red list) for local materials (in terms of the recycled content, the source of the material, the SRI value, and the VOC content) and develop a Green Material database (for locally manufactured construction materials) adhering to ISO standards.

7.3.5.2 Individuals

- Increasing the Demand for Sustainability Clients can make consultants, contractors and manufacturers eager to enhance their knowledge and practice sustainability in their works.

- Spread knowledge and awareness of BIM potentials among AEC professionals and owners, so they would be more willing to implement BIM tools into their building practices.

7.3.5.3 Communities of Practice

- Provide expert support and resources for ongoing projects to incorporate BIM technologies.
- Create a BIM open source platform, where BIM best practices are shared as role models.
- Publish a series of BIM guidelines to facilitate the process of implementation.

7.3.6 Technology

7.3.6.1 Software developers

- BIM should increase its capacity to effectively integrate with environmental analysis and improve interoperability.
- Assess industry readiness and technology maturity to define inefficiencies and areas needing more attention.
- Partner with BIM vendor professional associations, open standard organizations and academic research institutions.

7.3.6.2 Value-adding resellers

7.3.6.3 Technology advocates

7.3.7 Collaborative Actions

- Establish a protocol for BIM adoption in Egypt. This would need the cooperation of governmental bodies, private sector and academia to form a complete vision of how to enhance the construction industry and regulate green and efficient building practices in Egypt.

- Include the experts from both GBRS and LCA into the development process, so they can share their knowledge background and personal experiences of how to improve the shift roadmap.

7.4 Executive Summary

Building Information Modeling, in many ways, has proved its wide capabilities to improve the predictability of building performance and operation. It could, in a relatively short time, change the ways architecture, engineering, and construction practices used to be performed by introducing innovative ways to virtually design and manage projects.

Nevertheless, BIM on its own cannot be relied on to address the sustainability side of things in terms of; reducing negative environmental impacts or in maximizing the use of environmental-friendly resources and activities. In this regard, some other proven-successful perspectives need to be incorporated to effectively develop the Sustainable Building Design (SBD) process.

Therefore, an integrated framework (joining GBRS, LCA and BIM) would eliminate much of the problems associated with traditional design approaches, help to improve building quality and performance, enhance team productivity, save valuable resources like money, time and effort for all the involved stakeholders.

However, the lack of an efficient connection between the three trends and their practitioners, can hinder achieving the full potentials of such an integration.

Hence, to increase the methodology's effectiveness, AEC practices need to function within a collaborative work flow within projects' teams and engagement of all stakeholders, to achieve improved profitability, reduced costs, better time management, and improved customer-client relationships all in addition to the environmental paybacks and social benefits that lay behind.

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APPENDICES

Appendix A. BREEAM New Construction 2014 Category Weightings (1/3) (Karmany, 2016).

Categories	Weighting	Index	Criterion	Max. credits	%
Management	12%	Man1	Commissioning	2	2.18%
		Man 2	Constructors Environmental and Social Code of Conduct	2	2.18%
		Man 3	Construction site impacts	4	4.36%
		Man 4	Building user guide	1	1.09%
		Man12	Life Cycle Cost Analysis	2	2.16%
Heath and Well Being	15%	H0a 1	Daylighting	1	1.07%
		Hea 2	View out	1	1.07%
		Hea3	Glare control	1	1.07%
		Hea 4	High frequency lighting	1	1.07%
		Hea 5	Internal and external lighting levels	1	1.07%
		Hea 6	Lighting zones and control	1	1.07%
		Hea7	Potential for natural ventilation	1	1.07%
		Hea 6	Indoor air quality	1	1.07%
		Hea9	Volatile Organic Compounds (VOC)	1	1.07%
		Hea 10	Thermal comfort	2	2.14%
		Hea 11	Thermal zoning	1	1.07%
		Hea 12	Microbial contamination	1	1.07%
		Hea 13	Acoustic performance	1	1.07%
Energy	19%	Ene 1	Energy efficiency	15	11.87%
		Ene 2	Sub-metering of substantial energy use	1	0.79%
		Ene 3	Submetering of high energy areas and tenancy	1	0.79%
		Ene 4	External lighting	1	0.79%
		Ene 5	Low-zero carbon technologies	3	2.36%
		Ene8	Lifts	2	1.56%
		Ene 9	Escalators and traveling walkways	1	0.79%

Appendix B. BREEAM New Construction 2014 Category Weightings (2/3) (Karmany, 2016).

