Application of BIM in Sustainable Design and Its Benefits for Proprietors

Master Thesis

International Master of Science in Construction and Real Estate Management

Joint Study Programme of Metropolia UAS and HTW Berlin

Submitted on 12.09.2018 from

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Acknowledgment

I express my deepest gratitude to God-Parvardegar for his grace and mercy to me for the successful completion of my dissertation, may his name be praised forever.

I would like to dedicate to my parents, my mother whose love and kindness have been always the sunlight of my life and to my father, whose soul is inspirational to entire in my life. Furthermore, I should be grateful

for having family and friends for their commitments throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

I would like to highly appreciate my first supervisor Prof. Dieter Bunte. The door to Prof. Bunte office was always open whenever I ran into a trouble spot or had a question about my research or writing. He consistently allowed this paper to be my own work but steered me in the right the direction whenever he thought I needed it

I would also like to thank my second supervisor Prof. Eric Pollock for supporting my Master thesis research and I am honored to work with him who always tried to guide me patiently in this way. His guidance helped me in all aspects of research and writing of this thesis.

Neda Emami

12.09.2018

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University of Applied Sciences

International Master of Science in Construction and Real Estate Management Joint Study Programme of Helsinki Metropolia UAS and HTW Berlin USA

Conceptual Formulation of the Master Thesis Date 24th April 2017

Master Thesis for Ms. Neda Emami Koorabbasloo
Student number: 0557523

Topic: "Application of BIM in Sustainable Design and Its Benefits for Proprietors"

Summary

My main goal to select this subject is to research s Application of BIM in Sustainable Design and Its Benefits for Proprietors. This research will discuss the Application of BIM in Sustainable Design and Its Benefits for Proprietors, which combines both Building Information Modelling (BIM) and concepts in Sustainable Design process to increase the advantage for owners.

In reality, Building Information modeling and sustainable design are a new kind of production beginning from with an idea, then to feasibility, programming, initial research, making plans, initial investigation layout, and production, handing over, operation, and ending with demolition or maintenance of the construction. However, in the overall process, a preliminary investigation is the most crucial component due to the fact that different essential parts are designed according to it. Usually, the research procedure is completed with a purpose to acquire the required documentation for the final purposes. But for sustainable layout, there are a few elements that during the design stages should be taken into account which include electricity efficiency, environmental issues and etc.

In this thesis, the requirements of experts, owners and their expectations regarding BIM are studied. The determinant factors for BIM utilization by owners and their respective decisions are identified. After understanding owners' basic concerns of cost, time, and quality over the lifetime of the project, interviews with experts of both the design and construction phases were conducted. During the interviews the benefits of BIM for owners were emphasized, recommendations of interviewees to maximize those benefits were analyzed through academic resources and the respective comments of the author were outlined. In the end, the identified factors, which are extracted from

interviews, and their surroundings are discussed. This thesis eventually would be helpful for the process of decision making for owners, enabling the analysis of the most important factors recognized in this research, as to decide whether or not to use BIM in a project.

Introduction

"BIM has been playing an important role in designing efficient buildings with efficient methods, not only during the design and construction process but also through the whole lifecycle of the building."[1]

Nowadays, the architectural method has been affected by the significance efficiency of BIM around the word, which has led to a crucial controversy between traditional architectural method and BIM design process.

"The architect was traditionally the master builder and the profession's existence date back to the third millennium before Christ (B.C) however, these days the architects are supposed to seek out society's current needs and propose a solution to address those concerns." [2]

The architect is mostly involved in the design phase in the preliminary steps of the contraction phase, therefore, any updates or paradigm shifting in BIM method such as new utilization soft wares could affect their method and consequently requires them to add up to the latest changes which bring about some concerns and challenges and this issue will adapt to the architects burden.[3]

There has been a significant growth in applying BIM throughout the whole life cycle of the property from the inception to maintenance and even demolition that highlight the importance of adapting to its architectural and visualization updates in the design process. This will include the efficiently in the area such as:

Saving in cost and money, quality, Sustainability and overview the whole process. The objectives: how is BIM effecting the design process? Recent digital technologies and breakthrough outs have raised the question of the role of an architect in design step and its dominance in BIM method.

Research objectives

The main is a focus to application of BIM in sustainable design had several benefits for owners and the area in sustainable design contents sustainability aspects, economical approach and environmental direction also follow social requirements to fulfill the process, in sustainability

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[1] (Eastman, 2008)
[2] (Sacks, R., Treckmann, M., & Rozenfeld, O., 2009)
[3] (Hukkinen, 1999)

design normally improvement describe as energy saving and increase energy efficiency and enhance environmental impacts, but for existing housing the first issues that come in the preference is the residents of the building and how they won't deal with situation of site because energy efficiency usually instructed by municipal policymakers, by the way, one of the important privileges of sustainable and construction is to increase energy efficiency and save energy but for this purpose there is also risk and uneconomical ending practically high cost for investors in order to reach to the goal.

Questions to be answered for this research are:

- What are the benefits of using BIM for companies?
- What are the impediments which prevent owners from applying BIM in the projects?
- What are the significant elements involved in the application of BIM in sustainable design processes?
- What kind of tools and platforms are available and have the capacities to monitor different approaches of the sustainable aspects and BIM in the projects?
- Is there any profit in using BIM in sustainable design for owners and it is beneficial for the society and the environment?
- How great is the value of BIM for owners and how can it be translated into sustainability?

Methodology

The research will be divided into three phases, the first one will be a literature review to investigate the case of BIM and sustainability, then the thesis method will be displayed to help understand BIM and sustainability with the help of interviews (with professional BIM workers, owners) and case studies, which will lead to the 3rd phase that is the analysis of all those methods to help answer the research questions

The BIM process and sustainability in the construction industry from various perspectives concerning its use by architects, engineers, contractors, and owners will help accomplish the objectives of this research with each step discussed.

The questions of the investigation will be addressed at the end in form of a conclusion and recommendations for future investigations.

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Timescales

Date	Responsibility
24th April, 2017	Submission of the conceptual formulation
2nd May, 2017	Starting the literature review
2nd September, 2017	Data collection (first draft)
1st January, 2018	Data analysis (second draft)
2nd May, 2018	(final draft)
15th May, 2018	

References (Access date: 20th April 2017)

1. Christopher James Keegan, May 2010, BUILDING INFORMATION MODELING IN SUPPORT OF SPACE PLANNING AND RENOVATION IN COLLEGES AND UNIVERSITIES, Polytechnic Institute in Partial Fulfillment of the Degree, <https://www.wpi.edu/Pubs/ETD/Available/etd-042910 162540/unrestricted/CKeegan_Thesis_BIM.pdf>
2. Corey Cattano , Dec 2010, IDENTIFYING BARRIERS TO ADDRESS DURING THE DELIVERY OF SUSTAINABLE BUILDING RENOVATION PROJECTS, http://etd.lib.clemson.edu/documents/1306857767/Cattano_clemson_0050M_10991.pdf>
3. Graphisoft, 2005, White Paper Energy analysis with ArchiCAD A sustainable future needs sustainable architecture, Graphisoft White Paper Energy analysis with ArchiCAD, <http://www.stanford.edu/group/narratives/classes/0809/CEE215/ReferenceLibrary/BIM%20and%20Building%20Simulation%20Research/Energy_Anal ysis_with_ArchiCAD9.pdf>
4. Jon Southard & Torto Wheaton, Oct 2009, Renovating Green, BOMA International, <http://www.boma.org/research/Documents/Find%20a%20Resource/BOMA%20renovating%20 green-FINAL.pdf>

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Abstract

This research will discuss the Application of BIM in Sustainable Design and Its Benefits for Proprietors, which combines both Building Information Modelling (BIM) and concepts in Sustainable Design process to increase the advantage for owners.

In reality, Building Information modeling and sustainable design are a new kind of production beginning from with an idea, then to feasibility, programming, initial research, making plans, initial investigation layout, and production, handing over, operation, and ending with demolition or maintenance of the construction. However, in the overall process, a preliminary investigation is the most crucial component because different essential parts are designed according to it. Usually, the research procedure is completed with a purpose to acquire the required documentation for the final purposes. However, for sustainable layout, there are a few elements that during the design stages should be taken into account which include electricity efficiency, environmental issues etc.

BIM is a widespread system for reconnaissance of tasks' traits earlier the production. The usage of BIM assists proprietors, engineers, architects, and contractors to generate a common platform to explore all the components, test the characteristics and overall performance for the alternation and correction before the construction.

In this thesis, the requirements of experts, owners and their expectations regarding BIM are studied. The determinant factors for BIM utilization by owners and their respective decisions are identified. After understanding owners' basic concerns of cost, time, and quality over the lifetime of the project, interviews with experts of both the design and construction phases were conducted. During the interviews the benefits of BIM for owners were emphasized, recommendations of interviewees to maximize those benefits were analyzed through academic resources and the respective comments of the author were outlined. In the end, the identified factors, which are extracted from interviews and their surroundings, are discussed. This thesis eventually would be helpful for the process of decision making for owners, enabling the analysis of the most important factors recognized in this research, as to decide whether to use BIM in a project.

Keywords: Building Information Modelling, Sustainable Design, Benefits of BIM.

List of Abbreviations

2D	Two Dimension
3D	Three Dimension
AEC	Architecture Engineering and Construction
BREEAM	Building Research Establishment Environmental Assessment Method
CAD	Computer Aided Design
CAFM	Computer-Aided Facility Management
CO2	Carbon dioxide
EU	European Union
FM	Facility Management
HVAC	Heating, Ventilation, Air Conditioning
ISO	International Organization for Standardization
IES	Integrated environmental Solution
IFC	Industry Foundation Classes I
FMA	International Facility Management Association
ISO	International Organization for Standardization
LEED	Leadership in Energy and Environmental Design
MEP	Mechanical, Electrical, and Plumbing
USGBC U.S.	Green Building Council
VE	Virtual Environment
ROI	Return on Investment

CHAPTER 1: INTRODUCTION

1.1 Introduction

"*BIM has been playing an important role in designing efficient buildings with efficient methods, not only during the design and construction process but also through the whole lifecycle of the building.*"[1]

Nowadays, saving in cost and money, quality, sustainability and outline of the whole process. Additionally, the AEC industry has been implementing a different method to design, execute and operate buildings, by developing tools that allow the interoperability of all the team members, during any phase of the project. This method is known as a Building Information Modelling (BIM) and even though the concept has been around for a while, it was in the 2000s that actually started to be applied in construction projects and academia.[2]

Having introduced the concept of Sustainability and Building Information Modelling, the main goal of this investigation can be established, is the integration of sustainable practices with BIM concepts. Since it is well known the influence of these practices from an early design stage of a project, the research will focus on existing buildings that follow green practices and implementation of a BIM methodology, due to the lack of investigations on the matter.

In this paper, the majority of construction participants, challenges of construction properties are under focus. Owners as consumers of the construction industry, may not be enough familiar with the benefits of BIM and therefore may tend to do their construction works in the old manner of 2D which has been examined by them during years. The BIM process would be great for huge projects rather than a small project and the BIM needs more time to introduce and prove for proprietors. [3]

Sustainable architectures are a form of blueprint and have a plan regarding ecological environments and exploiting energy performance for synthetic surroundings for healthier environments, constructed with sustainability characteristic with the highest adaptability to it surrounding's and overall environment, in addition, sustainable structure provides conditions that might be bendy with the lowest harmful impact on the ecology and might be demandable concerning relevant mechanisms.

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[1] (Eastman 2008)
[2] (Ilhan, B., & Yaman 2013)
[3] (Abidin 2010)

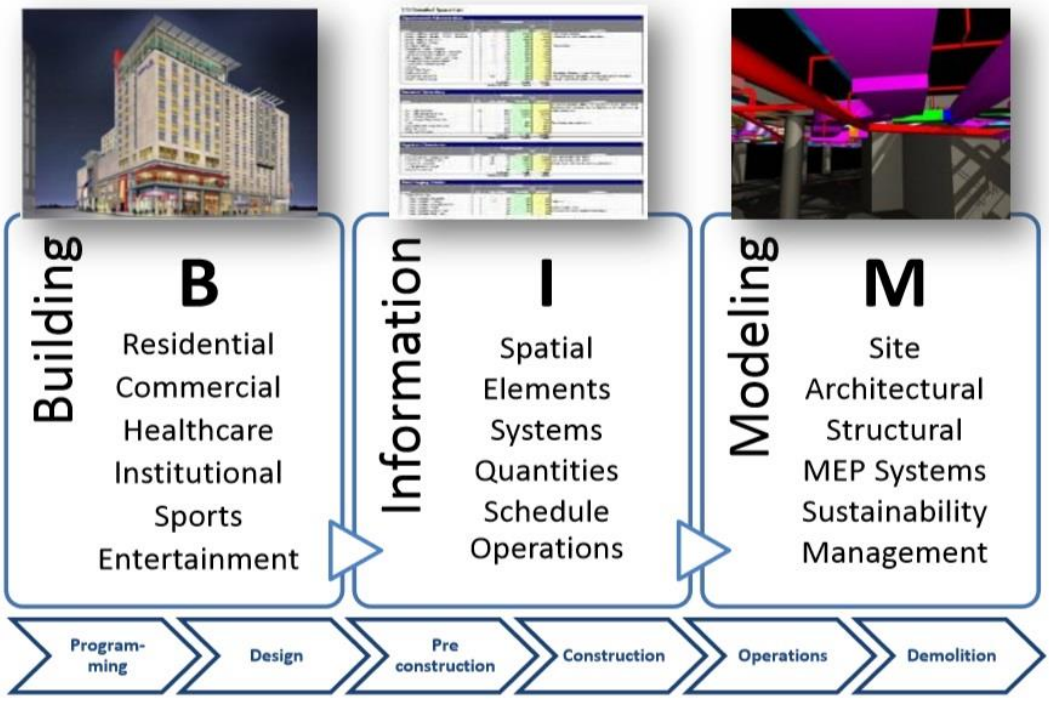


Figure 1- A Visual Representation of BIM Concept[4]

To have sustainable structures in construction it is ought to keep in mind the following apprehensions:

- Utilize the fundamental human contentedly
- Proficient effect on planning
- Design ought to consider the reduction of waste aspect as much as possible
- Reduce as much as possible building maintenance cost
- Present nature with a high value during the design for more development

1.2 Scope of Work

The scope of this research is a conjunction between BIM and sustainable design in Europe. The present proprietors and organizations are hoping to make sense of the best connection amongst BIM and reasonable outline that could be of favorable position to them and has numerous advantages for the earth and proprietors.

[4] (Salman Azhar, Michael Hein and Blake Sketo n.d.)

These days, manageability is a worldwide pattern because of it being one fundamental answer for environmental change; the world is on an opposition to lessen gas outflows and any destructive impression exercises that could influence the earth gravely. It is, truth be told, a ticking time bomb, and there will be a period when the acknowledgment that it is past the point of no return will come except if the move is made at this point. The manufactured condition and development industry has its offer of effect and is so far a significant hurtful one. The development of structures has a serious result on the earth; it is an essential purchaser of land and crude materials and makes an unnecessary measure of waste. Feasible development has as of late been perceived as a standout amongst the most imperative responses for structures ozone-depleting substance discharges and utilization of plant-based created power.[5]

1.3 Aims and Objectives

The requirement for use of complex developments inside a restricted skirt of time and spending plan has raised the requirement for a more unpredictable and propelled strategy for development instead of the customary approach.

At the end of the day, keeping in mind the end goal to abstain from outperforming the confinements, we have to consider a more coordinated and innovation included technique for configuration venture and in addition the assembling advance in the development procedure. Thus, an outlook changing from two-dimensional (2D), paper-based outline to a three-dimensional (3D) geometric PC created model of the working in BIM strategy is an imaginative upgrade for the business and business. This will prompt amplifying the part of the planner as a general venture organizer of the geometric model, which requires changes to practice and task understanding.

From one viewpoint, numerous experts endeavor to upgrade society's colleague about BIM, the compositional, and different advantages while a few scholastics consider that working in a BIM-based strategy may take away the spotless and adaptable innovativeness and creative energy of the brain of a draftsman.

There is yet an awesome number of experts who consider BIM to be a documentation apparatus; thus, they utilize it in the later stages when they are finished with planning

[5] (Alsaadi n.d.)

in their own strategy. It is significant to highlight on BIM as outstanding amongst other techniques to date for the most productive design. A secluded framework is proposed in a BIM-based strategy in which the undertaking profits by both BIM and supportability are coordinated together into one novel and extensively efficient blend. In this way, Automation of the plan and assembling procedure can be considered as a powerful answer for address numerous destinations viewing issues, for example, erection mistakes, misuse of materials, and therefore a low quality in executions. At the end of the day, a secluded framework can advance the assembling, construction and establishment ventures of the development procedure, which saves money on the assets and help dodge the flighty mistakes and apply a more exact, and point by point approach, for example, measured method.[6]

1.4 Research Questions

- What are the benefits of using BIM for companies?
- What are the impediments, which prevent owners from applying BIM in the projects?
- What are the significant elements involved in the application of BIM in sustainable design processes?
- What kind of tools and platforms are available and have the capacities to monitor different approaches of the sustainable aspects and BIM in the projects?
- Is there any profit in using BIM in sustainable design for owners and it is beneficial for the society and the environment?
- How great is the value of BIM for owners and how can it be translated into sustainability?

1.5 Methodology

The research will be divided into three phases, the first one will be a literature review to investigate the case of BIM and sustainability, then the thesis method will be dis-

[6] (Wei, W., & Issa, R. R. 2014)

played to help understand BIM and sustainability with the help of interviews (with professional BIM workers, owners) and case studies, which will lead to the 3rd phase that is the analysis of all those methods to help answer the research questions

The BIM process and sustainability in the construction industry from various perspectives concerning its use by architects, engineers, contractors, and owners will help accomplish the objectives of this research with each step discussed.

The questions of the investigation will be addressed at the end in form of a conclusion and recommendations for future investigations.

CHAPTER 2: LITERATURE REVIEW

2.1 Sustainable Design

This chapter seeks to discuss and review previous research studies on the concepts of Sustainable Design and BIM in the construction industry and business impact on the owner concerning this topic **(Application of BIM in Sustainable Design and Its Benefits for Proprietors**) and having an understanding of the concept through definitions.

2.2 Definition of Concepts

There has been increased concern over sustainable development in the world because of happenings around the world that affect the environment. The European Commission (2001) noted that the impact of the built environment constitutes the biggest number of greenhouse gas emissions, which is about 40% in terms of energy consumption. The impact of climate change around the world is very convincing and eminent[7]

The Kyoto protocol has it's focused on the reduction of greenhouse gas, the Agenda 21 document on Earth Summit in 1992 and other treaties show much concern about protecting and preserving the environment for the future; especially using sustainable means (sustainable development principles)[8] Sustainability or Sustainable development (SD) concept is seen and acknowledged globally as a concept that will address the negative impact on the present and future generation. There has been different views and definition of these words.

2.2.1 Sustainability

Sustainability is defined in terms of economic growth that meets the needs of current generations without compromising the willing-full opportunity and potentials of the future generation to meet their needs. In addition, defines sustainability as a concept used in corporate society in developing the triple bottom line principle. The principles which are social, environment and financial performance, these principles are connected to the concepts of sustainable development goals. Cooper, (2002) noted that these principles are equally important and interrelated. The acceptability of the term sustainability is increasing across the globe, including the corporate organization,

[7] (IPCC, National Greenhouse Gas Inventory Guidlines 2006)
[8] (Parkin 2000)

which uses it to show their use of best practices. Young, (1997) defines sustainability as an extension or a measure of how people lived well in harmony with the environment by having regard to the welfare of the people, the needs of the future generation and conserving the environment. Young, (1997) also describes sustainability in terms of society, the ecosystem and economy, which an impact on one of these terms will affect the remaining two because these terms are interrelated. Sustainability is defined as a condition that allows human existence to continue, and this aim and goals will be archived through sustainable development principles. Nevertheless, the human race and its existence have only been insufficient; as the quality of life that meets our needs is also needed[9]

Sustainability in this context refers to the capacity of the environment to meet the basic requirements for the existence of both living and non-living things of social, cultural, ecological and economic approaches in a way it will not hinder or limit the ability for both generations to meet its needs in all areas of the environment. However, human needs must be balanced to be able to carry the capacity of the planet and to protect the capacity to meet the future generation's needs. Subsequently, there is also the need to achieve a measure of economic equity among persons, communities, and generations, as well as social effort, must be made to ensure the respect for human rights and dignity; thus, even in the areas of distributions of wealth in terms of access and opportunities and an increase in prosperity for everyone[10]

2.2.2 Sustainable Development

The sustainable development concept has been generally accepted globally, but with different stakeholders having different views and ways of defining (SD). Thus, the most acknowledged and adopted definition is the Brundtland definition of (SD) which defines sustainable development as ‘‘*a developmental method or concept that meet the present generation's needs without restraining or compromising the abilities of the future generations to meet their own needs,"*[11] This simply means that the principal goal of (SD) is meeting the present generation needs in such a way that it will not endanger their potentials and the future generation capabilities to specially meet their needs.

[9] (Barron 1997)
[10] (C. d. Plessis 2001)
[11] (sustainable-development, 1987)

The global action plan and promotes ways of achieving sustainable development urges government, organizations and local government to define and adopt a framework for better sustainable development. Irrespective of the definition of (WCED), different stakeholders still have different definitions. Bartlett, (2006) noted that the concept is a controversial concept and is used in contradicting ways[12]

Sustainable development as safeguarding the good quality of life for present and future generations. This can be archived in four ways: Effective and prudent utilization of natural resources, proper protection of the environment, maintenance of good economic growth and social gains that reflects the wants and need of all [13]

However, there exist some consensus on the themes that encompass the concept of sustainable development. This is viewed from a holistic perspective, i.e. it is agreed that sustainable development comprises economic, social and environmental dimensions.

In view of the above definitions of (SD), sustainable development may be defined as improvement in technologies, socials, and the economy in the present living condition for a long-term process in order to secure the natural environment. However, this thesis will adopt the Brundtland definition of (SD) and it will be viewed in terms of preservation and protection of the environment, avoid resource depletion and effective resource utilization for the development and advancement of the present generation without limiting the development and advancement of future generations. According to du Plessis (2006) noted that in order to move towards a sustainable world, adequate steps must be taken, and be more drastic and idealistically in our visions.

According to the modified depiction of three pillars of SD by Lehtonen, (2004), the author noted that human social activities must be maintained within environmental limitations, and the economic activities should be carried out in order to serve all human society [14]

[12] (Our Common Future 1990)
[13] (Masood 2007)
[14] (Elkington 1997)

2.2.3 Sustainable Construction

The need for a responsible construction in attaining sustainability gives birth to the concept of sustainable construction. This concept has evolved as a project participant's looks for an alternative environmental means to carry out construction activities concerning sustainability principles. This concept describes the importance of sustainable development in the construction industry. The emphasis of this master thesis is on this concept. However, there are many definitions regarding the concept of sustainable construction. In most cases, it is defined as zero impact construction; this means that the construction activities have no or less negative environmental, social and economic impact.[15]

Defines sustainable construction as constructing healthy structures, facilities, or a built environment by using resource-efficient and Environment Society Economy Ecologically based principles.

Sustainable construction as a whole lifecycle process in construction, it defines sustainable construction as the application of sustainable development principles to whole or entire construction life cycle from the extraction and production and beneficiation of raw materials to planning, designing and construction of the structure to the demolition or deconstruction and management of its waste[16]

This process is aimed at restoring and maintaining the relationship between the built environment and nature, thereby creating shelters that sustain human dignity and aid economic equity. *"sustainable construction as a part of a sustainable development that includes the whole life cycle of construction activities starting from the design, tendering, material selection, site planning, and waste minimization"*

UNEP, (2003) views sustainable construction as the use or promotion of energy efficiency in building, management of construction activities and demolition waste and environmentally friendly materials. Also, Shen et al., (2010) noted that the sustainable construction practice involves different methods of carrying out construction projects or activities that have less impact on the environment, this method includes prevention

[15] (Charles J. Kibert 2000)
[16] (C. d. Plessis 2001)

of waste production, waste management and beneficial to society and also been profitable to the construction company.

Kilbert stated that sustainable construction is aimed at describing the construction industry's responsibility for attaining sustainability. The OECD on its description of sustainable construction defines sustainable construction in terms of sustainable building that have less adverse impacts on the natural and built environment, in terms of the buildings themselves, their immediate environs and as well as the broader regional and global setting.[17]

The sustainable building can be defined as construction practices that strive for integral quality, i.e. economic, social and environmental performance, in a broader way. However, rational utilization of natural resources and effective management of construction materials will enhance scarce resources, saving, energy conservation and improving environmental quality.

Tesserae et al, (2010) define sustainable construction as a responsible supply operation and maintenance of buildings, which meets the needs of their lifespan with little negative environmental impacts and encourages economic, social and cultural progress.[18] However, literature by Lee, (2008) acknowledged that the Hong-Kong housing describes sustainable construction through environmental, social and economic sustainability.[19]

- Environmental sustainability involves creating, repairing and management of our facilities or structures with the effective and efficient use of natural resource, reducing waste production by effective utilization of a natural resource, preventing negative effects on the environment by minimizing the impact on the environment.
- Social sustainability: this deal with encouraging social cohesions and creates a healthy and safe environment for all by responding to people's needs throughout the construction process.
- Economic sustainability: deals with increasing profitability through effective utilization of all construction resources, e.g. water and energy, labor and other

[17] (Charles J. Kibert 2000)
[18] (MustafaYılmaz and AdemBakış 2015)
[19] (Edwin ChanGrace K. L. Lee 2008)

materials, and building cost-efficient structures that is fit for purpose or meets the needs of the users by minimizing the operating costs and extending the service life of our structure through effective and prompt repairs and maintenance systems.

2.2.4 Principles of Sustainable Construction

There are six concepts or principles proposed by CIB, (1996) and Miya Kate, (1996) for Sustainable Construction. These principles are essential to achieving success in sustainable construction process or practices used in the six concepts, which are:

- Creating a healthy and nontoxic environment
- Using renewable and recyclable materials or resources,
- Minimizing resource consumption Maximizing resource reuse
- Emphasis on quality when carrying out construction activity and Protecting the natural environment[20]

There are several reasons why an owner or program manager may select to practice sustainability including:

- Reduced costs
- Reduced liability
- Efficient & effective management & disposal of materials
- The enhanced image in communities
- Corporate responsibility short-term & long-term[21]

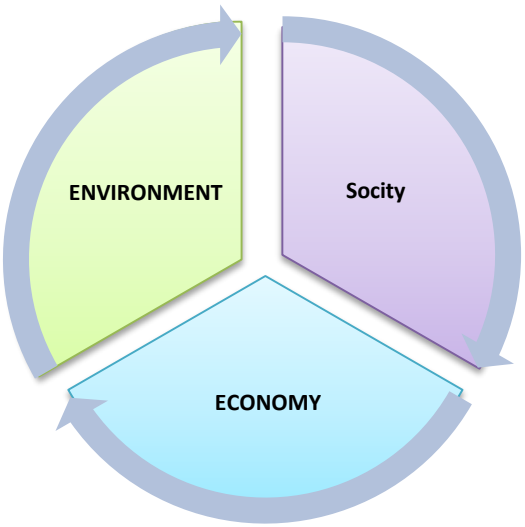
[20] (Susan Dzifa Djokoto, Kumasi Polytechnic, Faculty of Built and Natural Environment, 2014)
[21] (Prieto, n.d.)

Environment

- Reduce-Recycle -Reduce
- Minimize depletion of natural resources
- Prevent pollution
- Land use
- Biodiversity

Society

- Fit for purpose
- Encourages local community
- Culture and heritage
- Encourage social cohesions
- Quality of life



Economy

- Whole life cycle cost
- Training/ education
- Value Engineering
- Meets the needs of the users

Figure 2- Triple Line Principle (Elements of Sustainable Construction)[22]

[22] (Mann 2011)

In analyzing the Triple Bottom Line Principles shown in the figure above for the benefits of sustainable construction. The Triple bottom line elements of sustainable construction are as follows:

Fitness for purpose: The constructed structure or facility should meet the need of users or society.

Encourages local community: consider the needs of local communities, engage the local community fully in the development process.

Encourage social cohesions: foster better social relations, providing equal opportunities for employing ethnic minorities, women and disabled people.

- Quality of life: Improve the quality of life now and for future generations,
- Culture and heritage: sympathetic to local styles of architecture, new developments to reflect the cultural and historical context of the area, enhance or preserve existing culture and heritage. Whole Lifecycle cost: whole life value or cost must be taken into considerations when constructing a facility or structure
- Training and education: provide training and education on SC subjects to project participant. Land usage: encourage mixed uses of land, encourage the use of most appropriate sites for development.
- Biodiversity: consider long-term impacts of construction on bio-diversity, Protect and enhance biodiversity, avoid threats to local environmentally sensitive sites, sites of special scientific interest and protected species.
- Prevent pollution: prevent/reduce the impact of emissions, minimize the risk of water pollution, and reduce air pollution.
- Minimize the depletion of natural resources: minimize use, maximize utilization, use of renewable materials, and avoid materials harmful to the environment and humans, Use of sustainably sourced materials.
- Reuse and recycle material, reduce the amount of waste sent to landfill, reduce the impact of waste.[23]

[23] (Mann 2011)

2.3 Awareness of Sustainable Construction Principles

The awareness of sustainable construction and sustainability creation arises as a result of construction industry or construction activities impact on the environmental, social, and economic as well as the need of not compromising the future generation ability to meet its needs. Thus, the construction industry impact on the environment is huge.

According to Son et. al, (2011); Van Bureren and De Jong, (2007); Akbiyikli et al, (2012) and Berardi, (2013) Construction industry worldwide consumes natural resource, for example, it consumes about 40% of total energy produced, consume 40% of raw materials and 25% of timber, 16% of water consumption; it generates 30-40% of waste and it accounts for 35-40% CO2 emissions.[24]

In line with this consideration, the construction industries have influenced both negatively and positively, the above authors have clearly stated these impacts on their works and because of these impacts construction industries have in our societies; there has been a global level of awareness sustainable construction principles as shown in various publications. For instance, DETR, (2000) in the UK strategy for sustainable construction, declares promoting awareness and understanding of sustainable construction as its objectives. In addition, the awareness of sustainable construction needed to be increased.[25]

However, the need to increase awareness is because of lack of awareness because this might be because of some factors such as lack of clear sustainability benefits, lack of clear conceptualization of sustainability, traditional ways of construction that hinders sustainable construction, lack of integration of sustainable concepts into educational and training program. According to Zainul- Abidin, (2010) sustainable construction awareness is the beginning to achieve sustainable construction practice because knowledge is important to progress from just being aware of the implementation of sustainable construction approaches. However, as awareness of sustainable construction needed to be increased and the concept is having a global recognition, tools or grading systems have also emerged, e.g. LEED, BREEAM, CABA, CASBEE, etc. The most developed countries also have their grading systems.[26]

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[24] (Yong Han Ahn , Annie R. Pearce , Yuhong Wang & George Wang 2012)
[25] (IPCC, National Greenhouse Gas Inventory Guidelines 2007)
[26] (Abidin 2010)

2.4 Barriers to Sustainable Construction

For effective promotion and implementation of sustainable construction principles by the construction industry, the obstacles or barriers that hinder its implementations and practice must be identified; most concerns about sustainable construction implementations are within the construction industry. A review of existing literature highlights four major barriers: implementation issues, market perceptions, information gaps and infrastructure issues.

2.4.1 Implementation issues

Traditional method and practice in the construction industry still focus on the recurring use of old methods and practice, e.g. repetitive use of building plans or architectural plans and the fast construction method, thus builders, project engineers and architects, their dedication is a quick fix and with the aims of making quick profit by reducing initial cost. By using few or limited builders, project engineers and architects, Nevertheless, incorporating whole life design method required for sustainable construction practice may be difficult and might make it difficult to build up a communal knowledge base that will extend outside individual projects.[27]

2.4.2 Market Perceptions

The perception of people in the market is a very big barrier in promoting and implementing sustainable construction principles, because of this misplaced perception, that there is no client or consumer demand with the need for sustainable projects.

However, if there is no perceived demand the project participant is not willing to build and deliver such projects, for example, many people might have some certain question such as how can we make a profit and what will it cost me or benefit me in achieving sustainable construction principles, even when most people know the benefit of sustainable are essential and enormous.[28]

[27] (Pinske, J., and Marcel D 2008)
[28] (Choi 2009)

2.4.3 Information Gaps

According to RICS sustainable construction, many industries are not able to get the message to the consumer and the industry as well as the impacts of sustainable construction on their living environments. More information is needed to relate the real and agreed meaning of sustainable construction to project stakeholders.

2.4.4 Infrastructures issues

Construction industry methods focus on standardized light-frame constructions, which have been a principal construction principle for ages. This method, which focuses on existing systems, code and permits compliance will slow down and hinders sustainable construction implementations.
However, CIB report publications 237 identifies eight main barriers to organization and management of the implementation of sustainable construction and are linked to each other:

- Insufficient data
- Market delay
- Professional and institutional inertia defending the status quo
- Lack of understanding of the problem among construction professionals
- Lack of communication between data sets that don't exist
- Lack of client “Buy in”
- Political insecurity (government electoral periods limit the horizon)
- Inadequate or defective vehicles for participation by the stakeholders[29]

OCED, (2002) the report emphasized barriers to improving building sustainability.
The report emphasized the lower level of the construction industry be distinguished by the dominance of small-scale firms which in most instances do not have the technical expertise which is needed to improve the energy efficiency of the building.[30]

[29] (Chrisna du Plessis (B.Arch 1999)
[30] (OECD n.d.)

2.5 Demerit and Merit of Sustainable Construction

Rayna, (2005) noted that the only demerit of sustainable construction is the high initial cost when applying sustainable construction principle to sustainable construction projects; the initial cost of the sustainable construction project is high compared to the unsustainable construction project.

However, this demerit in sustainable building construction at the beginning of a particular project can be expensive or costly as the initial project begins. In other words, this can be addressed using a life cycle analysis method that will lead to operating cost reduction as well as leads to increases in productivity. Sustainable constructions have many merits or advantage than the unsustainable construction.

According to Rayna, (2005) in implementing sustainable construction principles, there are numerous merits and benefits to gain or achieve: which includes social, environmental and economic merits and some of these benefits will be explained in more details using bullet points below:

Environment Merits: Some of the environmental merits include: minimized depletion of natural resources, reduce-recycle- reuse, prevent pollution, land use, biodiversity, and reduced energy and water consumption.

Economic Merits: The economic merits include lower maintenance cost, lower operating cost, and the ability of the project to meet the need of the users.

Social Merits: The social merits can be in terms of community and health merits that reduce liability, encourage social cohesions, a good quality of life and enhancing the user's comforts and health, fitness for purpose, preservation of culture and heritage.[31]

2.6 Benefits of Sustainable Construction

Nonetheless, from the foundation of the concept of sustainable construction, it is aimed at addressing a wide variety of social, economic and environmental subject. Sustainable construction is a construction practice that uses natural resources effectively and efficiently while building healthier structures or facilities that improve human is lifestyles and health. In addition, it helps in to create a good environment as well as saves costs. Sustainable construction is also a construction practice that is designed to allow reuse

[31] (Charles Atombo · Joseph Cudjoe · Kwedza Dzantor · Aaron Agbenyegah Agbo 2015)

in an ecological and resource efficient way. The benefits of sustainable construction are many, e.g. the benefits of sustainable construction as listed by the United State of America Federal Energy Management Program (FEMP) as shown in the table below.

Table 1: Benefits of Sustainable Construction[32]

	Environmental	Economy	Social
Site	Reduced resource use, land preservation, protection of ecological resource, soil and water conservation, less air pollution restoration of brownfields	Reduced cost for site preparation, parking lots, road	Improve aesthetics, more transportation options for employees
Water Efficiency	Preservation of water resources for agriculture and wildlife, lower potable water use and reduce discharge to water ways	Reduce annual water and waste-water cost, lower fixed cost	Preservation of water resources for future generation, recreational and agriculture uses, fewer waste-water treatment plants
Energy Efficiency	Less air pollution and fewer carbon dioxide emissions, lowered impacts from fossil fuel production and distribution, lower electricity	Reduce peck power demand, lower initial costs, reduce demand for new energy infrastructure lower fuel and electricity cost	Reduce new power plants and transmission lines, improve comfort conditions
Materials and Resources	Reduce use of virgin resources, Increase in recycling markets, reduced strain on landfills	Lower waste disposal costs, reduce need for new landfills	Decreased traffic due to the use of local/regional materials, fewer landfills,
Indoor Environmental Quality	Reduce emissions of VOS compounds, better indoor air quality	Lower insurance costs, reduce litigation, high productivity	Better individual productivity, reduce adverse health impact
Commissioning, Operations, and Maintenance	Reduce air pollution and other emissions, lower energy consumption	Reduce occupant/owner complaints, lower energy costs	Improve occupants productivity, health, safety and satisfaction

[32] (Operations, OSEC n.d.)

2.6.1 Sustainable Design

Sustainable design is defined as a system that considers the project's life cycle and its impact on environmental and energy resources. Consequently, one of the key features of the sustainable design is to minimize material and resource consumption, the strategies for achieving this, is through sustainable construction. Sustainable design plays a major role in reducing or in helping to avoid increased vulnerability to the various impacts arising from climate change and to manage risks through adaptation. It is the initial step towards achieving sustainable construction.[33] summary, the tenets of sustainable construction and sustainability cannot be seen as an individual element to be selectively used at whim: it must be cohesively implemented in order to achieve the best environmentally, socially and economically practices and the full impact of these tenets. Regional variations alone offset this potential. As a sustainable construction practice is relatively in its infancy, many issues still remain associated with understanding how to fully work within the boundaries of the principles of sustainable construction. As a result, each individual principle establishes goals with positive impacts, the neglect of others can result in impacts, which can offset any benefits of those implemented. There can never be one particular prescriptive solution to sustainable construction. Thus, stakeholders in the construction industry must make efforts towards creating a functional prescriptive plan for more universal compliance. However, Mill ward et al., (1995) describe the sustainable design as a process of designing that involves the integration of a wide variety of considerations about the future. Based on this definition of sustainable design, sustainable design addresses the following:

- **Fitness for a purpose:** The ability of the structure or facility to fit or meet the purpose of which it was designed for, without changing over time.
- **Durability:** The durability of the structure or facility base on the performance of its fabrics in varying conditions of loading, humidity, and temperature.
- **Attractiveness:** The structure or facility been attractive to people in and around it as well as the users throughout its lifecycle[34]

[33] (Peakstoprairies 2005) In
[34] (Subcommittee 2016)

2.7 Implementation of Sustainable Construction within Projects

In the construction business industry today; there is always the thought of recognizing the factors that influence the success of a project that is interlinked with the activities of a given project. When implementing sustainability principles within a project, the project participant of a sustainable construction project should consider the whole process from the conceptual design stage to the final product completion, implementation of sustainable construction within should be done with the emphasis on benefits and negative impacts that will arise during the lifetime of the project. The ISO-15392; (2008) Identifies and establishes the principles of implementing sustainability in building construction, which is based on the life cycle of the buildings and other related construction works.[35] Therefore, with regards to ISO-15392; (2008) six objectives is used for implementation and promotion of sustainability with respect to construction works, they are as follows: (a) proactive approach (b) improvement of the construction industry (c) decoupling of economic growth from increased negative impacts (d) innovation (e) reconciliation of differing interest involving short-term and long-term decision making and (f) the reduction of adverse impacts even when improving values. However, in actualizing the promotion and implementation of sustainable construction goals, there are nine goals to be achieved in the ISO.[36]

- Holistic approach: This entails all areas of sustainability when thinking of sustainability in construction related works with respect to the construction project life cycle.
- Equity: This comprises ethics, interregional and intergenerational considerations, and the triple bottom lines.
- Responsibility: it includes moral responsibility in action taken.
- Transparency: The information about the decision-making process and materials should be credible, comprehensive, understandable and open.
- Long-term thinking: this deal with consideration of long, medium and short-term impacts of decision making.