Categories	Weighting	Index	Criterion	Max. credits	%
Transport	8%	Tra 1	Provision of public transport	2	1.76%
		Tra 2	Proximity to amenities	1	0.69%
		Tra 3	Alternative modes of transport	2	1.76%
		Tra 4	Pedestrian and cyclist safety	1	0.69%
		Tra 5	Travel plan	1	0.69%
		Tra 6	Maximum car parking capacity	2	1.76%
Water	6%	Wat 1	Water consumption	3	2%
		Wat 2	Water meter	1	0.67%
		Wat 3	Major leak detection	1	0.67%
		Wat 4	Sanitary supply shut-off	1	0.67%
		Wat 6	Irrigation systems	1	0.67%
		Wat 3	Sustainable on-site water treatment	2	1.33%
Materials	12.50%	Mat 1	Material specifications (major building elements)	4	3.85%
		Mat 2	Hard landscaping and boundary protection	1	0.96%
		Mat3	Re-use of building facade	1	0.96%
		Mat 4	Re-use of building structure	1	0.96%
		Mat5	Responsible sourcing of materials	3	2.66%
		Mat6	Insulation	2	1.92%
		Mat17	Designing for robustness	1	0.96%
Waste	7.50%	Wst 1	Construction site waste management	3	3.21%
		Wst 2	Recycled aggregates	1	1.07%
		Wst 3	Recyclable waste storage	1	1.07%
		Wst 5	Composting	1	1.07%
		Wst 6	Floor finishes	1	1.07%
Land Use & Ecology	10%	LE 1	Re-use of land	1	1%
		LE 2	Contaminated land	1	1%
		LE3	Ecological value of site & protection of eco logical features	1	1%

Appendix C. BREEAM New Construction 2014 Category Weightings (3/3) (Karmany, 2016).

Categories	Weighting	Index	Criterion	Max. credits	%
		LE4	Mitigating ecological impact	5	5%
		LE6	Long-term impact on biodiversity	2	2%
Pollution	10%	Pol 1	Refrigerant GWP - building services	1	0.63%
		Pol 2	Preventing refrigerant leaks	2	1.67%
		Pol 4	NOX emissions from heating source	3	2.5%
		Pol 5	Flood risk	3	2.5%
		Pol 6	Minimizing watercourse pollution	1	0.63%
		Pol 7	Reduction of night-time light pollution	1	0.63%
		Pol 8	Noise attenuation	1	0.63%
Innovation	10%	Inn 1	Innovations (1 credit per innovation, max. 10 credits)	10	10%
Total				119	100.7%

Appendix D. LEED v4 for BD+C checklist (USBGC, 2019).

LEED v4 for BD+C: New Construction and Major Renovation
Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	1
0	**0**	**0**		**Location and Transportation**	**16**
			Credit	LEED for Neighborhood Development Location	16
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	6
			Credit	Access to Quality Transit	5
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1
0	**0**	**0**		**Sustainable Sites**	**10**
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1
0	**0**	**0**		**Water Efficiency**	**11**
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1
0	**0**	**0**		**Energy and Atmosphere**	**33**
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2
0	**0**	**0**		**Materials and Resources**	**13**
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2
0	**0**	**0**		**Indoor Environmental Quality**	**16**
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1
0	**0**	**0**		**Innovation**	**6**
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1
0	**0**	**0**		**Regional Priority**	**4**
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
0	**0**	**0**		**TOTALS** Possible Points:	**110**

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

Appendix E. Example of the DGNB system Evaluation Matrix Ver.2009 (Miranda, 2013).