[35] (ISO 15392:2008) (Preview n.d.)
[36] (ISO 15392:2008) (Preview n.d.)

- Global thinking and local action: Involves considerations of global effects while working locally and using global policies and strategies reflect on the impacts and implications locally.
- Involvement of interested parties: Stakeholders should be involved by taking into account their responsibility, importance, timing, and views.
- Risk management: Precautionary method should be used for construction-related work through risk management.
- Continual improvement: the sustainability aspect of the construction works should be improved after a while.

2.8 Project Stakeholders Perception or Priority of Sustainable Construction within a Project

There exist different stakeholders in the construction sector with different emphasis placed on (cost, time and quality) where the emphasis is placed on one element and less is placed on the other two elements. For example, if an emphasis is placed on low-cost building; then time and quality will be sacrificed. However, it is believed that only two out of the three elements can be achieved at the same time. Project stakeholder perception of sustainable construction in most cases will also vary according to the concept of elements of sustainable construction which are in the (Economic, Social and Environmental) of which the need of the project is aimed to achieve. Sustainable construction projects are pursued by uncertainty with various means, and with different means and methods.

However, Williams, (2010) noted that only one element or aspect is clear, Williams went further to emphasize that all new construction projects will be achieved with a growing complex economic, technical, political and social environment. Sustainable development goals seem to an emphasis on extensive issues such as (economic, social and environmental) that has great importance to both present and future generations like resource depletion, climate change, energy, and material utilization and biodiversity.[37]

[37] (Williams 2010)

On the other hand, this emphasis is important; but base on this emphasis it makes it difficult for project stakeholders to clearly identify sustainable development requirements or the element they want to achieve.[38]

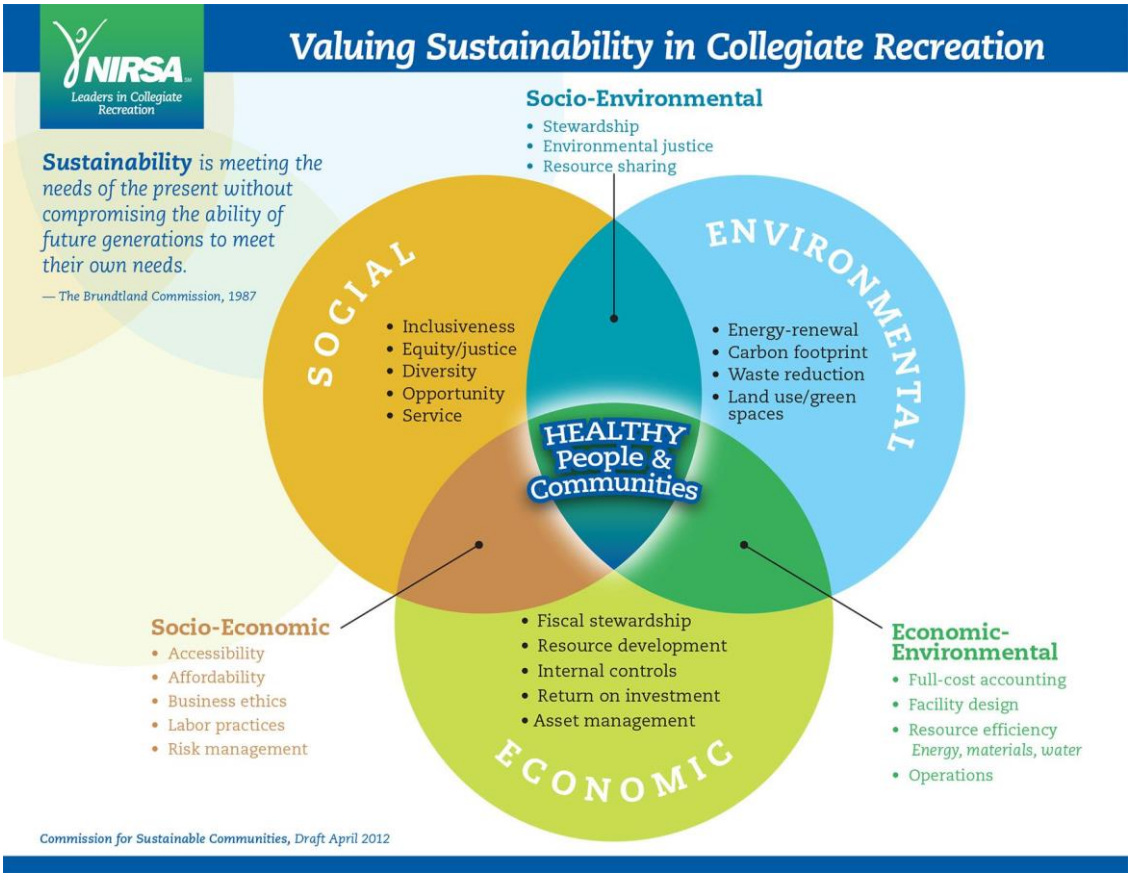

Figure 3- Triple bottom model[39]

2.8.1 Components for Sustainable Project Construction

During the Design Phase. The sustainable design for a project should take into account the designed parameters that are important to the project, which may include location, construction, orientation, structure and systems, operation and demolition of the structure and the effects of each decision on one phase of the project will affect or influence the other phases of the project. The basic components for sustainable construction during the design phase are as follows:

[38] (FIDIC 2004)
[39] (Recreation 2012)

- **Site:** Initiating an effective sustainable construction begins with good site selection. A good site is a site with a good geographic condition and guarantees a minimum loss of biodiversity. The vulnerability of the site towards natural hazards should be ascertained and designed in accordance.[40] However, adequate priority should be given to reuse or rehabilitation of existing structures, assessment of building orientation, entails the structure related to the weather and climatic conditions, proper and direct development to environmentally suitable site methods that maintain and enhanced ecology and biodiversity of the site. In order to achieve sustainable construction shrubs, native trees and plants can also be used[41]
- **Waste:** Waste generation and construction wastes are a major issue in the construction project and construction industry at large.

Construction waste has a huge and direct influence on productivity, profitability, a material loss that as a result affects project completion time.

According to Forsberg ET. Al, (2007) the authors affirmed that waste accounts for about 30-35% of project production cost. In most cases, the huge waste generated by this industry might be because of human error, weather effects, ineffective planning, using substandard material and ineffective site management.[42]

According to [43]Simon Elias Bibria and John Krogstie, 2016 construction waste is generated because of one or more reasons such as constant changes in design. To minimize waste generated in a construction project, it is important for the construction industry to adhere to the principles of sustainability and sustainable construction as well as using effective design systems to designing out a significant amount of waste.

Construction waste can be eliminated during design work or be designed out of the project through effective material selection, reduce and recycle construction waste; the building should be design to provide comfort and adaptability, design with less material use of sustainable construction principle and uses advanced techniques and methods.

[40] (Works 2016)
[41] (Group 1998)
[42] (Forsberg 2007)
[43] (Simon Elias Bibria and John Krogstie 2016)

- **Materials:** This involves material selections to achieve sustainable construction, especially for the selections of materials, which plays a very vital role. The Materials used should be non-combustible and affects positively to indoor air quality. The material life cycle needs to be ascertained concerning its ability to be reused, recycled, and taken into account for the energy uses in its production, its durability, availability, and cost of transportation.[44] The role of sustainable design is to minimize material consumption and resource depletion as well as reducing the life cycle of materials on the environment. To attain a sustainability through material selections; materials from renewable sources that is durable, reusable, biodegradable and locally produced material should be used.
- **Energy:** Inefficient energy usage for construction material production; such as heating, lighting and for other equipment will increase energy cost while efficient energy usage can minimize energy cost and improves comfort condition, reduces the negative impact to the environment as well as lower impacts from fossil fuel production and distribution. In order to minimize the inefficient energy consumption; energy source with low environmental impacts can be used; because the sustainable design system of optimizing the building placement or location and configuration of energy performance can be used or implemented for better energy efficiency.[45]
- **Water:** To achieve sustainable construction, we must sustain water resources by ensuring quality and availability, reduce the overall consumption of water, and reduce discharge to waterways will also minimize wastewater treatment needs.

2.8.2 Sustainable Construction/ Green Building Rating Systems

Base on the impact of the construction industry and its activities to society; there has been an increased awareness of sustainability principles as well as the concept of sustainable construction. Nonetheless, in most countries of the world today, they have developed their own rating systems or standard about their environment or locations.

[44] (Group 1998)
[45] (Works 2016)

According to Fowler and Rauch, (2006) they stated and emphasized that there are over 34 sustainable construction or green building rating.[46]

Systems, which are in existence in the European and US markets as in the year 2006; and examples, are from these countries mentioned below;

- **Sweden** – Eco Effect is an environmental assessment tool with an emphasis on the environmental effects of energy and materials consumption, lifecycle cost and indoor and outdoor environment.
- **Germany**-DGNB (German sustainable building council) its focus is to promote sustainable and economically efficient buildings
- **USA**- LEED (leadership in Energy and Environment Design) focuses on promoting whole building approach with emphasis on water saving, efficient energy, indoor air quality and the performance of site for sustainable development.
- **UK**- BREEAM (BRE Environmental Assessment Method) it focuses on the best practice in sustainable design, building environmental performance and addresses sustainability and environmental issues.
- **Finland**- Promise is a Finnish classification and environmental assessment system used for new and existing buildings; the system has four major groups: the consumption of natural resources, the health of the users, environmental risk and environmental loadings[47]

2.9 BIM as a Tool for Sustainable Construction

In order to reduce wastage and excessive resource consumption in the construction project; there is a need for the project participants in the construction industry to adhere to the sustainability concept and sustainable construction principle and the use of advanced techniques and method, for example, the use of BIM tools.

Traditional methods of carrying out construction are constantly having various challenges, which have impacts on the society and on the construction project itself.

Nevertheless, these challenges have been stated earlier above such as cost overrun, resources depletion, waste generation, time overrun, excessive consumption of resources, etc.

[46] (K.M. Fowler and E.M. Rauch 2006)
[47] (K.M. Fowler and E.M. Rauch 2006)

Investigations are needed first on the present construction methods for better improvements, however, observed that Investigations are required to check the construction methods used in the construction industry and the construction industries activities for better improvements; however, these in improvements can be achieved through the use of advanced and developed technological methods like the use of Lean techniques for construction, Value Engineering, Supply Chain Management and the use Building information modeling (BIM) for designing and modeling. However, as a means of minimizing the challenges of traditional means of carrying out construction; there is a need to update and improve the traditional ways of construction. [48]

BIM tools can be used to achieve sustainable construction through a sustainable design from the conceptual or the initial planning phase of the project to the construction phase and subsequently the operational and demolition phase of the structure especially for better and future of sustainability of the building.[49]

2.10 Building Information Modelling (BIM) and Sustainable Construction

Building Information Modeling (BIM) it is well known nowadays in the AEC industry, since facilitates the construction process from beginning to end, by offering a digital representation or Model of the building rich in data, useful to many of the stakeholders of the process, helping the decision making and refining the process of executing the project.

During this section, a general outline of BIM development in the construction industry, as well as the reasons behind the implementation of it, including the tools that take part on the creation of these digital representations will be presented. Building Information Modelling is a complex topic that includes many regulations and technical information created with the intention of standardizing the application and responsibilities behind the implementation of this practice. In this investigation, the standards and regulations will not be needed as a theoretical background, since it is assumed that the reader is already aware of this information. [50]

The general principles of sustainable construction emphasize on methods of constructing or building a construction project using methods that are environmental, socially

[48] (Hardin 2011)
[49] (TayyabAhmad, Muhammad JamaluddinThaheem 2017)
[50] (Abidin 2010)

and economically responsible; and also in a resource efficient way with regards to all project phase i.e. site selection, design, construction, and operation. BIM plays a crucial role in attaining sustainable construction and protecting the environment through sustainable design, which enables design teams to design for efficient utilization of resources. There have been many different definitions of BIM given by various stakeholders, persons, and organizations; nonetheless, BIM is defined in various terms as a construction management, and as a model as well as a data design. Häkkinen, (2008) describes BIM ‘‘as creating, the coordinated use of computable information about a building project throughout the lifecycle from the design phase, construction and building operation and management’’.[51] The America National BIM Standard (2007) defines BIM in three ways or ways, which are as follows:

- BIM as a system, it includes the communication structure and the business work that enhance efficiency and quality.
- BIM as a product, it is a structured data set that describes the building.
- BIM as the process involves creating a building information model.[52]
    - BIM can also be seen as three-dimensional perspective. Views BIM as a conceptual system to design building and construction that involves 3D parametric modeling of the structure for detailing, designing and computer sharing of building information between design, construction and other profession and well as a design and Project data management.[53]
- BIM as interacting processes and systems to handle building design and project data in digital format across all project phases or life-cycle stages. However, BIM as a construction management can be seen as a smart simulation of architecture to accomplish an integrated project delivery.[54] Building Information Modelling (BIM) is an innovative model and one of the most advanced techniques used for developments in the AEC industry (architecture, engineering, and construction) that makes efficient realization of sustainable designs; thus, with the use of BIM technology or tool, a precise virtual model of a building is constructed digitally.

[51] (Hukkinen 1999)
[52] (Standard 2007)
[53] (David J. Gerber1, Burcin Becerik-Gerber2, and Alex Kunz3 2010)
[54] (Eastman 2008)

Thus, in achieving sustainable construction concept in a construction project, which involves the reduction of the negative impact of construction activities on the environment throughout the structure's lifecycle, required the use of sustainable design approach, and this can be achieved with BIM techniques. The usability of BIM for design can help the design partners create a digital model of the structure before the actual on-site construction; this helps in avoiding clashes during on-site construction, which in turn reduces wastage of resources and guarantees sustainability in construction.

Kam-din and Qing, (2013) defined Building Information Modelling as a significant element in reducing waste generated from the industries; this waste includes wasted energy, reducing environmental damage and adds value to industrial products; at the same time BIM have some BIM-based sustainability analysis software that can be useful for sustainability.[55] However, present literature from Kam-din and Qing, (2013) argued that; there are presently three BIM-based technology tools in the market for sustainability purpose; they are namely:

- Integrated Environmental Solutions (IES)
- Virtual Environment (VE)
- Autodesk ECOTECT

Other software firms such as Autodesk, (2005) stated that BIM can be used to reduce cost that is linked to traditional energy (sustainability analysis) while at the same time, achieving energy analysis by *"through the provision of information required to carry out a sustainable design, analysis, and certification regularly available as a byproduct or an offshoot of the standard design process"*.[56] On the other hand, BIM is an essential tool for sustainable design.

Krygiel & Nies, (2008) proposed that BIM is helpful in construction processes and can help aid sustainable design in the following areas:

- Site and logistics management- it reduces carbon footprint and waste
- Energy modeling- it reduces energy needs and analyses renewable energy alternatives and it enhanced low energy costs
- Sustainable mate rails- it minimizes materials needs or demand and uses recycled materials (4) Building orientation- by choosing good orientation will reduce energy costs

[55] (Fan 2013)
[56] (Autodesk n.d.)

- Water harvesting and Daylighting analysis – it can reduce water needs in a building.[57]

2.11 General Outline

The concept of Building Information Modelling started in the 1970s and Charles Eastman introduced it; nevertheless, the significance of the practice and its influence in the integration between design and construction was not understood until early 2000s when its application in the AEC industry and in academic researches started to increase.[58]

BIM is a method used to design, build and operate facilities that include the creation and use of smart 3D models. In comparison with traditional 2D drawings, a Building Information Model offers to all the parties involved a better understanding of the project, leading to the improved and more predictable construction process. A BIM differs from a 3D CAD drawing because the model uses a technology of integrated databases that combine and relates information into de models, considering that a smart 3D model.[59]

The methodology of design offered by BIM can be considered as one of the major developments of this time in the construction sector. BIM has changed the way the AEC industry works, by creating a digital format for the interoperability of information during all the life cycle of a building, including design, construction, and operation of a facility. This correlation of data allows BIM to avoid conflicts that usually occur due to the lack of coordination between the project´s teams, providing better results, reducing risks that translate into time loss and money; all of this included in a 3D model that facilitates the visualization for the teams and the client.[60]

[57] (Eddy Krygiel and Brad Nies, 2008)
[58] (Ilhan, B., & Yaman 2013)
[59] (Autodesk. 2014)
[60] (Ilhan, B., & Yaman 2013)

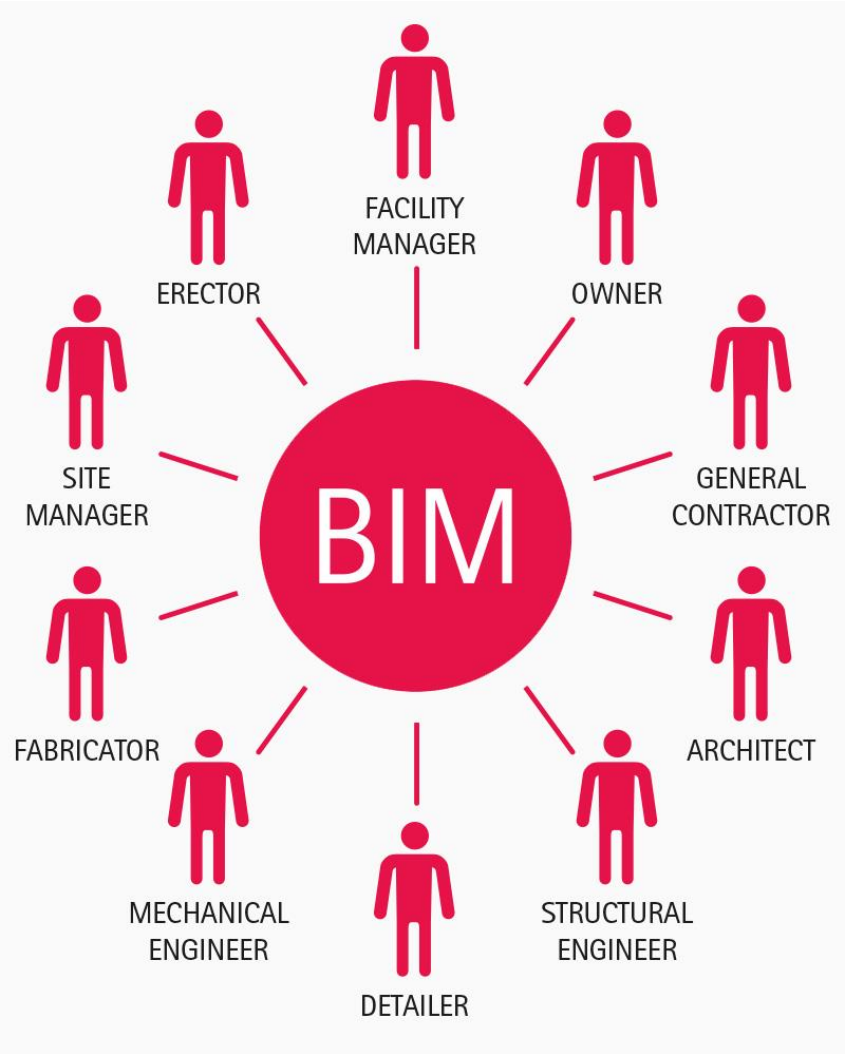

Figure 4- An open approach to BIM connects different stakeholders to each other[61]

The BIM approach (figure 4) is possible because each team involved in the construction process is responsible for developing their own specific model, which includes architecture, structure, MEP, schedules and cost estimators, to later integrate all the information into one rich model. The integration of information is necessary during different stages of the construction process, allowing a BIM coordinator to insert, extract or develop information out of the model.