Evaluation Area	Criteria Group	Criteria	Criteria Points Achieved	Criteria Points Max. Possible	Weighting Factor	Weighted Points Achieved	Weighted Points Max. Possible	Group Points Achieved	Group Points Max. Possible	Group Performance Index	Group Weight	Total Performance Index
Environmental Quality	Life Cycle Analysis	Global Warming Potential	10.0	10.0	3	30.0	30.0	178.5	200.0	89.3%	22.5%	[illegible] (GOLD)
		Ozone Depletion Potential	10.0	10.0	1	10.0	10.0					
		Photochemical Ozone Creation Potential	10.0	10.0	1	10.0	10.0					
		Acidification Potential	10.0	10.0	1	10.0	10.0					
		Eutrophication Potential	7.1	10.0	1	7.1	10.0					
	Global and Local Environmental Impact	Local Environmental Impact	8.2	10.0	3	24.6	30.0					
		Sustainable Use of Resources / Wood	10.0	10.0	1	10.0	10.0					
	Resource Consumption and Waste Generation	Nonrenewable Primary Energy Demand	10.0	10.0	3	30.0	30.0					
		Total Primary Energy Demand and Proportion of Renewable Primary Energy	8.4	10.0	2	16.8	20.0					
		Drinking Water Demand and Volume of Waste Water	5.1	10.0	2	10.2	20.0					
		Land Use	10.0	10.0	2	20.0	20.0					
Economic Quality	Life Cycle Costs	Building-Related Life Cycle Costs	9.0	10.0	3	27.0	30.0	47.0	50.0	94.0%	22.5%	
	Economic Performance	Suitability for Third-Party Use	10.0	10.0	2	20.0	20.0					
Sociocultural and Functional Quality	Health, Comfort and User Friendliness	Thermal Comfort in Winter	10.0	10.0	2	20.0	20.0	251.1	280.0	89.7%	22.5%	
		Thermal Comfort in Summer	10.0	10.0	3	30.0	30.0					
		Indoor Air Quality	10.0	10.0	3	30.0	30.0					
		Acoustic Comfort	10.0	10.0	1	10.0	10.0					
		Visual Comfort	8.5	10.0	3	25.5	30.0					
		User Influence on Building Operation	6.7	10.0	2	13.4	20.0					
		Quality of Outdoor Spaces	8.0	10.0	1	8.0	10.0					
		Safety and Security	8.0	10.0	1	8.0	10.0					
	Functionality	Accessibility	8.0	10.0	2	16.0	20.0					
		Efficient Use of Floor Area	5.0	10.0	1	5.0	10.0					
		Suitability for Conversion	7.1	10.0	2	14.2	20.0					
		Public Access	10.0	10.0	2	20.0	20.0					
		Cycling Convenience	10.0	10.0	1	10.0	10.0					
	Aesthetic Quality	Design and Urban Planning Quality through Competition	10.0	10.0	3	30.0	30.0					
		Integration of Public Art	10.0	10.0	1	10.0	10.0					
Technical Quality	Technical Quality of Building Design and Systems	Fire Prevention	8.0	10.0	2	16.0	20.0	74.0	100.0	74.0%	22.5%	
		Indoor Acoustics and Sound Insulation	5.0	10.0	2	10.0	20.0					
		Building Envelope Quality	7.7	10.0	2	15.4	20.0					
		Ease of Cleaning and Maintenance	7.1	10.0	2	14.2	20.0					
		Ease of Dismantling and Recycling	8.2	10.0	2	16.4	20.0					
Process Quality	Quality of the Planning Process	Comprehensive Project Definition	8.3	10.0	3	24.9	30.0	188.6	230.0	82.0%	10.0%	
		Integrated Planning	10.0	10.0	3	30.0	30.0					
		Comprehensive Building Design	8.6	10.0	3	25.8	30.0					
		Sustainable Aspects in Tender Phase	10.0	10.0	2	20.0	20.0					
		Documentation for Facility Management	5.0	10.0	2	10.0	20.0					
		Environmental Impact of Construction Site / Construction Process	7.7	10.0	2	15.4	20.0					
		Prequalification of Contractors	5.0	10.0	2	10.0	20.0					
	Construction Quality	Construction Quality Assurance	10.0	10.0	3	30.0	30.0					
		Systematic Commissioning	7.5	10.0	3	22.5	30.0					
Site Quality	Site Quality	Site Location Risks	7.0	10.0	2	14.0	20.0	93.3	130.0	71.8%		
		Site Location Conditions	7.1	10.0	2	14.2	20.0					
		Public Image and Social Conditions	1.0	10.0	2	2.0	20.0					
		Access to Transportation	8.3	10.0	3	24.9	30.0					
		Access to Specific Use Facilities	9.7	10.0	2	19.4	20.0					
		Connection to Utilities	9.4	10.0	2	18.8	20.0					

Appendix F. GPRS, Example for New construction scorecard (1/2) (Karmany, 2016).

	Category / sub-category	Credits expected	Evidence available
1	**SUSTAINABLE SITE, ACCESSIBILITY, AND ECOLOGY**		
	1.M.1 Project Design and Implementation Plan	✓	✓
	1.1.1 Desert area development	1	✓
	1.1.2 Informal area redevelopment	-	
	1.1.3 Brownfield site redevelopment	-	
	1.1.4 Compatibility with National Development Plan	1	✓
	1.2.1 Transport infrastructure connection	1	✓
	1.2.2 Catering for remote sites	1	✓
	1.2.3 Alternative methods of transport	1	✓
	1.3.1 Protection of habitat	-	
	1.3.2 Respect for sites of historic or cultural interest	1	✓
	1.3.3 Minimizing Pollution during construction	1	✓
		7/10 points	
2	**ENERGY EFFICIENCY**		
	2.M.1 Minimum Energy Performance Level	✓	✓
	2.M.2 Energy Monitoring & Reporting	✓	✓
	2.M.3 Ozone Depletion avoidance	✓	✓
	2.1 Energy Efficiency Improvement	6	✓
	2.2 Thermal Comfort Strategies	2	✓
	2.3 Energy Efficient Appliances	3	✓
	2.4 Vertical Transportation Systems	2	✓
	2.5 Peak Load Reduction	3	✓
	2.6 Renewable Energy Sources	4	✓
	2.7 Environmental Impact	4	✓
	2.8 Operation and Maintenance	1	✓
	2.9 Optimized balance of Energy and Performance	4	✓
	2.10 Energy and Carbon Inventories	-	
		29/50 points	
3	**WATER EFFICIENCY**		
	3.M.1 Minimum Water Efficiency	✓	✓
	3.M.2 Water Use Monitoring	✓	✓
	3.1 Indoor Water Efficiency Improvement	5	✓
	3.2 Outdoor Water Efficiency Improvement	4	✓
	3.3 Efficiency of Water-based Cooling	3	✓
	3.4 Water Feature Efficiency	-	
	3.5 Water Leakage Detection	6	✓
	3.6 Efficient water use during construction	3	✓
	3.7 Waste Water Management	-	
	3.8 Sanitary Used Pipes	4	✓
		25/50 points	
4	**MATERIALS AND RESOURCES**		
	4.M.1 Schedule of Principal Project Materials	✓	✓
	4. M.2 Elimination of exposure to hazardous and toxic materials.	✓	✓
	4.1.1 Regionally procured materials	2	✓
	4.1.2 Materials fabricated on site	1	✓
	4.1.3 Use of readily renewable materials	2	✓
	4.1.4 Use of salvaged materials	1	✓
	4.1.5 Use of recycled materials	-	
	4.1.6 Use of lightweight materials	1	✓
	4.1.7 Use of higher durability materials	1	✓
	4.1.8 Use of prefabricated elements	2	✓
	4.1.9 Life Cycle Cost (LCC) analysis of materials in the project	1	✓
		11/20 points	
5	**INDOOR ENVIRONMENTAL QUALITY**		
	5.M.1 Minimum Ventilation and Indoor Air Quality	✓	✓
	5.M.2 Control of Smoking in and around the Building	✓	✓
	5.M.3 Control of Legionella and other health risks	✓	✓
	5.1 Optimized Ventilation	1	✓
	5.2 Controlling emissions from building materials	5	✓
	5.3 Thermal Comfort	2	✓
	5.4 Visual Comfort	2	✓
	5.5 Acoustic Comfort	1	✓
		11/20 points	

Appendix G. GPRS, Example for New construction scorecard (2/2) (Karmany, 2016).

6	**MANAGEMENT**		
	6.M.1 Integrated Plan and Method Statement for site operations	✓	✓
	6.M.2 Compliance with Health & Safety and Welfare regulations	✓	✓
	6.M.3 Demolition Method Statement18	✓	✓
	6.1.1 Containers for site materials waste	2	✓
	6.1.2 Employing waste recycling workers on site		
	6.1.3 Access for lorries, plant and equipment	1	✓
	6.1.3 Identified and separated storage areas	2	✓
	6.2.1 Project Waste Management Plan	1	✓
	6.2.2 Engaging a company specialized in recycling and disposal	2	✓
	6.2.3 Protecting water sources from pollution	2	✓
	6.2.4 Waste from mixing equipment	-	
	6.2.5 Control of emissions and pollutants		
	6.3.6 Providing a Building User Guide	3	✓
	6.3.7 Providing a Periodic Maintenance Schedule	2	✓
		15/28 points	
7	**INNOVATION AND ADDED VALUE**		
	7.1 Cultural Heritage	1	✓
	7.2 Exceeding Benchmarks		
	7.3 Innovation		
		1/3 points	

Appendix H. TARSHEED Categories' Credits. (Karmany, 2016).