This combination of data, where all disciplines collaborate it is impossible to be found without the creation of a digital data format that is open and neutral of specifications such as the one represented by the Industry Foundation Classes (IFC), necessary

[61] (Tekla n.d.)

since each of the BIM software from developers such as Autodesk or Graph iSOFT, have their own data structure and property over their offered data.[62]

The influence of BIM over the industry is unquestionable, improving the coordination of projects and execution and maintenance of constructions. Nonetheless, BIM tools will not change the way the industry works without the influence and performance of its users, who are responsible for correct practices and maximization of the tools when adopting the BIM methodology, including proper use of the data in each model to report during design, construction and operation phases.[63]

2.12 Implementing BIM

The implementation of BIM represents benefits and risk for a user, but there is also the question of the need or not to implement it on a project. Following, the reasons for the application of BIM will be presented, and once there have been made clear the when's and why's of BIM adoption, the challenges that come with the application of BIM for existing buildings, since it applies to the case study, will be exposed.

2.12.1 Reasons Behind BIM Implementation

Adopting BIM could be a decision taken by the stakeholders of the project before it has even begun, related to saving cost or improving communication, but it could also be a forced step, required by regulations or clients; here are some of the main reasons behind the implementation of BIM:

Government pressure: The best example for government pressure is no other than the UK Government that has established a regulation where from 2016 on, the adoption of BIM will be compulsory on al publicly funded projects. The reasons behind these standards are no other than to provide sustainable buildings with a value for money.[64]

Client pressure: The client will always demand the best outcomes with the project that represents less investment in the end and under schedule. An informed client asks

[62] (Alsaadi n.d.)
[63] (Mactavish 2013)
[64] (Group., Efficiency and Reform 2011)

not only for the ability of the contractor to offer BIM but also for the experience in previous projects, forcing different professionals in the AEC industry to adopt BIM, even before government´s regulations do.[65]

Innovation and competitiveness: A portion of the construction business has decided to apply BIM since the beginning of this practice with the simple vision of staying ahead of the game, considering the challenges associated with early adoption overshadowed by the advantages of offering the client the newest and best of the capabilities.[66]

- Provide complete life value to the client:

As previously established the capability of BIM to offer an interoperability among stakeholders, allows a project to deliver sustainable practices, costs, schedules and other analysis that represent the whole life cycle of the building, influencing the environmental performance of the building as well as the occupants´ satisfaction; the smart model that characterize BIM can offer also the facility manager the methods to operate the building, analyze the possibilities of re-use or decommissioning.[67]

Improve efficiency and quality of the design: The close to real visualization provided by BIM offers the client the option to understand how the design will look like once it is completed, allowing changes to be done immediately during revisions and avoiding any changes on site because misinterprets of the client during site visits.[68]

Improve communication to operatives: As BIM models facilitate the communication with the client thanks to the visualization that offers, it does as well with the workforce, allowing the recreation of sequences of operations to show skilled and unskilled labor the way the tasks should be executed on site.[69]

Cost savings: When BIM is used to its full capacity and all the information related to the project is loaded, such as suppliers and subcontractor's information, a BIM is capable of generating cost estimation for different proposals or changes during construction. BIM can account for delays for weather conditions, holidays or even contingency sums from risk management exercises during the estimations.[70]

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[65] (Coates, P., Arayici, Y., Koskela, L., & Usher, C. 2010)
[66] (TRADA 2012)
[67] (Azhar, S., Carlton, W., Olsen, D., & Ahmad, I n.d.)
[68] (Eastman, C., Teicholz, P., Sacks, R., & Liston, K. 2011)
[69] (Sacks, R., Treckmann, M., & Rozenfeld, O. 2009)
[70] (Barlish, K., & Sullivan, K. 2012)

Time savings: Time is always a major factor in the success of a project, all the time invested for every change on a project with re-planning, regenerating, and re-estimating; is reduced or avoided with the use of BIM models, where the parties involved on the project can interoperate and discuss changes online that can be solved immediately, delivering all the process from planning to estimation in the same meeting.[71]

Clash detection: The interoperability of different disciplines is the main approach when implementing BIM; the representation of the smart model provides to the stakeholders of the project the possibility of simulate clashes among different elements of the building; clashes that without the adoption of BIM are only detected during the construction phase, resulting in more time and costs for the project.[72]

Automation of schedule: A BIM software offers the creation and distribution of schedules for every activity of the project; reducing this time-consuming task involved in the management of a construction project.

In the event of changes, BIM also allows the generation of electronic new schedules that are delivered in no time to all the participants of the project.[73]

Facilitate pre-fabrication: Many contractors have adopted the practice of prefabrication of all the possible elements of a building in order to avoid delays for weather and other factors.

BIM provides to the manufacturers all the detailed information of every component without adding time to the project schedule since all the information is already included on the smart models.[74]

Facilitate operation and maintenance activities: The handover of the final model to the facility manager can be linked to the known FM system and offer a faster and more accurate management process, with the capability of executing space management, monitoring preventive maintenance and schedule different maintenance activities with real-time data, reducing time and avoiding emergency repairs.[75]

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[71] (Azhar, S., Hein, M., & Sketo, B 2008)
[72] (Azhar, S., Carlton, W., Olsen, D., & Ahmad, I n.d.)
[73] (Azhar 2011)
[74] (Azhar, S., Carlton, W., Olsen, D., & Ahmad, I n.d.)
[75] (Crotty 2012)

2.12.2 Use of BIM in Sustainable Building and Construction

However, the use of BIM tools can achieve sustainable construction through a sustainable design from the conceptual or the initial planning phase of the project to the construction phase and subsequently the operational and demolition phase of the structure.

According to Häkkinen, (2008) BIM can be used in different phases of construction projects and these phases of construction projects and related BIMs, which are as follows:

- Analysis of needs and objectives
- Requirement model: Project requirements and requirements of the authorities,
- Design of alternatives, Alternative mass, and spatial models
- Bidding phase o Approved detailed design and construction model
- Construction and commissioning
- Construction model and as-built model
- Facility management and maintenance
- Maintenance model [76]

Planning and Design: BIM tool is used in the planning, design, and execution of the project, BIM tools can use by all project participants to help them make decisions on BIM implementation during and after construction. The BIM model for planning can be used for checking an existing condition of modeling, cost estimation, phase planning 4D modeling, programming and site analysis. Using BIM techniques in sustainable construction for planning will enhance site utilization, space coordination, and product information.[77]

While in design BIM tools are used for design tasks such as [Design authoring, structural, lighting, and energy analysis]. However, the advanced uses of BIM design tools are for Mechanical and other engineering analysis as well as LEED evaluation and code validation. The BIM tool is also a good design tool; it enables the designer to visualized designed project and the coordination of designs. In addition, the most tools used in BIM design are mostly in the area of structural designs.[78]

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[76] (Hukkinen 1999)
[77] (Salman Azhar, Michael Hein and Blake Sketo n.d.)
[78] (Rafael Sacks, Lauri Koskela, Bhargav A. Dave 3 and Robert Owen 4 2009)

The 3D digital models are used in the building design to examine detail layouts, sight lines, constructability and clash detection. This design tools are useful in the elimination of construction issues that arises at the early stage in the design and it can significantly reduce requests for information change orders, team conflicts and re-work when compared to Manuel design method.

Construction and Operation: BIM techniques are used for construction management and control and to ensure consistency in construction planning and execution, the information provided by BIM techniques during this planning and execution of the project may be used during the operation and maintenance stage. Although, construction works require building information models as a preliminary data control system to enhanced and complement design documents.[79]

IBC Institute for BIM in Canada, (2011) stated that BIM tools can help improve teamwork and communication which increases efficiency and reduces errors as well as in turn reduces resources (energy and materials) consumption or demand and waste generation.[80]

Grilo and Jardin-Goncalves, (2010) emphasized that BIM tools can also improve teamwork and communication which is seen as a vital aspect in managing successful sustainable construction.[81]

2.12.3 Benefits of BIM for Sustainability (Sosa 2014)

The benefit of using BIM tools in sustainable construction is enormous and advantageous for the architectural, construction and engineering industry today.
The use of BIM tool in architectural, construction and engineering will enhance sustainability in the industry and will help enhance better quality of life through eco-friendly buildings and it can also reduce error and clashes; for example, using BIM during design phase facilitate good decisions to be made quickly due to the quality of BIM software, speed and availability of design data.

[79] (The Computer Integrated Construction Research Group 2010)
[80] (IBC n.d.)
[81] (Grilo, A., & Jardim-Goncalves, R n.d.)

According to Azhar et al, (2011), early decision making before and during the design process is important. BIM-based sustainable construction analysis model can help project participants to predict building performance from the design or conceptual phase of design, and this prediction of performance will improve both the quality and cost during its life cycle.[82]

However, Kam-din and Qing, (2013) emphasized that BIM-based sustainability analysis software is very good for the analyses of software to attain the triple-bottom-line principle in the following areas mentioned below.[83]

Economic Aspects: BIM aid optimization of design, minimizing whole life cycle costs and capital by improving material and energy efficiency. Integrated Project Delivery (IPD) improves teamwork and communication whereby decrease project cost and reduces construction wastage.

Environmental Aspect: BIM integrated analysis tool can be used when carrying out building performance assessment and can reduce resource consumption (water, materials, and energy) it can also reduce wastage due to efficient project delivery process.

Social Aspect: The social aspect of BIM can be viewed in terms of good design quality, i.e. fitness for purpose, meaning the quality of the design and construction of the structure or building can be improved to the enhanced good living environment.

According to Construction Innovation 2007 (CRC) report, mentioned accurate geometrical representation of building part in an integrated data environment as one of the benefits of BIM. However, BIM benefits of sustainable construction are as follows:

- **Better and quality design;** the BIM base model can be used to design and run simulations in the building to determine building performances and performance benchmarked[84]
- **Improving energy efficiency and sustainability;** the energy modeling tool can be linked to the building model in order to estimate the energy usage this offers an opportunity to design a building with improved energy efficiency by improving the quality of the building [85]

[82] (Azhar 2011)
[83] (Fan 2013)
[84] (CRC n.d.)
[85] (Eastman 2008)

- **Reduced Reworking**; repetition of work is less due to the facts that errors are fixed or corrected at the early designing stage, and in turn, reduces excessive resource consumption.

2.13 BIM Software

A BIM software or application is that one that uses parametric objects of any discipline that are able to relate among them and from which it is possible to extract different types of information, either graphic representations or alphanumeric ones.[86]

There have been numerous software developed, each of them working as a BIM tool, nevertheless, it is important to understand that each application can increase resource efficiency during different phases of the project, in order to use the tools in the most productive method. Following each of the BIM uses, resource efficiency opportunities and BIM software that fit into each use are presented:[87]

Design authoring: With the use of BIM software such as Autodesk Revit, ArchiCAD, Bentley AECOsim, Vectorworks, Tekla Structures, CADduct, and Autodesk Civil 3D, the selection and computation of materials, the inclusion of prefabricates elements that optimize design and the evaluation of the possibilities to achieve the project´s goals is possible.

Taking advantage of the visualization techniques of the tools reduces the need for design changes on site.

Optimization of design features: Tools like Autodesk Revit Structure, Autodesk Revit MEP, and Autodesk Civil 3D make possible the use of algorithms that will assist on the reduction of waste during the life cycle of the building by providing the correct materials needed for the execution of building.

Specification development: Insert data related to resource efficiency of different and specific components into BIM software like NBS Create.

Building environmental analysis: Water and energy efficiency, as well as a selection of sustainable materials, is improved as a result of the adoption of applications like Autodesk Ecotect, Green Building Studio, EcoDesigner, IDA Indoor Climate & Energy, Simergy, DesignBuilder, IES, and ArchiWIZARD.

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[86] (Sosa 2014)

[87] (Mactavish, A., Turner, A., & Iqbal, N. 2013)

3D design coordination: Clash detection and design coordination are one of the major BIM collaborations when it comes to resource efficiency due to the fact that will reduce construction waste due to re-dos on site.

Tools like Tekla BIMsight, Navisworks (clash detection), Solibri Model Checker, and Bentley Navigator make this possible.

Construction sequencing: Optimization of construction methods to avoid unnecessary practices is achieved by Navisworks (timeline) and Synchro, collaborating once again on the best use of resources.

Cost estimation: Autodesk Quantity Takeoff (QTO), Exactal Cost X, Dprofiler, Vico, and iRIB Two, assist on the computation of materials, as well as the analysis of needed resources, offering a more informed decision-making.

Once a clearer understanding of the variety of BIM tools, the most recognizable and the ones that fit best with the intentions of the research will be briefly described, including only the tools that take part during the creation of the models; since tools that assist or simulate specific performances related to the investigation will be defined further ahead.

2.13.1 Revit

Autodesk Revit it is nowadays the leader in the BIM market. A small company in Massachusetts developed it; nevertheless, Autodesk purchased it in 2002 and decided to continue with the original name of the software. Revit offers integration, as any BIM tool is required to do, with a series of applications Revit Architecture, Revit Structure, and Revit MEP. All of the software is independent for every stakeholder to work on their own model; nevertheless, all the files can be linked through a common RVT extension.[88]

The latest version of Revit is the 2016 edition released in 2015. Revit can be defined as a design and documentation system that provides data about the design of the project as well as the quantities, no matter the stage that the information is needed. Because Revit is defined by parametric design, all the information is connected and related. Parametric components or also called families represent the base for all the construction components design under Revit. The relationship between each component

[88] (Bynum 2010)

allows any change to be updated through the entire project and to generate custom-made schedules (figure 5) for every family or component of the project depending on the requirements needed, selecting all the criteria to show, from the area, volume, number or type of element, location, lifespan, and many others.[89]

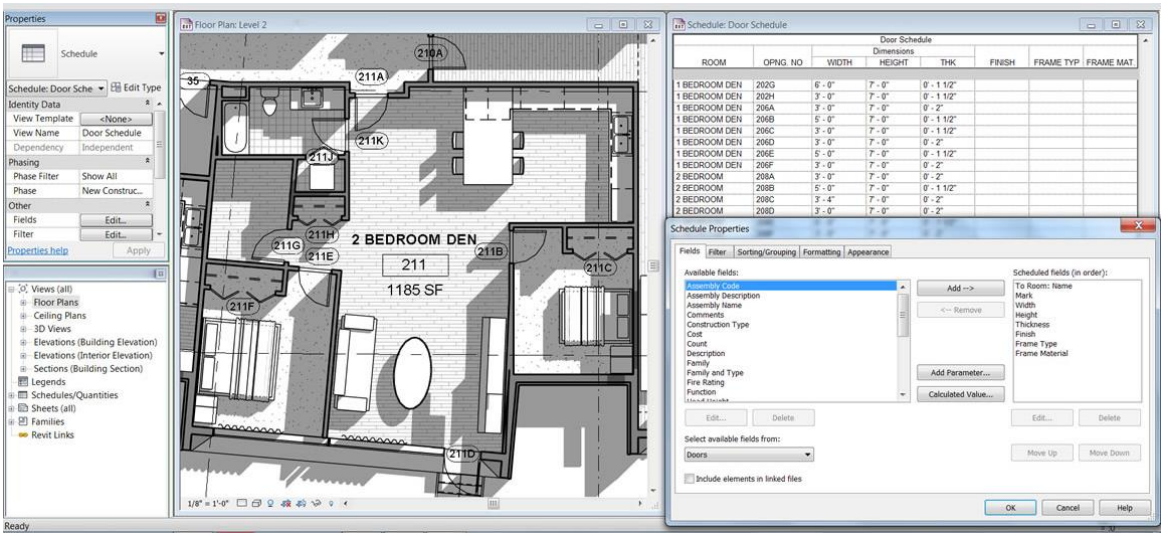

Figure 5- Schedules generated in Revit [90]

The software offers Revit Server that facilitates the collaboration between all the team members, even if they are geographically apart, with Revit models share through a Wide Area Network (WAN). The server helps to maintain an integrated and transparent range of models in a unique central server that it is accessible from any local server.[91] Revit can only manage the main aspects of design, being architecture, structure, and MEP, for the rest of the cases, there are connections with specific applications that can use the same BIM model.

The number of this kind of applications increases every year, offering analysis from project scheduling to waste management. Nevertheless, every version of Revit keeps offering more simulations at a general level. For example, there are tools for energy analysis at a conceptual level, this assists during the design process to achieve sustainable practices. The energy analysis is cloud-based, which makes it easier to do

[89] (Autodesk. (2016 n.d.)
[90] (Autodesk. (2016 n.d.)
[91] (Bynum 2010)

quick comparisons of energy consumption and life cycle costs between different design options.[92]

The results from every analysis are an offer by Revit on a graphic format with plenty of visual aids that facilitate the result´s interpretation (figure 6). When more extensive energy analysis is needed the model can be export for example to Green Building Studio in gbXML format; the efficiency of the design can be analyzed with Ecotect, or an indoor lighting analyze can be executed with 3ds Max Design.[93]

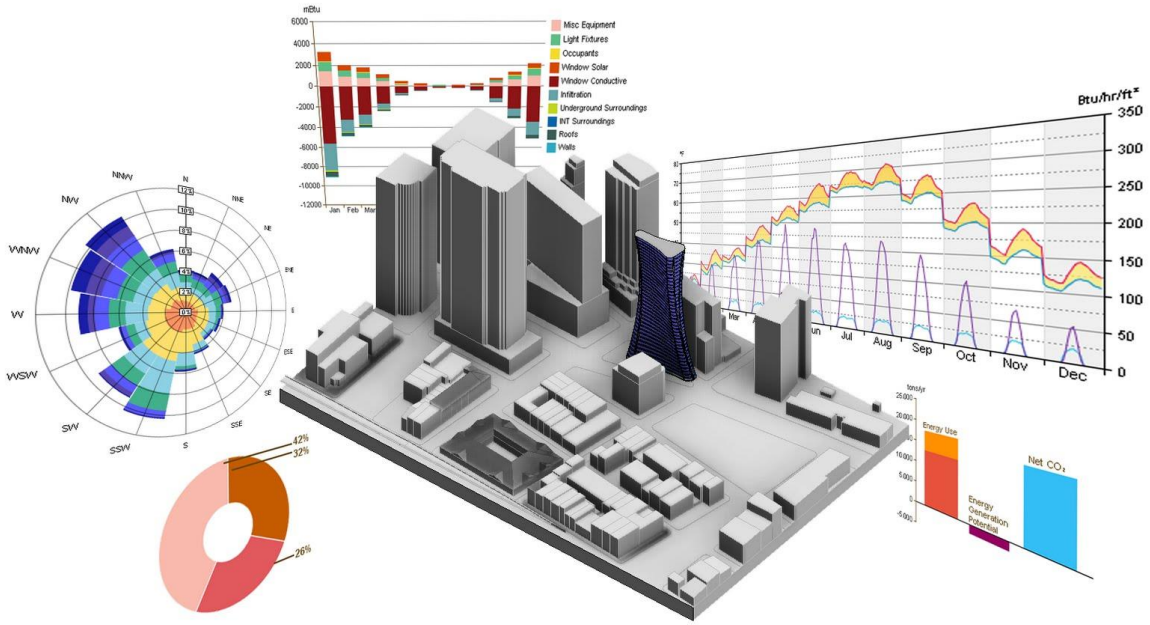

Figure 6- Energy analysis generated by Revit[94]

The interoperability among all the mentioned software is possible because Autodesk provides Revit with a variety of exchange interfaces. Revit supports file extensions like DGN, DWG, DWF, DXF, SAT, and SKP, in order to import a CAD drawing into the program as a reference for the modeling of the project. In order to allow participation of every stakeholder of the project all renders, images an videos generated by Revit can be exported to common extension files like JPG, TIF, BMP, PNG, TGA, or AVI.