	ENERGY	%
	ENVELOPE	15.00%
E01	WINDOW TO WALL RATIO	2.00%
E02	EXTERNAL WINDOW SHADING	2.00%
E03	ROOF INSULATION	2.00%
E04	EXTERNAL WALLS INSULATION	2.00%
E05	BASEMENT OR FLOOR SLAB INSULATION	1.00%
E06	LOW-E COATED GLASS	1.50%
E07	HIGHER PERFORMANCE GLASS	1.50%
E08	AIR TIGHTNESS	3.00%
E09	COOLING	25.00%
E10	HEATING	5.00%
E11	HOT WATER	10.00%
E12	LIGHTING	20.00%
E13	APPLIANCES	15.00%
E14	SMART METERS	2.00%
E15	THE KILL SWITCH	1.00%
E16	EFFICIENT ELEVATORS	4.00%
E17	EXTERNAL LIGHTING AND CONTROLS	3.00%
E18	RENEWABLE ENERGY	
		100.00%

	WATER	%
	INDOOR	79.61%
W01	SHOWERHEADS*	27.86%
W02	KITCHEN SINK FAUCETS*	15.92%
W03	LAVATORY FAUCETS*	15.92%
W04	WATER CLOSETS*	19.90%
	IRRIGATION	20.39%
W05	REDUCE GRASS	10.19%
W06	IRRIGATION EFFICIENCY	10.19%
	ADD ON	
W07	GREY WATER / AC CONDENSATE / RAINWATER	
	*UPC and IPC code	**100.00%**

	HABITAT	%
	OUTDOOR	**42%**
H01	READY-MIX CONCRETE	5%
H02	REFLECTIVE TILES FOR ROOF AND OUTDOOR PAVING	10%
H03	REFLECTIVE PAINT FOR EXTERNAL WALLS	5%
H04	SHADED PARKING	10%
H05	BICYCLE RACKS	2%
H06	ORGANIC FRUITS AND VEGETABLES GARDEN	8%
H07	OUTDOOR LIGHTING FULL CUTOFF	2%
	MATERIAL	**34%**
H08	PROPER DISPOSAL OF CONSTRUCTION WASTE	5%
H09	RECYCLING CONSTRUCTION WASTE	2%
H10	WASTE SEGREGATION AT SOURCE	10%
H11	PRODUCE YOUR OWN COMPOST	2%
H12	LOCAL FLOORING	8%
H13	LOCAL CERAMIC	5%
H14	RECYCLED CONTENT	1%
H15	MATERIAL REUSE	1%
	INDOOR	**24%**
H16	ENTRYWAY SYSTEM	3%
H17	LOW VOC PAINTS	10%
H18	WINDOWS FOR LIVING SPACES	10%
H19	KITCHEN EXHAUST	1%
		100%

Appendix I. Survey (1), For GBRS experts (Author, 2019).

Structured Interview (1): **Date:** ____________

Investigating the efficiency/ influence of Green Building Rating Systems principles application on the Construction Industry in the MENA Region

Participant's Name:

Title:

Current position:

Discipline: **Highest level of academic achievement:**

The Organization you are currently working for:

Q1 Which GBRS are you expert in? How context-convenient do you think is it in MENA Region?

Q2 Have you ever used the Egyptian Green Pyramid Rating System? Please describe your experience.

Q3 Please name the 'sustainable' projects you have worked on, in Egypt or elsewhere. Please specify the level of certification of they achieved (if any).

Q4 Which certification system is the most widely used in MENA region? Why? (from your point of view).

Q5 Have you ever worked with the Egyptian GPRS?

Q6 In general, what are the barriers of GBRS application in the Egyptian market? How could that be overcome?

Q7 From your point of view, what are the motives behind certifying a building? Or applying green building efficiency principles? Do they actually achieve sustainable design, or is it just seeking for the certification?

Q8 What are the design tools you usually use for sustainable design?

Q9 Do these tools include BIM? Have you ever considered implementing BIM? Please specify how useful it could be in enhancing the whole design process.

Q10 If not using BIM, how do the involved team members exchange project information?

Q11 Have you ever considered the life-Cycle Assessment within the sustainable design of a project? How beneficial was it? Did the project get certified? If yes, please specify the rating level.

Q12 Can you refer any other GBRS experts who would be willing to participate in the survey?

Your cooperation is highly appreciated.

Appendix J. Survey (2), For LCA professionals (Author, 2019).

Structured Interview (3): **Date:** ____________

Investigating the application of Life-Cycle Assessment approach within construction practices in Egypt

Participant's Name:

Title:

Current position:

Discipline: **Highest level of academic achievement:**

The Organization you are currently working for:

Q1 Do you think LCA as an environmental assessment approach is well known in Egypt?

Q2 What are the barriers that hinders its adoption?

Q3 What are the triggers that would enhance its adoption?

Q4 How useful do you see the LCA approach? Please provide evidence from your professional experience.

Q5 Which type of software do you use to perform Life-Cycle assessment?

Q6 Have you ever worked on a project integrating LCA with Green Building Rating Systems (such as LEED, BREEAM, GPRS or any other)? Please give a brief. What was the benefits of the integration?

Q7 Have you ever worked on a project integrating LCA with Building Information Modeling (BIM)? Please give a brief. What was the benefits of the integration?

Q8 Can you refer any other LCA experts who would be willing to participate in the survey?

Your cooperation is highly appreciated.

Appendix K. Survey (3), For BIM practitioners(Author, 2019).

Structured Interview (3): **Date:** ____________

Enhancing BIM adoption in the Construction industry

Participant's Name:

Title:

Current position:

Discipline: **Highest level of academic achievement:**

The Organization you are currently working for:

Q1 When has your Organization shifted to BIM implementation? Which level of maturity are you using? How do you think it could be developed?

Q2 Is there a standard BIM protocol used in Egypt? Which BIM protocol is your organization using? Please explain.

Q3 Which level of development/ detail (LOD) do you use? How is it identified?

Q4 How do you decide which BIM dimension to use?

Q5 Which software do you usually use? And which type of data exchange format is used?

Q6 Is there any other software you use for purposes other than architectural design (e.g. scheduling, cost estimation, energy simulation, performance assessment, risk detection)? Please specify.

Q7 What are the values added from using BIM, regarding quality, cost, time and effort? Please include other benefits (if any).

Q8 What are the challenges facing wider implementation of BIM in the region?

Q9 what are the drivers/ opportunities for wider implementation of BIM?

Q10 How did using BIM affect the team structure? And all the involved teams? And the relation between consultants, contractors as well as other stakeholders?

Q11 Have you ever worked on a project integrating BIM with sustainable design measures or seeking for Green Building certification? Was it certified? Please specify the top benefits of BIM implementation in green building design.

Q12 Have you ever heard of Life-Cycle Assessment? Is LCA approach considered when using BIM in projects design in Egypt?

Q13 Can you refer any other BIM experts who would be willing to participate in the survey?

Your cooperation is highly appreciated.

Appendix L. Sustainable architectural design criteria by category to consider in Framework - Phase (2) (1/4) (Moreno, et al., 2017).

Categories:		Sustainable architectural design requirements (architectural scale)
Sort of variable	Sustainable design variable	
Natural (environmental)	Sustainability of the place and outdoor environmental quality	1. Assessment of biotic and abiotic resources of the place and analysis of the equipment and urban infrastructure and land use
		2. Protection and restoration of the habitat including the avoidance of protected areas
		3. Wind control
		4. Rainwater and flood control
		5. Reduction and mitigation of heat islands
		6. Reduction of light and noise pollution and from bad odors
		7. Prevention of pollution from construction and maintenance
		8. Right orientation and placement of the building
		9. Management plan of external works
		10. Landscape protection and erosion control
	Regional priority (urban scale)	1. Community management and participation to develop or modify urban development plans
		2. Priorities and needs of the population
		3. Infrastructure services, urban equipment and services ecological in nature
		4. Consider the local uses and customs in design and planning
		5. Inclusive design (disabled people and with special needs)
		6. Offer suitable air quality in the cities (quantifiable)
		7. Regional and global energy reduction by using clean renewable alternative energies with low carbon footprint in the cities
		8. Advantages and opportunities for economic development for the zone (advantages and opportunities for business, government and citizens)
		9. Prevision and provision of use of land
		10. Plan of urban mobility and interconnectivity, preferably for pedestrians, with ecologic transport and low energy consumption
		11. Sustainable management of parks and garden in the cities (reforestation and greater carbon sequestration)
		12. Integral management of city waste, including construction waste
		13. Planning of durability and service life of components and buildings. Information useful for the calculation of carbon footprint of the construction materials

Appendix M. Sustainable architectural design criteria by category to consider in Framework - Phase (2) for the architectural scale (2/4) (Moreno, et al., 2017).