Undoubtedly, nothing shows more interoperability than the fact that Revit also offers the building-SMART object-oriented file format, IFC, being an international standard.[95]

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[92] (Sosa 2014)
[93] (Autodesk. (2016 n.d.)
[94] (Autodesk. (2016 n.d.)
[95] (Eastman, C., Teicholz, P., Sacks, R., & Liston, K. 2011)

2.13.2 ArchiCAD

ArchiCAD was founded in 1982, by Graph iSOFT, who claims that the software was the first to offer to the user the possibility to create both 2D and 3D drawings on personal computers. The newest version of the application is ArchiCAD 19, released in 2015. This version improves the modeling capacities in the BIM environment with an external BIM workflow that uses priority-based connections and smart building materials.[96]

As many other BIM software, ArchiCAD 19 provides to the user numerous object library (figure 7) from where to design all the needed elements for specific projects. The platform allows faster operation, especially when working on larger projects thanks to the processor that is equipped with, presented as the bigger improvement over the latest version and over their competitive applications. ArchiCAD provides add-ons like Building Explorer, MEP Modeler, and EcoDesigner that simplifies the different building analysis possible as well as clash detection.[97]

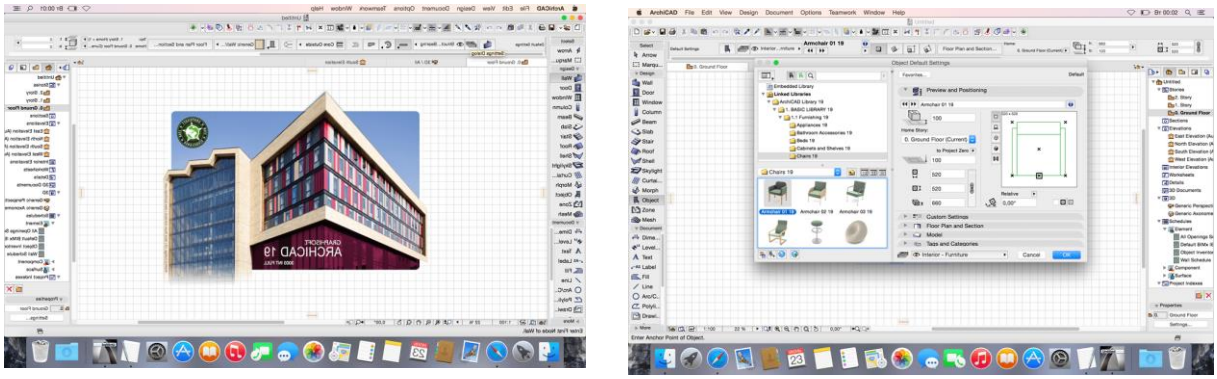

Figure 7- Object Library in ArchiCAD 19[98]

Similar to Revit, ArchiCAD offers a series of compatible file extensions that allow the user to import drawings like DWG or DXF formats, and also the rendering programs in the applications are able to convert the video, image or render files into JPG, TIF, BMP, PNG, PDF, TGA, or AVI file extensions.

[96] (ArchiCAD. 2015)
[97] (Khemlani 2015)
[98] (ArchiCAD. 2015)

ArchiCAD also provides the most demand interoperability in every BIM project by including a large database of elements that help on the recognition of components in analysis applications.[99]

Unfortunately, ArchiCAD keeps being a single disciplinary software instead of a multidisciplinary BIM platform and compared with a competitor like Revit, the parametric modeling has limitations, which compromises the integrity of the model and makes it less reliable with other applications during analysis or simulations. [100]

2.14 Sustainability and BIM

The increased application of BIM in the AEC industry, in addition with the urge to tackle energy consumption and greenhouse gas emissions, has led to the development of an integrated design practice that combines BIM technology with sustainable strategies; offering efficient buildings created under a high-performance process.[101]

This design practice is known as Green BIM, and in this section, the areas of sustainable design that this practice can assist on, as well as the existing BIM tools that make this possible will be described.

2.14.1 Green BIM

Green BIM can be defined as the collaboration between BIM and green building, with the objective of achieving green practices, especially in energy efficiency, into the building lifecycle. Even though there is no academic concept for this new term, it has been building up in the AEC industry, making it obvious the need to implement this concept in early stages of the project in order to make informed decisions earlier, improving the efficiency and performance of any construction project.[102]

The application of Green BIM cannot only be neglected to achieve sustainable designs, it should also be extended to construction stages, operation, and maintenance and demolition phases of the lifecycle of a building.

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[99] (Azhar, S., Carlton, W., Olsen, D., & Ahmad, I n.d.)
[100] (Bynum 2010)
[101] (Jalaei, F., & Jrade, A. 2014)
[102] (Wei, W., & Issa, R. R. 2014)

BIM can provide strategic assistance in aspects of sustainable design such as the selection of proper building orientation to reduce energy costs; analysis of building form to optimize the building envelope; day-lighting analysis and water harvesting to reduce water needs; energy modelling to reduce energy requirements and options that can lead towards low energy costs; reduction on material usage by analyzing sustainability of the resources and computing exact quantities required; site and logistics management to reduce waste during construction due to the reduction of errors in the design phase.[103]

Daylighting and energy analysis programs have been available for years but hardly used during the design process by the team members, because they involved complicated calculation, specific knowledge, and high costs. Large projects could afford to outsource the analysis but in limited stages of the project, usually, the energy performance information would not be available during the decision-making process of the project rather by the end of it. However, with Green BIM that has changed since a BIM model offers enough information for the existing BIM tools to complete analyses earlier in the design cycle and make it regularly to modify the design options. [104]

A diversity of energy simulation and analysis tools have been developed over the years, among them Green Building Studio, EnergyPlus, eQuest, Ecotect, and Integrated Environmental Solution (IES-VE).

It has been made essential the execution of energy analysis from the early stages of the project since it influences the efficiency of the design and furthermore a strong effect on the lifecycle cost of a facility. BIM tools such as Integrated Environmental Solution (IES-VE) and Ecotect are integrated to modeling software like Revit and are able to run simulations that represent a comprehensive building performance analysis that includes solar analysis, lighting analysis, acoustic analysis, thermal analysis, ventilation and airflow analysis, building regulations and resource management.[105]

These environmental analysis tools will be explored further ahead in the investigation as well as the modeling tools like Revit and ArchiCAD were described previously.

[103] (Dowsett, R., & Harty, C. 2014)
[104] (Autodesk. 2014)
[105] (Jalaei, F., & Jrade, A. 2014)

2.14.2 Implementation on Early Stages of the Project

The influence of the implementation of Green BIM from the early stages of the project has been made clear previously, the decisions taken from the beginning of the design process are crucial in order to achieve sustainability.

A complete adoption of BIM during the design process of the building will lead to a full application of these software simulations and analysis during the entire lifecycle of the facility. Following a description of every phase of the lifecycle and the influence, that Green BIM could offer from the beginning, enabling the achievement of sustainable practices.

Building planning and design: the ways BIM can assist during this phase have already been mentioned, is the benefits that are most exploited form a BIM approach. They go from building orientation and massing, daylight analysis, water harvesting potential, building energy performance, sustainability of materials and site management.[106]

Building construction process: there are several investigations into on-site monitoring of carbon emissions through BIM tools; an example could be the application of BIM with the integration of a Geographic Information System (GIS) technology to optimize the use of construction processes such as concrete truck mixers routes to reduce carbon emissions.[107]

Building operation: the advantages of adopting BIM from early stages and being able to continue with the methodology during the utilization phase of the facility, could assist on achieving efficient sustainable practices and operations by improving user comfort, reducing the rate of emergencies related to maintenance in the building, improving safety performance and reducing resource waste.

Some of the applications include analysis of heating and cooling requirements, analysis of daylighting to reduce lighting loads and selection of proper building equipment that can reduce energy use.[108]

Building demolition: a facility that employs BIM from cradle to grave, could achieve an entirely sustainable process, including demolition, since BIM tools can, for example,

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[106] (Krygiel, E., & Nies, B. 2008)
[107] (Artenian, A., Sadeghpour, F., & Teizer, J. 2010)
[108] (Che, L., Gao, Z., Chen, D., & Nguyen, T. H. 2010)

calculate the exact information on volumes and materials to determined waste, assisting on the prediction of transportation needed for disposal charges. [109]

Even though BIM can be present in every phase of the lifecycle of a building it is important to understand that is always through different tools or applications, a reason why it is imperative the development of a BIM tool that can provide a cradle to grave management of a building´s environmental sustainability. Some developers like Autodesk have started working on this needed tools with the incorporation of cloud-based technology into energy analysis tools, nevertheless, there should develop in the future application that includes cloud computing and management of more aspects related to green BIM. [110]

2.15 BIM and Green Building Rating Systems

When pursuing green building certifications many credits required the submission of drawings in order to assess the sustainable strategies implemented in the facility. A building that has implemented BIM, has the opportunity to produce these drawings more efficiently than using conventional CAD software. These scenarios is presented in every scheme of the certification that the building is pursuing to achieve, from new constructions where all the information of the building has been modeled with BIM tools; to existing buildings or operation and maintenance certifications where a BIM model has been updated regularly and has consistency with the current situation of the facility.[111]

BIM tools offer additional information needed when pursuing green certifications; from lists of material reused, recycled or salvage in the project, which are easily produced with schedules or lists of building components, from the calculation of areas, volumes or costs of the building materials or assemblies. [112]

[109] (Cheng, J., & Ma, L. 2013)
[110] (Wong, J. K., & Zhou, J. 2015)
[111] (Autodesk. 2014)
[112] (Azhar, S., Carlton, W., Olsen, D., & Ahmad, I n.d.)

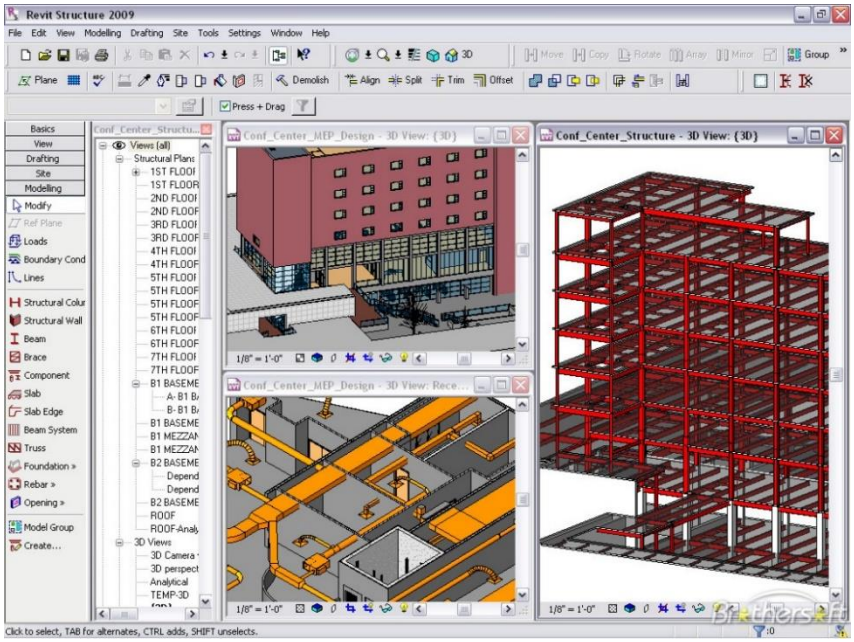

Figure 8- BIM plug-in e-SPECS, the database can be integrated into Revit[113]

Most of the required lists of materials by the assessment tools, aim to encourage the use of green products, which involves the tracking of suppliers that guarantee sustainable practice during the manufactured process of the used materials or components of the building. BIM offers certain tools that work as databases of already certified suppliers, such as e-SPECS(Figure 8) that allows the selection of these sustainable materials during the design process, identifying and storing in schedules at the same time the potential green certificate credits gained by these selected items.[114]

BIM tools influence directly or indirectly during the certification process of green buildings, saving time and resources during the generation of required documentation.

Nevertheless, it is important to take into consideration that all the results from analysis and simulations offered by the different BIM applications will not be 100% reliable due to the fact that the information inputted on the models could have some inaccuracies, reason why it is always recommended by the revised literature that manual checks are made during the gathering of the documentation. [115]

[113] (Hughes 2012)
[114] (Jalaei, F., & Jrade, A. 2014)
[115] (Wong, J. K., & Zhou, J. 2015)

CHAPTER 3: METHODOLOGY

3.1 Method procedure

This chapter will incorporate the method used to have a clear understanding of the thesis subject, and how it will allow a clear answer to the thesis questions.

The research method of this thesis is a qualitative one, based on case studies of real projects and interviews with owners as well as experts, who have hands-on experience in construction and BIM in sustainable design and whose job is to encourage owners and other trades to buy into BIM and its benefits to proprietors.

The scope relating to this thesis including researches and interviews are conducted in both Europe and the United States whereas Leif Granholm, building SMART representative, indicates is among BIM leaders in the world:

"Based on national and governmental initiatives and support for construction industry development projects and standardization, Finland, Norway, Singapore, and the USA are clearly in the lead"[116]

Therefore, this attitude of thinking globally regarding BIM will help other countries, including developing countries, to be more influenced and motivated to move towards paradigm changes in building industry and to be able to apply those standards and enjoy the benefits that BIM provides.

Encouragement of the industry by BIM marketer in the United States and European countries are mainly done by periodic conferences. Since there are many truths and myths about BIM, the challenge is to recognize the actual truths within the claims of BIM marketer which might not be realistic in some cases and be just myths to sell their product.

The significant impact of this subject can be comprehended by an in-depth study of "Many well-meaning BIM connection in sustainable design, decision-makers, and practitioners in the building industry at-large which have had disappointing experiences after attempting to adopt BIM because their efforts and expectations were based on misconceptions and inadequate planning."[117]

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[116] (Juhola, Virve 2011)
[117] (Eastman, C., Teicholz, P., Sacks, R., & Liston, K. 2011)

Grasping all the issues regarding BIM and sustainable design, as well as uncovering the advantages of their use for owners, is the main focus of this thesis.

Building Information Modeling (BIM) has turned out to be progressively used over the development business inside the United States. While in presence since the 1980s, it just as of late that the innovation has been across the board inside the nation.

While there is no broad order for the appropriation of BIM in the United States, ongoing examinations have uncovered that the procedure is presently incorporated into the lifecycles of more development ventures. A 2014 McGraw Hill Construction Market Report uncovered that BIM reception by contractual workers in North America extended from 17% out of 2007 to over 70% out of 2012.

Its emotional ascent being used over the previous decade can be credited to long past due industry acknowledgment of the advantages that it offers to the task administration process and to building demonstrating when all is said in done. These incorporate expanded exactness, shorter task lengths, and diminished development costs.

The expanded selection of BIM innovation has not been kept to the U.S. advertise. All around, as indicated by an Allied Market Research titled, "World Building Information Modeling (BIM) Market - Opportunities and Forecasts, 2015-2022," the BIM advertise is relied upon to create $11.7 billion in income by 2022.

In light of developing interest from development/designing firms and individual development experts to learn and comprehend the estimation of BIM innovation, RICS has built up an inventive half year remove pick using Certificate Program in BIM Project Management. The course will empower clients to deal with the BIM procedure at each phase of their undertaking lifecycles.[118]

3.2 Interviews

Interviews with owners are conducted to get familiar with their main requirements and issues regarding BIM in sustainable design.

In fact, the reason for interviews with owners and experts is to first validate the theoretical benefits of BIM for owners, claimed by academics and vendors, against the

[118] (RICS 2016)[118]

shortcomings and obstacles which discourage or prevent them using BIM in actual work; and secondly to withdraw owners' recommendations and comments to improve and reach a better BIM which motivates them to apply in their projects.

Expert perspectives are more realistic and subtle due to the experiences gained in constructing various types of projects. In fact, they have been more open-handed to spend and take the risk of using BIM in pilot projects comparing with individual owners, and therefore their ideas and thoughts regarding BIM are more reliable and accordingly could be a good starting point to approach to the subject of this thesis.

It should be considered that the construction sector is so fragmented and therefore different participants' perspectives and actions can affect other trades actions and decisions. This includes the impacts of other trades' actions on the owners' decisions.

In addition to interviews with owners, interviews with experts of other trades are conducted and their perspectives regarding BIM and their concerns are reviewed. The experts who are working in service provider firms (AEC professionals and software providers) are consisting of architects, engineers, BIM managers, builders, construction managers, fabricators and BIM vendor's representatives whose different perspectives regarding BIM will potentially affect owners' decisions in the path of applying BIM.

Both interviews with owners and experts are conducted through semi-structured interviews. Semi-structured interviews, by definition, are done by using a guide with questions and topic that must be covered. This kind of interview is based on a two-way conversation between interviewee and interviewer in which, additional questions regarding the topic of the interview might be asked by an interviewer for clarifying purposes which are usually based on interviewee's answers.[119]

In the whole process of interviews in this thesis, including the guide creation, the emphasis is on owners' benefits to understanding how other trades can contribute benefits to owners through BIM.

In this context, the selection of the expert interviewees was another challenge. Looking for different BIM oriented companies through Europe and the U.S to be able to network and contact people in the industry who are actively working in BIM and trying to learn new things as well as have a feedback form was not an easy task.

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[119] (Harrell, Margaret, and Melissa Bradley 2009)

Understanding the owners' main requirements in conjunction with different service providers' perspectives through interviews gives the opportunity to evaluate the owners' requirements against the AEC sector and BIM vendors' capabilities in the next steps of this thesis.

Results of interviews are evaluated throughout the academic internet and library resources by considering the owners' requirement to ultimately testify the benefits of BIM which are truly advantageous for owners and also find solutions to improve BIM shortcomings in the market and leverage the pace of BIM adoption in the industry. Of course, due to the wide purview of BIM, seeking all solutions is not possible and can be the subject of another study by interested researchers.

3.2.1 Interview participants and questions

In this section, description of interviewees' backgrounds, which was determinant for their selection, is shortly outlined at the beginning of each segment to hopefully give readers a level of reliance regarding this research. Questions of these interviews are designed in a way to consider owners' benefits and issues.

Interviews were conducted with architects, engineers, designers as well as on-site practitioners and construction managers of contractor companies.

In the selection of interviewees, a balance between interviewees who believe in using BIM in Sustainable design, against the ones who are not that much interested or even is against it was desired.

The interviewees are experienced in their majors and most of them have touched the transition from hand-drafting to 2D and therefore their opinions about the transition from traditional 2D-CAD to BIM would be interesting. In this way, the opinions of different parties are collected and would be the base of discussion in the next chapter.