Categories:		Sustainable architectural design requirements (architectural scale)
Sort of variable	Sustainable design variable	
		14. Preservation of land, air and water in the cities
		15. Prevention and mitigation of risks in the cities
		16. Avoid places vulnerable to risks (e.g., flooding or protected such as natural reserves. Review and consult the Plan and Programs of Urban Development of the place)
		17. Analysis of urban equipment and infrastructure (to find out the impact range of the project), (for instance for a possible arrival in bicycle or motorbike, or prevent bad odors, noise, or light pollution). Of course, to improve public services in the zone.
		18. Erosion control and management plan for the landscape around the place. (Proposal to prevent erosion during and after construction), (gardening proposal using endemic vegetation, adequate for winter and summer, depending on the building orientation, weather and sort of construction).
		19. Transport alternatives in the place: (consider parking areas for bicycles and motorbikes, as well as accesses and routes). Includes the strategic assessment of transport, safe, comfortable and attractive streets, bike lanes and improvement to ecologic low-energy public transport.
Human (Social)	Indoor environmental quality	1. Air quality optimization, including moisture control
		2. Avoid tobacco smoke
		3. Use of materials and finishes of low toxic emissivity
		4. Management plan for the quality of air during construction, use and maintenance of the building
		5. Air quality verification
		6. Thermal comfort (both active and passive)
		7. Lightning comfort (both active and passive)
		8. Acoustic comfort
		9. Bad odor control
		10. Optimal visual relief
		11. Prevention of vibrations in structures and latticework
		12. Control by occupation and ergonomics
	Historic value of the building	1. Intervention of the specialist in architectural heritage and landscape
		2. Preliminary research of the Historic building
		3. Research on advanced knowledge about energy in the building
		4. Research on advanced knowledge about diagnosis tests in materials and forms of degradation
		5. Research on advanced knowledge about diagnosis studies and structural monitoring
		6. Reversible intervention in preservation
		7. Compatibility of expected use and its benefits
		8. Structural compatibility regarding the existing structure
		9. chemical and physical compatibility of mortars and other restoration materials
Technologic	Location, transport and mobility	1. Location for the development prioritizing neighborhoods
		2. Priority of use of land according to low-carbon planning

Appendix N. Sustainable architectural design criteria by category to consider in Framework - Phase (2) (3/4) (Moreno, et al., 2017).

Categories:		Sustainable architectural design requirements (architectural scale)
Sort of variable	Sustainable design variable	
		3. Diversify and density the uses of land (compaction)
		4. Accessibility to transport routes
		5. De-motorization of transport (bicycles)
		6. Reduction of parking for private vehicles
		7. Use of eco-fuel vehicles
		8. Preference for the use of public transport systems
		9. Improvement of transport infrastructure (transport and intelligent and sustainable mobility)
	Materials, waste and resources	1. Recollection and storage of recyclable products
		2. Reuse of waste from constructions and demolitions
		3. Reduction of impacts from the materials' life cycle analysis
		4. Use of environmentally certified and endorsed materials (low environmental impact and low carbon emissions)
		5. Avoid the use of materials that surpass toxic contents
		6. Design and build to deconstruct, not to demolish
		7. Use of recyclable and reusable, biodegradable and natural materials
		8. Use of materials preferably ceramics over metallic and polymers
		9. Reduction of building volumes and architectural spaces
		10. Use of locally-produced materials
		11. Use of durable materials
		12. Reduction of waste and refuse over the entire life cycle
		13. Suitable management of hazardous waste
		14. Reuse of buildings, components and installations
		15. Flexible design
		16. Recycle and reuse of wastes
		17. Separation and rating of wastes and rejects over the entire life cycle of the building included its correct final disposition
	Innovation	1. Use of nanomaterials to optimize some components and construction systems
		2. Automation of some systems and installations
		3. Use of new construction materials and systems
		4. Implementation and use of parametric design
		5. Implementation and use of digital construction in the building or its parts
		6. Life cycle design
		7. Durability and service life design
		8. Use of new low-carbon models and methods in integral urban-architectural projects
Economic	Energy efficiency	1. Reduce the use of energy both indoors and outdoors
		2. Optimize energy performance, actively or passively
		3. Use of advanced technology to measure and monitor energy
		4. Cover the totality of demand in the building
		5. Use and production of renewable and alternative energies

Appendix O. Sustainable architectural design criteria by category to consider in Framework - Phase (2) for the architectural scale (4/4) (Moreno, et al., 2017).

Categories		Sustainable architectural design requirements (architectural scale)
Sort of variable	Sustainable design variable	
		6. Improvement in the use of refrigerants and related supplies
		7. Use of green energy and apply carbon offsets
		8. Building orientation for gain and loss of heat
		9. Optimization of the envelope and sealing of the building
		10. Provide natural lightning
		11. Provide natural ventilation
		12. Passively ventilate, heat and cool
		13. Natural control of moisture in the building
		14. Application of saving systems and equipment to clean, illuminate, ventilate, cool or heat
		15. Automation of some active illumination systems, air conditioning, heating, security, firefighting systems, etc.
		16. Optimize the performance of the systems both passive and active
		17. Use of saving equipment and apparatuses
		18. Installation of reducers and capacitors in electric installations
	Water efficiency	1. Reduction of potable water use indoors and outdoors
		2. Control in water consumption measurement
		3. Use of water in passive climate conditioning
		4. Use of saving technologies in the installations
		5. Reuse of gray water
		6. Waste water treatment
		7. Catchment and use of storm water
		8. Efficiency and minimal use of installations
	Quality of the building service	1. Estimation of service life
		2. Durability plan for the building
		3. Operation and use manual of the building
		4. Maintenance manual of the building
	Management	1. Intervention of a specialist certified in design and construction
		2. Adapt new projects to plans on resilience to the local climate change
		3. Establish the objectives of the building functionality over its entire service life
		4. Define specialized working groups during the design
		5. Foresee measuring and monitoring over service life including assessment of costs by life cycle and analysis of environmental impacts by life cycle
		6. Environmental management over the construction phase including waste and residue management

Appendix P. Mapping of Environment Impacts assessed by LCA methods (Ali, et al., 2014).

Category	Sub-categories/ method terminology	Category	Sub-categories/ method terminology
Global warming	Global warming	Solid waste	Solid waste
	Climate change		Bulk waste
Embodied energy	Cumulative energy demand		Slags/ashes
	Embodied energy LHV	Hazardous waste	Hazardous waste
	Consumption of energy	Radioactive waste/radiation	Radioactive waste
Nuclear fuel depletion	Nuclear energy		Radiation (ionising)
Fossil fuel depletion	Fossil fuels	Ozone depletion	Ozone layer depletion (ODP)
	Non-renewable energy	Acidification	Acidification
	Oil and gas		Soil acidification
Mineral resource depletion	Minerals (resources)		Terrestrial acid/nutri
	Minerals and fuel	Human toxicity	Human toxicity
Mineral resource depletion and fossil fuel depletion	Depletion of reserves		Human toxicity air
	Abiotic depletion		Human toxicity water
	Resources (all)		Human toxicity soil
Photo-chemical smog	Respiratory organics		Carcinogens
	Photochemical smog		Life expectancy
	Photo-chemical oxidant formation		Severe morbidity
Eutrophication	Eutrophication		Morbidity
	Nutrification	Indoor environment quality	Indoor environment quality
Ecological diversity	Biodiversity		Indoor air pollution
	Species extinction	Respiratory Inorganic	Resp. inorganics
	Ecological diversity		Particulate matters
Land transformation and use	Land use		Urban air pollution
	Land occupation	Eco-toxicity	Eco-toxicity
	Energy land		Water toxics/aquatic eco-toxicity
	Cropping land		Fresh water aquatic eco-tox.
	Grazing land		Eco-toxicity water chronic
	Forest land		Eco-toxicity water acute
	Consumed land		Marine aquatic eco-toxicity
	Timber impact		Terrestrial eco-toxicity
	Crop growth capacity		Eco-toxicity soil chronic
	Consumption of biotic resources	Human toxicity and eco-toxicity	Heavy metals
	Wood growth capacity		Pesticides
	Fish and Meat production	Nuisance	Noise (traffic)
Salinisation	Soil Salinisation		Severe Nuisance

Appendix Q. Structured Interview, For Model preliminary validation (Author, 2019).

Structured Interview (4): **Date:** ____________

Validation of Conceptual Framework integrating GBRS, LCA and BIM for Efficient AEC activities

Participant's Name:

Title:

Current position:

Discipline: **Highest level of academic achievement:**

The Organization you are currently working for:

The conceptual framework illustrated hereafter was developed by accumulating a set of integrated frameworks (collected from literature review and case studies) joining GBRS with LCA, LCA with BIM, GBRS with GBRS and all GBRS, LCA and BIM together. The main purposes are to enhance the adoption of the three methods in the Egyptian AEC activities and to use the benefits of each method to overcome the shortcomings of the others.

Please review the attached 'Conceptual Framework' which is intended for integrating GBRS, LCA and BIM for Efficient AEC activities, and answer the following questions;

Q1 Please provide your feedback.

Q2 How feasible do you think the framework is?

Q3 How effective can it be regarding the enhancement of adopting Sustainability and Efficient Buildings measures to the Egyptian AEC measures?

Q4 What are the pros and cons of the proposed model?

Q5 How could it be developed?

Q6 Any other comments?

Your cooperation is highly appreciated.