In other words, results of these interviews in conjunction with the interviews with owners will give information which makes it possible to analyze and evaluate them regarding owners' benefits and throughout academic literature.

However, BIM vendors among all other parties in the industry usually are not responsible or involved in construction projects' procedure and execution, their opinion, and perspective regarding BIM have a significant impact on the process of decision making

by owners regarding BIM utilization. Therefore, interviews with BIM vendors are conducted to withdraw their claim about their products (BIM applications) by focusing on the benefits particularly for owners.

The purpose of these interviews and base of the interview questions was to:

- Fulfill owners' requirements as much as possible by the aid of BIM in Sustainable Design
- Finding realistic motivating factors for BIM utilization by owners
- Finding creative ideas for BIM improvements to benefit the most
- Examination of owners' recommendations regarding BIM

Here is a small presentation about the interviewee's background:

Mr.Pedro Aibéo "*An Architect (M.Sc., Dipl. Ing., TU Darmstadt, Germany), Civil engineer(M.Sc., Licenciatura, FEUP, Porto), Cultural and Political Activist, Entrepreneur, Media Artist, Musician, Theatre Producer, Comic Novelist, Lecturer and Researcher on "Building vote based system". Moreover, the author and Artistic Director of "Cidadania" theatre recreations gathering, Germany, with more than 50 structures outlined and based on 15 nations right now rehearsing at "AIBEO design". He is additionally a Visiting Associate Professor at UNAM University, Mexico and at Wuhan University of Technology, China, and a Lecturer, Research Assistant and Doctoral Candidate at Aalto University, Finland on "Compositional Democracy". He has additionally consistently addressed Architecture at the Universities of QUT Brisbane, TU Darmstadt, and FAUP Portugal*".[120]

Mr. Navid Sanei Sistani is a Master graduate in Construction Management with more than five years of professional international experience in Construction Management with excellent interpersonal and management skills. He has a total number of seven publications in international conferences mainly in the field of BIM.

Currently, he is a **Construction Manager in Europe at WeWork** managing several projects (up to 5) between 5000 and 12.000 m2.

Mr. Peter Morton who is a principal consultant at Turner & Townsend. He published several papers related to BIM.

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[120] (Aibeo n.d.)

Mr. David Cheshire is a Regional Director at AECOM, having some expertise in manageability in the manufactured condition.

Case studies: The case studies that were chosen for further analysis in this thesis are all BIM related. However, there was a mix of choice regarding different uses of BIM for different projects to tackle various aspects of BIM uses and benefits on actual real projects.

3.3 Case study 1: Wellness Centre Building at the campus of Auburn University, Auburn, Alabama, April 2013

This contextual analysis shows the utilization of BIM for wellbeing arranging and administration. The task is Wellness Center Building at the grounds of Auburn University, Auburn, Alabama which is finished in April 2013. The undertaking group built up the BIM model of the office in the venture configuration stage and uses it for site coordination and constructability examination. Through-composed gatherings including venture supervisors, site directors, and subcontractors, all conceivable major and minor site dangers are recognized and suitable relief designs are produced (see Figure 9).

The important 4D liveliness is likewise utilized in the toolkit gatherings to show everyday development exercises to the laborers. Up until now, no major or minor mishap is accounted for at the site. The site directors evaluated BIM as "… an awesome apparatus for teaching laborers in brisk time about the site risks"[121]

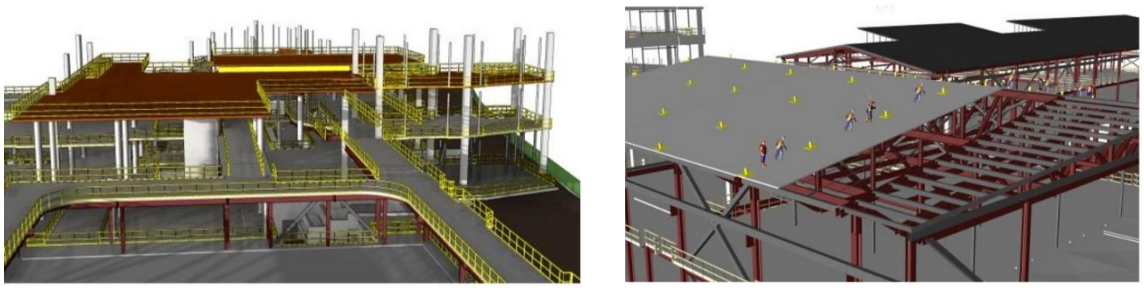

Figure 9 BIM-based site-specific safety plan[122]

[121] (Azhar, S., Carlton, W., Olsen, D., & Ahmad, I n.d.)
[122] (Azhar, S., Carlton, W., Olsen, D., & Ahmad, I n.d.)

3.3.1 BIM in the Construction Phase

In the development stage, the venture group can utilize BIM for the accompanying exercises:

- Project advance observing utilizing 4D staging designs;
- Trade coordination gatherings (see Figure 9);
- Integrating RFIs, change requests and punch list data in the BIM models.

All through the development time frame, the undertaking group should ceaselessly refresh the BIM demonstrate with the goal that it mirrors the most progressive data which later on can be utilized by the office directors for building tasks and upkeep.

The advantages of cell phone and tablets innovation have permitted temporary workers and too much of the time utilize BIM models at the activity site for data extraction and coordination.[123]

3.3.2 BIM in the Post Construction Phase

A building data show envelops finish data about an office as it develops through arranging, plan, and development. This data can be utilized for downstream use by office administrators subsequently making activities and support of an office more effective. Research recommends that 85% of the lifecycle cost of an office happens after development is finished and roughly $10 billion in yearly lost in the U.S. alone because of lacking data access and interoperability issues amid activities and support stages. The utilization of BIM for office administration (FM) can fundamentally keep these misfortunes. [124]

The basic preferred standpoint of a BIM show is that it gives data about a building and its spaces, frameworks, and segments. The primary essential objective is to move this information into office administration tasks. In this technique, data about building frameworks and gear can be gotten by tapping on a protest in a BIM demonstrate. For example, the data that is abused by a bit of gear, for example, a VAV box is an area, name, demonstrate number, item composes, activity and upkeep manuals, charging

[123] (Rubenstone 2010)
[124] (Newton 2004)

data and execution information. This makes it exceptionally straightforward for a support laborer to get to the required data fundamental to various frameworks in the work.

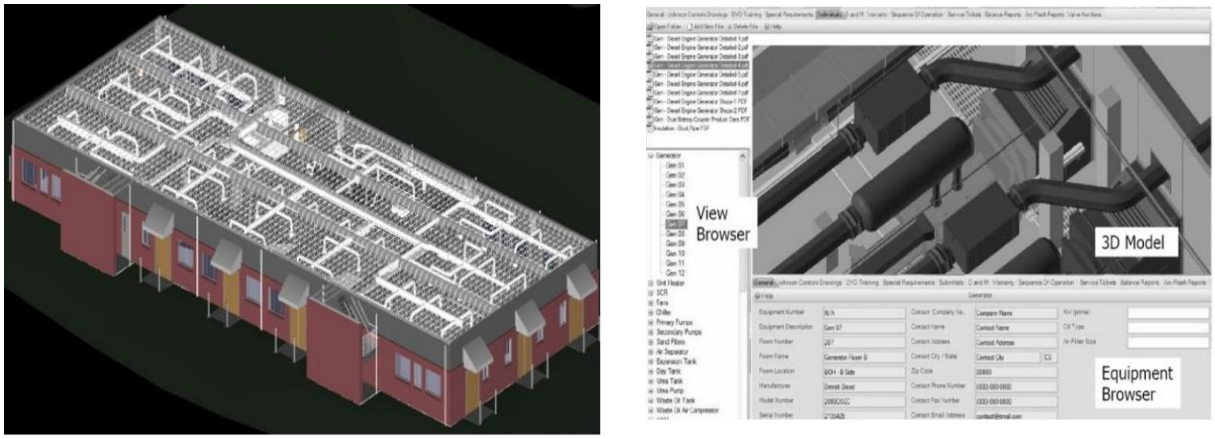

Figure 10 Illustration of the use of BIM in facility operations[125]

There are some extra applications of BIM for FM(Facility Operation) and management in terms of:

- Work order management and maintenance
- Emergency service usage management;
- Space planning and management;
- List management and control;
- Move management;
- Real estate portfolio investment and management. [126]

3.3.3 BIM Benefits for Project Stakeholders

Prior to examining the advantages of BIM for venture proprietors, originators, constructors, and office administrators, it is valuable to outline BIM applications for these partners. The individual advantages of BIM for every partner are consulted in the accompanying segments.[127]

[125] (Salman Azhar, Michael Hein and Blake Sketo n.d.)
[126] ((Philips and Azhar 2011)
[127] (Weygant 2011)

3.3.4 Project Owners

Proprietors can accomplish huge focal points on ventures where BIM innovation and procedures are connected. Eastman et al. (2011) and Reddy (2011) abridged the accompanying advantages of BIM for venture proprietors: (1) Early plan appraisal to guarantee venture necessities are met; (2) Operations re-enactment to assess building execution and viability; (3) Low money related hazard in view of dependable cost evaluates and lessened number of progress orders; (4) Better showcasing of undertaking by making compelling utilization of 3D renderings and stroll through liveliness; and (5) Complete data about building and its frameworks in a solitary document.[128]

Table 2: BIM applications for projects[129]

BIM Application	Owners	Designers	Constructors	Facility Managers
Visualization	x	x	x	x
Options analysis	x	x	x	
Sustainability analyses	x	x		
Quantity Survey		x	x	
Cost Estimation	x	x	x	
Site Logistics	x		x	
Phasing and 4D scheduling		x	x	
Constructability analysis		x	x	
Building performance analysis	x	x	x	x
Building management	x			x

3.3.5 Project Constructors

In the United States, general interim workers are the early adopters of BIM among all partners. The temporary workers and subcontractors can utilize BIM for the accompanying applications:[130]

- Quantity take-off and cost estimation
- Early recognizable proof of outline blunders through conflict discovery

[128] (Ku and Taiebat 2011)
[129] (Ku and Taiebat 2011)
[130] (Hardin 2011)

- Construction arranging and constructability examination
- Onsite confirmation, direction, and following of development exercises
- Offsite construction and modularization
- Site wellbeing arranging
- Value designing and execution of lean development ideas
- Better correspondence with the undertaking proprietor, creator, subcontractors,

Because of applications, constructors can accomplish the accompanying advantages:

- High benefit client
- Financial benefits and timetable pressure;
- Better creation quality;
- More educated basic leadership;
- Better wellbeing arranging and administration.

3.4 Case Study 2: the campus of Emory University, Atlanta, Georgia, USA

This contextual investigation delineates the utilization of BIM by the general temporary worker (GC) to limit plan blunders by means of conflict identifications. The venture is a $35 million scholarly working at the grounds of Emory University, Atlanta, Georgia, and the USA. The venture designer created the building model. The GC obtained 2D auxiliary and MEP frameworks illustrations from venture designs and changed over them into 3D BIM models. By incorporating all "single" BIM models and through conflict identifications in the preconstruction stage, the GC could unpleasant spare $259,000 as shown in Figure 11.[131]

Item	# Of Collisions	Estimated Cost Avoided	Estimated Crew Hours		Coordination Date
Construction (MEP/ Structure Collisions)					
Basement	9	$2,041	5.5	hrs	*December 12, 2007*
Level 1	107	$93,050	188	hrs	*April 14, 2008*
Level 2	43	$41,913	87	hrs	*February 14, 2008*
Level 3	78	$61,070	132	hrs	*May 12, 2008*
Level 4	65	$33,525	77	hrs	*February 29, 2008*
Level 5	87	$78,543	164	hrs	*April 22, 2008*
Penthouse	25	$25,684	52	hrs	*May 12, 2008*
Subtotal Construction Labor	414	$335,826	705.5	hrs	
15% Material Factor		$50,374			
Subtotal Cost Avoidance		$386,200			
Deduct 33% assumed resolved via conventional methods		($127,447)			
Approximate Cost Avoidance		**$258,753**			

* Direct Collision Detection Savings Only. Indirect Savings (i.e. General Conditions, Escalation, Design on Construction Administrative Time Savings Not Included.)

Figure 11 Use of BIM in the project preconstruction stage (Courtesy of Holder Construction Company, Atlanta, GA)[132]

[131] (Azhar, S., Carlton, W., Olsen, D., & Ahmad, I n.d.)
[132] (Salman Azhar, Michael Hein and Blake Sketo n.d.)

3.4.1 Facility Managers

The utilization of BIM has two noteworthy advantages:

- The same basic data is available in a solitary electronic document;
- The office administrators do not need to filter through the heaps of data to assemble information.

As specified by Reddy (2011), *"with the BIM database, any data around a hardware is only a single tick away."* The office directors can tap on any gear or apparatus to get data on the item, guarantees, the existence cycle of the item, upkeep checks, substitution cost, establishment, and repair techniques, and even put in a request for a substitution on the web.[133]

The benefits of cell phones and tablet gadgets, for instance, iPhone®, iPAD®) and Augmented Reality (AR) has made it feasible to latest data about a building part by simply pointing the tool towards it.[134]

3.4.2 Hazards and Barriers to Implementing BIM

Other than various focal points of BIM for venture partners, there are numerous risks and boundaries for executing BIM. As it were, BIM is not a panacea for each venture and each firm. The BIM related dangers can be isolated into two general classifications: (1) Risk in Technology related and (2) Dangers in process related

Following areas exhibit a concise exchange on every classification.

Innovation related Risks he principal innovation related hazard is an absence of BIM norms for display reconciliation and administration by multidisciplinary groups. Incorporating multidisciplinary data in a solitary BIM demonstrate requires multiuser access to the BIM show. This requires the foundation of conventions in the task programming stage to guarantee consistency in data sets and arranging styles. Right now, since there are no standard conventions accessible, each firm receives its own guidelines.[135]

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[133] (Jordani 2010)
[134] (Jordani 2010)
[135] (Weygant 2011)

It can make irregularities in the model, which if not appropriately identified, could prompt wrong and conflicting BIM show. The task group ought to perform visit "show reviews" to guarantee evasion of any such issues.[136]

The interoperability issues, however fundamentally lessened amid the most recent 5 years, still posture extensive hazard. Interoperability is the capacity to trade information between applications to encourage evasion of information re-entry. The presentation of Industry Foundation Classes (IFC) and XML Schemas has altogether understood interoperability issues. In any case, both of these methodologies have their innate impediments. The clients must research interoperability while choosing BIM programming applications. At the point when the venture colleagues other than the proprietor and modeler/design contribute information that is coordinated into the building data demonstrate, permitting issues can emerge. For instance, gear and material sellers offer plans related to their items for the comfort of the lead fashioner with expectations of initiating the originator to indicate the merchant's hardware. While this training may be useful for business, permitting issues can emerge if the plans were not delivered by an architect authorized in the area of the venture. [137]

3.4.3 Process-related Risks

The primary hazard is the absence of assurance of responsibility for BIM information and the need to ensure it through copyright laws and other legitimate channels. For example, if the owners spending money for the plan, at that point the owners could feel qualified for possessing it, however in the event that employees are taking data restrictive to utilize on the venture, all the exclusive data could be ensured.

Accordingly, there is no reply basic to the topic of information owners; it needs a novel response for every single task contingent upon the members' needs. The objective is to restraints or disincentives that demoralize members from the total comprehension of a potential model. To keep a contradiction over copyright issues, the best arrangement is to set forward in the agreement reports possession rights and obligations.[138]

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[136] (Smith and Tardif 2009)
[137] (Thompson and Miner 2007)
[138] (Rosenberg 2007)

Also, frameworks, for example, spaces, dividers, pillars, and sections. A building data demonstrate conveys all data identified with the building, including its physical and utilitarian qualities and task life cycle data, in a progression of "brilliant articles".[139]

Shown that the accompanying kinds of advanced models under the class of BIM:

- Plans and models which contain 3D information just and no protest properties
- Models are made out of numerous 2D CAD reference documents that should be attached to characterize the building
- Models cannot be converted to measurements in a single view that there are not consequently reflected in different perspectives. [140]

[139] (CRC n.d.)
[140] (Eastman, C., Teicholz, P., Sacks, R., & Liston, K. 2011)

CHAPTER 4: RESULTS AND ANALYSIS

4.1 Interviews Analysis

In this chapter, the results of interviews with owners as well as expert service providers are explained and analyzed. The focus in all interviews was on owner's benefits to understand their issues, concerns, and requirements regarding Application of BIM in Sustainable Design and how to fulfill them to the best possible level.

4.1.1 Owners and Experts Discussion

The choice of interviewees was based on their field of activity, career, experiences and general thoughts' towards the subject. It covers a majority of owners and experts issues, concerns, and requirements regarding the subject matter of BIM.

The majority of the interviewees believe in BIM except for one who has moderate ideas and is not really a BIM supporter unless it is for some special complicated projects. So there is a difference of opinions regarding BIM too.

Following is the summary of debates which reflect the main results of these interviews with owners, and experts about general concerns and partially their recommendations for a better BIM:

Mr. Pedro Aibeo who is an MSc Architect and MSc Civil Engineer, he is the CEO of "Gamified Cohousing", a Vis. Associate Professor at UNAM and researching on the topic of "Architectural Democracy" at the Aalto BIM lab, Aalto University.

Mr. Pedro Aibeo explained:

In my company, Gamified Cohousing Oy, BIM has been used to combine the different models from the old buildings we are renovating. Data from laser scans are combined with classical measurements for example, or sometimes through Photogrammetry modeling. An example is the ongoing Hyrsylän Koulu renovation in Finland that we are working on.

BIM is only useful if the facilitator (designer) has already the know-how in place and if the scale of the work justifies it. If the projects are small, using BIM is too time-consuming, and time is expensive.

the significant elements involved in Application of BIM in the sustainable design as most of the companies, we are not really thinking about sustainability but about being in the forefront of what is being done in the sector. If you think of the most direct notion of sustainability, which is, something you can repeat forever, BIM is just one more step of the ever ongoing changes in the architecture and construction industry.

As we are still a small company with small projects, the data is compiled and validated mostly manually by allocating it into the right folders on the cloud: work in progress folders, shared with the client (validated but requiring feedback) and then published. We try to do these in a lean agile way, in small steps of each stage. Does this support sustainability in our projects? Maybe! We have no data to support it.

Using BIM allows a more controlled set of data and drawings that can be updated in the future and likely integrated into other platforms (whichever these will be). This is our biggest bet on part of sustainability, that it allows integration into future steps decreasing errors and improving the passage of information.

Our business idea is about gamifying cohousing and co-working, to turn empty buildings into economies, mostly from old buildings. The data we get is rough and so it is very important to have it updated and to make these new buildings fit for future usage. This might be labeled as sustainable design, to be concerned about the readability of documenting a project for our team but mostly for others and future generations.

Navid S.Sistani who is working as a Construction Manager in Europe at WeWork explained that the company is using BIM from the beginning (laser scanning) until end of construction. They are using the form of Common Data Environment (online platform for data exchange and collaboration) supported by (server, cloud-based system, etc.).

The company uses laser scanning to capture as build situation of the building and create the automated model based on the existing situation of the building. The layouts and interior design are done by Revit. Working on a BIM model from the beginning results in a fast transition from one phase to the next one. The execution drawings are also created in Revit which makes extracting the required information in form of the plans very easy. The clash detection and creating coordination plans are other advantages of using BIM and base on having informative data. The stakeholders can benefit from the advantages in terms of time and money because of using this method.

According to Mr. Sistani, the impediments which prevent owners to apply BIM in several projects is the learning curve, the lack of well-established process for starting to use BIM and the lack of local standards for using BIM in Germany. There are several companies which are interested in using BIM, but they can't find a proper consultant or team to integrate BIM into their business.

The most impressive characteristics of BIM, which have a significant effect on sustainability, are:

- Facilitating the process by accelerating the transition between phases and helping with data flow among different stakeholders.
- Saving time and cost by providing faster communication between different parties and avoiding the clashes and reworks.
- Meet the society requirements (legal) and needs (personal) by using the 3D models and simulation.

The tools and platforms which are available and have the capacities to monitor and approach multitask regarding the sustainable aspects and BIM in the WeWork company projects are:

- Revit (BIM 360) enable different parties to work on the same model which can save a huge amount of time and effort.
- Laser scanning machines make it possible to capture the real specification of the buildings and create the most accurate as the build model.
- Working on the model improves the decision making the process by accelerating applying and reviewing the changes to the model.
- The 3D model improves the understanding of the final result (especially interior design) at the earliest stages.

The disadvantage that could alter BIM’s utilization and decision-making factors of owners is their uncertitude about the success in using BIM and lack of local standards and well-established processes.

The business idea of his company (WeWork) is to gather the people from different companies and with different expertise as a big community to not only work but also

be able to share their experiences and expertise with each other. For this reason, BIM helps his company to achieve this goal by creating a most efficient layout which creates the best "member experience" (social). Using BIM also enable them to have a complete overview of the costs and usage of material and energy (which is very helpful in fulfillment of sustainable certificate requirements).

There are could be several profits in using BIM in sustainable design and it is beneficial for the society and the environment because using BIM make it possible to calculate and monitor the green characteristic of the building (material usage, energy consumption, CO2 emission, etc.)

The biggest effect of BIM on their company's society is a more efficient customer satisfaction (the growth of the company in the last 5 years is proof of this).

Peter Morton who is a principal consultant at Turner & Townsend expressed that BIM is an **empowering tool:** it has brought greater efficiency to projects, added value for stakeholders and increased awareness of physical and data security. Its use empowers engaged clients to specify their asset requirements to achieve operational efficiencies with their built assets.

This new approach to technologies, processes, and behaviors has also created new roles, responsibilities, and authorities. The BIM-enabled project manager, for example, now plays a crucial role in advising clients, and internal and external stakeholders on the benefits of BIM, and in implementing and managing BIM processes throughout the project life-cycle.

It also has an **engagement party effect**: Many clients are still disengaged from the BIM process, either through lack of knowledge or awareness. Ultimately, they may not fully appreciate what they want to achieve from using BIM on their projects, or what value can actually be realized. This can leave clients as passengers, rather than an integral part of the process. It is the project manager's role to engage clients and identify exactly what they want to achieve from BIM, and the purpose of any data requirements throughout the project life-cycle.

BIM enables an **altogether now**: A BIM-expert project manager should demonstrate a deep knowledge of the BIM process, and be able to foster a positive and collaborative environment, in which a project can realize the full potential of BIM. It is also important to simulate the BIM life-cycle processes, both on the client side and the delivery side,

before putting them into practice. Technical requirements have to be balanced with project management skills, so you can confidently implement a BIM methodology.

BIM is a **gold mine of information**: It is vital to have a good command of delivery documentation, such as organization information requirements, asset information requirements, employer's information requirements (EIR) and the BIM execution plan, among others. The EIR (Employer Information Requirements) is particularly important, as it enables you to communicate the client's requirements to stakeholders in a clear, structured format.

David Cheshire, a Sustainability Director at AECOM, provides insight into the need for a more circular economic model in the built environment.

"He conveyed that the construction industry accounts for approximately 60% of UK materials use and one-third of all waste arising. Buildings are stripped out every few years and often torn down well short of their design life with hardly any products or materials being reclaimed for reuse. This linear model of 'take, make and dispose of' is depleting the world's precious resources and is creating mountains of waste with very little scope for reclamation.

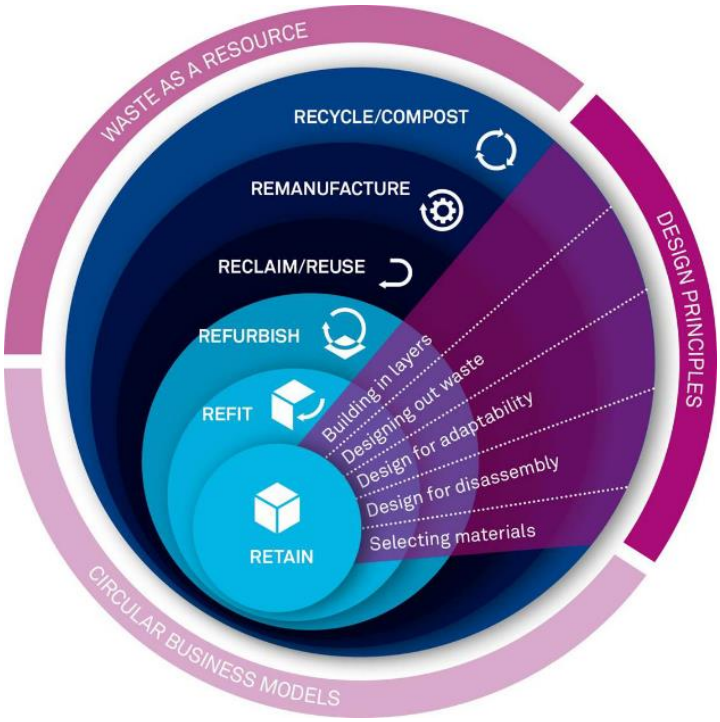

Figure 12- circular-economy-built-environment (Cheshire 2016)[141]

[141] (Cheshire 2016)

A new model is emerging, one that moves away from this current 'linear economy', where materials are mined, manufactured, used and thrown away, to a more circular economy where resources are kept in use and their value is retained. Designing and constructing buildings that can be adapted, reconstructed and deconstructed, and which are made from materials that can be reused or recycled, would help to create a more regenerative built environment".[142]

Predrag.J believes in general that except special projects, using BIM for every project is not cost-efficient or actually necessary. However, he has already required the use of BIM for special projects, he thinks BIM utilization should be case specific and based on the project complexity and conditions. Moreover, in those kinds of projects, he mainly counts on pre-construction benefits of BIM rather than post construction; because he believes in practice and due to maintenance staffs' lack of knowledge or motivation at this time, it's not realistic to count on long-term benefits of BIM for having more efficient facility management and building maintenance.

His examples of special projects are laboratories and animal facilities were, for instance, the interstitial space above the ceilings are up to 6 feet for duct works; in this case use of BIM can reduce the interstitial height to 4 feet by accurate and efficient use of space, which saves the big amount of money in the whole building's construction costs. Another example is quarantine rooms in laboratories where isolation level should be high-ended and therefore seeks a high level of accuracy which is too difficult or even not possible without BIM.

Precisely, Predrag's personal concerns are not about the initial costs of BIM but the maintenance cost of BIM; the effort which should be taken to update the model during its lifetime is challenging and expensive. He sees the remedy in using 2D CAD as before and using BIM whenever it's necessary and in a case-specific manner.

Furthermore, Predrag truly believes almost all the features which BIM applications promote etc., were being done before while using traditional AutoCAD 2D files. He talks about his personal experiences by working in previous big projects, all in 2D CAD.

"Our change orders resulting from interferences were extremely low. Change orders were almost no existing. ", he continues, "Even the several change orders we were facing with were due to concept change or changes due to site conditions which have

[142] (Cheshire 2016)

nothing to do with BIM affairs." He believes "If the designer and engineers are good and consulting and quality control teams check constructability properly and review team is professional, you'll be fine and there is no need of BIM."

Accordingly, he offers the use of 2D CAD plus information management in the projects, which he calls "2D Building Information Management" or "2D BIM". The advantage will be achieved when all trades are doing their jobs as before and only some of them are involving with information management of existing data. This will possibly save time and money due to the reduced number of involved people and systems. In other words, he translates 2D BIM as a traditional 2D CAD system which is boosted by Building Information Management (BIM). He recommends some improvements in means and methods of data exchange between respective software. Consequently, the benefits of information management are maximized with less investment in hardware upgrades and training.

"The good thing about BIM is the communication platform it provides," Predrag noted. His focus while talking about communicational benefits is on communication between architect and owner by 3D visualization and walk-through feature of BIM applications. Communication between owner/user and architect by BIM makes it possible to design based on users' needs and requirements in which it will avoid further change orders. It should be noticed that he believes "change orders due to conflicts can be eliminated by hiring professional experienced architects and engineers instead of BIM." He thinks, however, 3D visualization has been existing before BIM emergence, the detail and quality is boosted by BIM and therefore using

BIM for visualization purposes could be beneficial. On the other hand, he states, "Better communication among other trades of construction is good but it is not a concern that an owner should deal with and pay for it."

As a conclusion of the interview, he states, "If you ask me today if I would do my projects like before I would say yes!" In his opinion using BIM for mechanical or structural design (except special projects) is not necessary and only imposes new costs on the building and owner. "Why should I apply BIM for a residential building with the simple mechanical system if it costs me more than before?" He doesn't deny the benefits of accurate and coordinated design for better quality but at the same time he thinks in

every business including construction business, every benefit has a cost and in this case, the benefits are not worth the costs they impose (in short-term and long-term).

Regarding Predrag recommendation about 2D BIM, it should be considered that data management in the 2D system is possible, but seeks huge effort and perfect organization for managing a high volume of fragmented data. In most cases, it is subject to defeat due to the disorderly massive amount of information. In fact, the problem with subsidiary 2D CAD-based software is that they are not integrated into one platform as they are in BIM applications. All BIM is doing is to get together all these functions into a single platform by means of information management, in 3D and with a better quality if applied efficiently.

However, Predrag's concerns are in a way correct but some of the problems mentioned due to lack of knowledge about BIM and by solving this problem, other issues will be solved smoothly thought the path of BIM adoption. As it is mentioned in chapter one, this path will be passed predictably just like other technologies have passed so far; the smart action is to accelerate the adoption properly and quickly.

Predrag's opinion for not using BIM for every project is also because of his experience in complicated large projects which have been successfully delivered with minimum clashes. His point of view traces back to his experience, so he feels confident about doing the job in the same manner he used to do. But the question is: what about a new generation of engineers and designers who might not even imagine hand drafting or 2D CAD? Technology enhancement is running and surely every technology's mission is to provide new handy options or to improve previous ones in an easier manner. In fact, it shouldn't be forgotten that technology is for human beings to make tough, difficult or even impossible things possible and easier.

When the technology of BIM already exists, why a fresh engineer should do the job in an old time-consuming fashion? The answer might be the fiction of training issues or costs of BIM, but training issues are the only transitioning problem for engineers who want to shift from the old system to the new system. However, learning BIM requires a serious and organized undertaking; new generation's efforts for learning BIM could be presumed to be equal or even less compared with learning 2D CAD software by previous generations. This is because of the popularity of computer-aided affairs in today's

world. Nowadays everybody is a geek in using computers and therefore learning BIM is not as difficult as learning AutoCAD was 20 years ago.

Mr. Mostafa Dadashi who is a Ph.D. student in the field of Construction Engineering and Management at Amirkabir University of Technology (Tehran Polytechnic) and founder of the BIM lab in the university and have implemented BIM in several projects in Tehran.

He stated that their pursuit trend for projects is to prepare an assistant for projects management. BIM is implemented through the lifecycle of the project mostly in the design and construction phase and managerial services such as project control and monitoring which are also part of the work scope. Web-based tools are used in order to exchange the information and reporting system. Jahad ministry project is one of their experiences in BIM implementation. The consultant prepared the drawings and the process of modeling were carried out by the team members and then clash detection through different parties (Architecture, Structure, and MEP) were run. Afterward, clash reports were sent back to form the base for drawings correction. Moreover, constructability analysis was run through 4d simulating the project construction phase. Precise volume estimating was also another use of BIM models in the project. Virtual Reality has also been used to reduce the change orders by finalizing the spaces allocated by the consultant's schema.

BIM is a new approach in Iran's construction industry and lack of awareness about its benefits by owners and employers is the most important impediment to its implementation. Moreover, the increase in project cost in initial phases is another factor because the cost saving in the construction phase that origins from BIM implementation in the design phase are not tangible for owners. They have not used BIM models in real projects for sustainable purposes but they wish they would have the experience.

There is a misunderstanding for BIM concept in some owners that have not had former positive experience of BIM implementing that they think BIM is just a 3D model. This could have influenced the project's decision-makers through using BIM in project or not.

Price of energy in countries such as Iran is not comparable with developed countries so there was not a resolved inclination in taking advantage of the opportunities provided by BIM approach. On the other hand, water and energy crisis in Iran makes it

clear that in future sustainability analysis, it will be widely considered in the construction industry of the country.

4.1.2 Experts (AEC & BIM Marketer)

After interviews with the owner, the main issues and concerns of them are recognized as:

- Costs that BIM imposes to the project
  - Pre-construction
  - Post-construction
- The time it takes to design in BIM
    - Liability issues

The opinions of different experts regarding the above-mentioned points were quite different. Followings, the opinion of the interviewees was underlined in which comprehensively reflects the opinion of other interviewees.

The question was asked to interviewees about the initial (pre-construction) costs of BIM which are increased compared to traditional project delivery systems.

Different ideas were explained:

After being asked several questions about the benefits of BIM in Sustainable Design for owners, **Mr. Parveen.Sh** who is a BIM Engineer said:

That in his idea Using BIM has several advantages which include:

- Better Cooperation and Communication
- Model-Based Cost Evaluation
- Preconstruction Project Visualization
- Improved Coordination and Clash Detection
- Decrease Cost and Mitigated Risk
- Improved planning and Scheduling
- Enhancement Productivity and Prefabrication
- Secure Construction Site
- Powerful Building Handover and Facility Management

4.1.3 Several Benefits of using BIM

According to the evaluation of using BIM in the UK, Canada, USA, New Zealand, and South Korea, the BIM take a long-term to achieve because the Building Information Modelling still has not been fully implemented.

Significantly, the first three places are employed by benefits regarding various process phases: internal, design and construction. This determines in evidence the transversally of BIM: it has significant effects on each phase of a project.

Table 3 demonstrates 15 BIM benefits pinioned by experts and companies including Architecture, Construction, and Engineering.[143]

Table 3: BIM Usage Benefits[144]

BIM USAGE BENEFITS	% VOTES	BENEFIT TYPE: INTERNAL	PROJECT PHASE	CONSTRUCTION PHASE
1. REDUCED ERRORS AND OMISSIONS	41		★	
2. COLLABORATION WITH OWNERS / DESIGN FIRMS	35			★
3. ENHANCED ORGANIZATIONAL IMAGE	32	★		
4. REDUCED REWORK	31		★	
5. REDUCED CONSTRUCTION COST	23		★	
6. BETTER COST CONTROL / PREDICTABILITY	21			★
7. REDUCING OVERALL PROJECT DURATION	19		★	
8. MARKETING NEW BUSINESS	19	★		
9. OFFERING NEW SERVICES	14	★		
10. INCREASED PROFITS	14	★		
11.MAINTAIN REPEAT BUSINESS	13	★		
12.REDUCED CYCLE TIME OF WORKFLOWS	10			★
13.FASTER CLIENT APPROVAL CYCLES	9			★
14.IMPROVED SAFETY	7		★	
15. FASTER REGULATORY APPROVAL CYCLES	6			★

BIM Usages E

[143] (Francesc Salla 2014)
[144] (Francesc Salla 2014)

4.1.4 Difficulties and Challenges of Implementing BIM

One of the most significant difficulties and challenges that owners should deal with and could have the significant impact on the whole process from Design to Operation and Maintenance is the selection of team members and participants in a project. By applying BIM, the responsibility of owners for selection of team members becomes more crucial than before. As BIM concept is based on integration, the quality of each member's work can affect others and subsequently qualified team members can lead a project to success and lack of proper team qualification can cause major failures in a project.

In addition, proper RFP reflects the owners' BIM goals, requirements and their expectations of BIM teams. "Many Requests for Proposals (RFPs) by owners include a set of pre-qualification criteria for prospective bidders."[145] Below metrics and points can be considered by owners to outline proper RFP:

- Alignment with the business corporate metrics
- Milestone dates · Safety expectations
- Sustainability goals (energy performance, rating system compliance, etc.)
- Number of RFIs and change orders
- Definition of value and measurement of achievement
- Schedule
- Budget

As a result, having motivated and professional co-workers with the sense of collaboration and willingness to examine a new type of project delivery is a great opportunity that could definitely have tremendously positive impacts on the work environment.

- Is this association set up to be fruitful with BIM?
- Is the BIM aptitude you will require to accomplish your coveted execution procedures and objectives accessible in your land region/locale? If not, would you be able to secure it adequately somewhere else?
- How will the planning group, development group, specialists, and subcontractors grasp the utilization of BIM?

[145] (Eastman 2008)

- Are their states of mind about BIM lined up with your task and friends objectives?
- Are your current venture advisors and constructors BIM proficient? On the off chance that they have not utilized BIM, would they say they are eager and ready to progress to a BIM procedure?
- Will, you consider investigating new associations with new colleagues who have shown BIM ability?

Furthermore, considering below-mentioned points regarding selectees' organizations will help owners for better qualification:

- Identify the inner bosses to lead the BIM usage process.
- Ensure that upper administration is completely on board and steady of the procedure.
- Consider the company's eagerness or capacity to take part in substitute types of undertaking conveyance.

4.1.5 Preliminary Costs Justification

BIM has the potential benefits for service providers who use it. In most cases, among all initial costs of BIM, training costs exceed the hardware and software upgrades and subscriptions. Traditionally, service providers are not likely to make such investments "unless they perceive the long-term benefits to their own organization and/or the owner subsidizes the training costs".[146] However as it's been mentioned by one of the interviewees this attitude should change and actually is changing in many design consultant organizations, the challenge remains for owners to:

- Identify outstanding service providers who are willing to bear the initial costs of applying BIM (training costs) themselves and actually they have already applied it for their own benefits (not paying more for BIM service as many smart owners do).

[146] (Eastman, C., Teicholz, P., Sacks, R., & Liston, K. 2011)

- Even if the service provider company is willing to charge more for BIM delivery, owners should evaluate the potential gains in productivity, quality, asset management, time and cost savings, etc. against the agreed initial costs with the service provider company.

As a matter of fact, justification of preliminary costs by owners requires an accurate assessment of the project which in change demands the owner's involvement. The sooner is this involvement; the more opportunities will be achieved for effective BIM employment.

4.2 Case study Analysis

4.2.1 Case study 1: Wellness Centre Building at the campus of Auburn University, Auburn, Alabama; April 2013

The developed project BIM model of facility management in the design phase was utilized in site for coordination and construction. Having the project team, site superintendents and subcontractors involved in the project management helps define major and minor site risks. The advantages of BIM in the construction phase are several, which include using 4D phasing plans that help monitor the project process, manage the business meeting, and unite RFIs to shift order and list information in the BIM models.[147]

Nowadays, the several benefits of using smartphone and tables have permitted contractors to use BIM models all the time on the site for the latest information and exercise more effort for the project. Using BIM for facility management could have a remarkable influence to integrate information of the whole planning, design, and construction. It can also impede losing money in the whole of the life cycle of a building.

The essential benefits of BIM model are to prepare the information about the building, systems, and details. The most significant aim is to convert this data into facility management operations.[148]

[147] (Azhar, S., Carlton, W., Olsen, D., & Ahmad, I n.d.)
[148] (Rubenstone 2010)

- Proprietors could achieve remarkable benefits on projects where BIM technology and processes are applied.
- The summarized benefits of BIM for project owners include:
- Checking several times primary design assessment to ensure project requirements are met;
- BIM helped to evaluate building performance and maintainability;
- Reduce financial risk because of reliable cost estimates and less number of change orders;
- Superior marketing of project by using 3D renderings and walk-through animations; and complete information about building and its systems in a single file. [149]

According to other perceptible and imperceptible benefits of BIM, large project owners are requiring designers and contractors to use BIM in all project aspect.

The project architects and engineers will make the most of BIM in the schematic of design, and construction particularisation phases as consequence in the following are of a number of the most stages of BIM for project types:

- Higher style by strictly analyzing digital models and visual simulations and receiving a lot of valuable input from project owners
- The early connection of owner options in building design to predicts its environmental performance
- Higher code compliance via visual and analytical checks
- Early rhetorical analysis to diagrammatically assess potential failures, leaks, evacuation plans and then forth and fast production of look or fabrication drawings.[150]

In the USA, general contractors are mostly adopters of BIM among all stakeholders. The contractors and subcontractors can use BIM for the following applications:

- Latest identification of clash detection throughout style errors
- Analysis construction designing and constructability overview
- In site verification, guidance, and the pursuit of construction activities

[149] (Pinske, J., and Marcel D 2008)
[150] (Ku and Taiebat 2011)

- Offsite fabrication and modularization
- Site security and safety designing
- Higher communication with the project owner, designer, subcontractors and employees on the website.[151]

4.2.2 Case Study 2: The Campus of Emory University, Atlanta, Georgia, USA.

The goal of this study was to demonstrate the benefits of using BIM by utilizing the general contractor in order to minimize design errors via clash detections. However, it should be mentioned that there are several barriers and hazard which are basically an integrate parts of utilizing BIM. Therefore, it should be taken into account that the BIM is not the suitable remedy for any types of project and even for all firm. According to the studies, the most common type of risks in utilizing BIM could be divided into two categories such as Technology based ricks and Process-related risks.

Technology-related Risks: Lack of necessary standards in BIM for integrated modeling and management through multidisciplinary groups. Desegregation of multi-disciplinary information is an example of a single BIM model, which requires the BIM to be multi-user access. In order to answer this demand, the institution of protocols within the project programming section needs to the confirm the consistency of the information context and data formatting designs. In the instant, due to lack of the access to any customary protocols, every firm adopts on its own standards. This issue will cause inconsistencies within the model which if not properly be identified will lead to inaccurate and inconsistent BIM model. The project team ought to perform frequent “model audits” to confirm rejection of any such problems.[152]

The ability problems, though considerably reduced throughout the last five years, still cause appreciable risk. Ability is that the exchange of information between applications is to facilitate automation and rejection of information re-entry. The introduction of business foundation categories (IFC) and XML schemas has considerably helped to re-

[151] (CRC n.d.)
[152] (Jordani 2010)

solve ability problems. However, each of those approaches has their inherent limitations. The users should analyze the ability whereas choosing BIM package applications. [153]

Certifying problems arise once other projects teams (sidewise from the Architect/Engineer and owner) add to the project information, which becomes integrated into the building model. For example, material suppliers style their products for the suitability of the principal designer in the hope of making the designer mention and specify the supplier's product, which can cause licensing problems if the designer did not create the products. [154]

These processes are subject to risk, and hold legal, written arrangements and configuration of risks. One of the main risks is the absence of clear determination of ownership of BIM information and consequently has to protect it throughout copyright laws or other legal stations. For example, if a proprietor is paying for the planning design, then he could feel eligible to own it, but if some suppliers are offering data to be used in the project, their ownership data must still be safeguarded. Therefore, it is not easy to answer the question of information proprietorship; it is only answered depending on each project and the contributors of it.

It is important to escape reserves or impediments that can dissuade contributors from creating the model's full potential. To avoid dispute over ownership problems, it is more effective to clearly distinguish within the contract documents ownership rights and obligations. [155]

A building's information model conveys all information related with the building, as well as its bodily and beneficial characteristics and life cycle information in a series of what is called 'smart objects'. For example, subordinate air-conditioner unit among BIM smart objects should conjointly comprise data regarding its supplier, manoeuver and maintenance measures, flow rates and permission requirements. [156]

- Displays the following types of digital models do not include the class of BIM: models that comprise three-dimensional data only and no object characteristics.

[153] (Weygant 2011)
[154] (Weygant 2011)
[155] (Thompson and Miner 2007)
[156] (Smith and Tardif 2009)

- Models with no backing of behaviour;
- Models that are comprised of numerous second CAD resource files that need to be joint to shape the edifice.
- Models that permit alterations to dimensions in one display that is not mechanically reflected in alternate views.[157]

[157] (CRC n.d.)

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1Conclusion

The concept of BIM is genius impactful in the AEC industry. BIM's potentials and advantages are of great influence on the society and the environment, but it still needs more time to be well adapted.

The Value of BIM for owners has been described as follow: Saving money and time during the whole Building's Lifecycle. Training in the technical aspects of BIM for its users; from owners, designers to builders and maintenance staffs as well as promoting the culture of BIM in societies is a vital factor which should be taken more seriously; otherwise BIM can only be considered a great opportunity which gradually will become unused due to lack of awareness and knowledge about it. Recently several developed countries such as Scandinavian countries, Germany and also Canada are much more interested in using BIM in a different field of construction and facility management, not only BIM utilization has several benefits for the environment but it also has several advantages for owners in different aspect especially in huge projects rather than small ones.

Operating BIM for owners can improve building quality significantly, reduce building lifecycle costs, help understand design projects from beginning to end, optimize operational efficiencies, and increase occupancy and use rate. In addition, it saves money and time in the design phase (in conceptual design, sustainable design & design documentation) as well as up internal business advantages such as decreased document errors and omissions (61%), reduced rework (36%), decreased construction cost (30%), decreased project duration (22%) and fewer claims (17%).

Moreover, it should be observed that considering the initial or secondary costs of BIM alone, is not enough factor in making a decision regarding BIM's utilization, as many owners do. As it has been explained through this research, these costs will be normalized through the path of adoption, this is mainly due to the competition in the market for winning projects at better bids as well as the demand/supply relationships which are already mentioned. More concentration on other decision-making factors (mentioned in this thesis) especially socio-cultural factors (which are more overlooked by owners) and evaluating them against each project's specific conditions are recommended to ultimately find a balance between different factors introduced and explained.

The balance between the qualitative and quantitative benefits of BIM is needed in order to achieve maximum effectiveness of BIM in construction projects. Until the day this balance is established, it should be tried to implement BIM in more projects by encouraging owners to require BIM in their projects; so industry experience more opportunities for BIM adoption.

This fundamentally necessitates owners' awareness about the quantitative benefits of BIM resulting in cost and time reduction besides having better quality; as well as qualified benefits of BIM utilization as socialo-cultural determinant factors in the process of decision making.

As it is mentioned in this research, BIM like CAD will be inevitably adopted and utilized until the next technology (related to design and construction) emerges. Logically the faster the adoption occurs the sooner the benefits of BIM will be achieved by the industry. It should be also noticed that by "adoption" it is meant an adoption that is adequate and technical and cultural viewpoints are considered in it.

The role of governments in this adequate adoption and transition acceleration is significant which can be performed by motivating owners for BIM utilization more and more. BIM increases the quality of life of the people residing or working in buildings, reduces costs and energy. Moreover, it better fulfills the green building criteria, speeds up the society's level of development, and will subsequently lead to the cities, countries and ultimately global gradual growth. These all could be enough reasons for governments to help faster adoption of BIM.

On the other hand, by accounting the BIM efforts and costs through the building's lifetime, and comparing them with the benefits it presents, it can be concluded- as one of the interviewees said: "BIM is not going to be cheap"- because even by the normalization of BIM initial costs, future maintenance and updating costs of BIM are a new added cost which previously didn't exist. At the same time, the profits that BIM brings to a project, which is due to its accurate and more organized information management in an intelligent model, should be taken into account by owners. In order to decide whether to use BIM in a project or not (which is the topic of this thesis), a comprehensive evaluation is needed to consider all different factors which are already mentioned in this research besides careful attention to each project 's specific conditions.

While the importance of socio-cultural benefits (qualitative benefits) of BIM and their impacts on owner's decisions is discussed in chapter four, it seems there is still room for more research about those factors and their reasons of being overlooked by many owners. Moreover, quantitative aspects of BIM utilization and at its top economic benefits, as the owners' main concentration point, are remarkable. Owners regardless of their understanding level of all other benefits of BIM can realize the economic differences. In other words, the quantitative benefits of BIM and especially its economic benefits are good drivers to motivate owners (with any degree of awareness) to require BIM for their projects.

"Data on the achievable cost savings of applying BIM on construction projects must be gathered and evaluated to be able to persuade owners of the benefits of paying supplementary fees."

As a result, a balance between quantitative initial factors and qualitative secondary factors of decision-making should occur in a project to get the best results both in the desired project as well as the industry as a whole for better and faster adoption.

This means well-adoption of BIM in the industry is connected to BIM projects' level of success, as a proof of prosperity, and positive impacts on its popularity in the construction industry.

5.2Recommendation

Owners recently are expanding their BIM application, and there is a big requirement for them to comprehend how to allow their projects teams to provide them with the greatest BIM value and evidently became a good BIM owner.

There is a set of guidance that can provide a good BIM experience and outcomes for all related:

- **Steering BIM not randomly driving it:** BIM owners have to understand the value that BIM brings even without the deep technical knowledge of it to manifest its benefits.
- **Preparing their Business for BIM**: Owners will benefit if they have the right internal frameworks for BIM like founding goals for BIM (cost/benefit, less

rework, faster achievement), allocating internal competencies that support BIM as well as assigning the right internal technology for BIM.

- **Requesting for and receiving the correct things at the correct time:** outlining the expectations for BIM and the level of elaboration intended of BIM.
- **Remaining involved:** BIM is complicated as it is, and has a critical planning system in which the owner should always be aware of from beginning to end and always be an operational member of it.
- **Boosting partnership:** endorsing collaboration between the teams is highly recommended for a BIM owner as it facilitates all the transitions necessary during the work and aid in finding opportunities through different phases.
- **Evaluating what matters:** Owners always need to be reminded that the value of BIM is usually found in money and time not being wasted rather than a calculable decrease of cost and schedule.
- **Thinking about the finish:** assuring that models and documents precisely imitate each other through the whole project life cycle, and permitting their use during facility management if required.

References`

(Philips and Azhar. 2011. "'Role of BIM for Facility Management in Academic Institutions', Proceedings of the 6th International Conference on Construction in the 21st Century (CITC-VI),." Kuala Lumpur, Malaysia. Accessed 05 04, 2018.

Abidin, Nazirah Zainul. 2010. "Sustainable Construction." *International Journal of Social Sciences 5:2 2010.* Accessed 05 12, 2018. https://www.scribd.com/document/347909528/Sustainable-Construction-in-Malaysia-pdf.

Alsaadi, A. N. (2014). n.d. "Sustainability and BIM: The Role of Building Information Modeling to Enhance Energy Efficiency Analysis." Accessed 06 04, 2018. https://www.academia.edu/6420316/Sustainability_and_BIM_The_Role_of_Building_Information_Modeling_to_Enhance_Energy_Efficiency_Analysis.

ArchiCAD. 2015. *Faster than ever.* http://www.graphisoft.com/ftp/marketing/ac19/pdf/archicad19-brochure.pdf.

Artenian, A., Sadeghpour, F., & Teizer, J. 2010. "A GIS Framework for Reducing GHG Emissions in Concrete Transportation. Construction Research Congress ." Accessed 05 13, 2018. http://ascelibrary.org/doi/abs/10.1061/41109(373) 156.

Autodesk, Inc. n.d. *Building Information Modeling for Sustainable Design. Autodesk, Inc. White Paper.* Accessed 06 13, 2018. www.autodesk.com.

Autodesk. (2016, February 8th. n.d. *Revit Fundamentals.* Accessed 05 29, 2018. https://knowledge.autodesk.com/support/revit-products/learn.

Autodesk. 2014. Accessed 06 09, 2018. http://staticdc.autodesk.net/content/dam/autodesk/www/campaigns/test-drive-bimq3/bds/latam/bim-business-brief-04-aec-staying-competitive-esp.pdf.

Azhar, S. 2011. "Building Information Modelling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry." *Leadership and Management in Engineering, 20.* Accessed 05 04, 2018.

Azhar, S., Carlton, W., Olsen, D., & Ahmad, I. n.d. "Building Information Modelling for Sustainable design and LEED Rating Analysis." *Automation in Construction.* Accessed 06 04, 2018.

Azhar, S., Hein, M., & Sketo, B. 2008. "Building Information Modeling (BIM): Benefits, Risks and Challenges." Accessed 05 23, 2018. http://ascpro.ascweb.org/chair/paper/CPGT182002008.pdf.

Barlish, K., & Sullivan, K. 2012. "How to Measure the Benefits of BIM - A case study approach." *Automation in Construction, 24.* Accessed 05 14, 2018.

Barron, Hills and. 1997. *the challenge of sustainability, Land Use. Policy.* Hong Kong: Land Use Policy, 41-53. Accessed 05 07, 2018.

Bynum, W. P. 2010. "Building information modeling in support of sustainable design and construction. The University of Florida." Accessed 05 13, 2018. http://etd.fcla.edu/UF/UFE0041667/bynum_w.pdf.

Charles Atombo · Joseph Cudjoe · Kwedza Dzantor · Aaron Agbenyegah Agbo. 2015. *Project management.* International Journal of Construction Engineering and Management. Accessed 07 18, 2018. article.sapub.org/10.5923.j.ijcem.20150401.02.htm.

Charles J. Kibert, Jan Sendzimir, G. Bradley Guy. 2000. *Built Environment, Environment and Sustainability.* London: 15 November 2001.

Che, L., Gao, Z., Chen, D., & Nguyen, T. H. 2010. "Using building information modeling for measuring the efficiency of building energy performance. International Conference on Computing in Civil and Building Engineering (ICCCBE)." Accessed 06 02, 2018. http://www.engineering.nottingham.ac.uk/icccbe/proceedings/pdf/pf83.pdf.

Cheng, J., & Ma, L. 2013. "A BIM-based system for demolition and renovation waste estimation and planning. Waste Managemen, 33." Accessed 05 29, 2018. http://www.sciencedirect.com/science/article/pii/S0956053X13000068.

Cheshire, David. 2016. "RICS Training course." *Sustainability Director at AECOM provides insight into the need for a more circular economic model in the built environment.* Accessed 07 12, 2018. https://resources.rics.org/content/what-circular-economy-built-environment.

Choi, C. 2009. "Removing Market Barriers to Green Development: Principles and Action Projects to Promote Widespread Adoption of Green Development

Practice." *The Journal of Sustainable Real Estate.* Accessed 04 06, 2018. www.josre.org.

Christina du Plessis (B.Arch, M.Arch.). 1999. *Agenda 21 for Sustainable Construction in Developing Countries.* 237. Accessed 15 05, 2018. http://www.irbnet.de/daten/iconda/CIB4162.pdf.

Coates, P., Arayici, Y., Koskela, L., & Usher, C. 2010. "The changing perception in the artifacts used in the design practice through BIM adoption." Accessed 04 06, 2018. http://usir.salford.ac.uk/9674/.

Construction, Building Design and. 2008. *New AIA Documents include BIM Agreement and Two New IPD Contracts.* Accessed 05 14, 2018. http://www.bdcnetwork.com/article/CA6600255.html.

CRC. n.d. "CRC report reveals BIM more effective." Accessed 05 26, 2018. https://www.insideconstruction.com.au/site/news/1034312/crc-report-reveals-bim-effective.

Crotty, R. 2012. "The Impact of Building Information Modelling Transforming Construction." Accessed 05 16, 2018.

David J. Gerber1, Burcin Becerik-Gerber2, and Alex Kunz3. 2010. "BUILDING INFORMATION MODELING AND LEAN CONSTRUCTION: TECHNOLOGY, METHODOLOGY, AND ADVANCES FROM PRACTICE." July. Accessed 05 18, 2018. www.researchgate.net/profile/David_Gerber7.

Dowsett, R., & Harty, C. 2014. "Evaluating the benefits of BIM for sustainable design. A review. TSBE Conference. Whiteknights: University of Reading." Accessed 06 12, 2018. https://www.reading.ac.uk/web/FILES/tsbe/Dowsett_TSBE_Conference_Paper_2013.pdf.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. 2011. "BIM Handbook: A Guide to Building Information Modelling." *New Jersey: John Wiley & Sons Inc.* Accessed 05 18, 2018. http://www.only4engineer.com/2014/10/bim-handbook-guide-to-building.html.

Eastman, Chuck. 2008. *“BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors.* Accessed 06 18, 2018. https://www.goodreads.com/book/show/2747803-bim-handbook.

Eddy Krygiel and Brad Nies. 2008. *Green BIM: Successful Sustainable Design with Building Information Modeling.* Accessed 05 26, 2018. https://play.google.com/store/books/details/Green_BIM_Successful_Sustainable_Design_.

Edwin ChanGrace K. L. Lee. 2008. "Critical factors for improving the social sustainability of urban renewal projects." Accessed 07 01, 201. https://link.springer.com/article/.

Elkington, Cannibals With Forks. 1997. "The Triple Bottom Line of 21st Century Business. Capstone."

2013. "Evaluating the benefits of BIM for sustainable design. A review. TSBE Conference. Whiteknights: University of Reading." Accessed 04 13, 2018. https://www.reading.ac.uk/web/FILES/tsbe/Dowsett_TSBE_Conference_Paper_2013.pdf.

Fan, Kam-din Wong, and Qing. 2013. *Building Information Modelling (BIM) for Sustainable Building Design.* Accessed 05 24, 2018. https://www.scribd.com/document/358753725/Building-Information-Modelling-BIM-for-Sustainable-Building-Design.

FIDIC. 2004. *Improving the Quality of Construction (2004).* Switzerland: 1913. Accessed 06 18, 2018. fidic.pub@fidic.org.

Forsberg, A., and Saukkoriipi, L. 2007. "Measurement of waste and productivity in relation to lean thinking." Accessed 04 12, 2018. http://iglc.net/Papers/Details/458.

Francesc Salla. 2014. "15 advantages of using BIM." Accessed 07 14, 2018. https://blog.visualarq.com/2014/03/12/15-advantages-of-using-bim/.

Grilo, A., & Jardim-Goncalves, R. n.d. "Building information modeling and collaborative working environments", Automation in Construction." Accessed 05 13, 2018.

Group, The World Bank. 1998. *World Bank - Pollution Prevention and Abatement Handbook.* Washington, D.C. Accessed 05 19, 2018.

https://www.scribd.com/doc/106662608/World-Bank-Pollution-Prevention-and-Abatement-Handbook.

Group., Efficiency, and Reform. 2011. "Government Construction Strategy." Accessed 06 06, 2018. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61152/Government-Construction-Strategy_0.pdf.

Hardin. 2011. "BIM and Construction Management, Indianapolis: Wiley Publishing, IN ." Accessed 06 14, 2018.

Harrell, Margaret, and Melissa Bradley. 2009. *“Data Collection Methods: Semistructured Interviews and Focus Groups.” RAND Corporation.* http://www.rand.org/content/dam/rand/pubs/technical_reports/2009/RAND_TR718.pdf.

Henttinen. n.d. "BIM SOLUTIONS FOR PROJECT MANAGEMENT." Accessed 05 12, 2018. https://www.scribd.com/document/329976191/5-Tomi-Henttinen-BIM-in-Finland.

Hughes, Daniel. 2012. *Bradley Revit Family Library Joins E-Specs Integrated Specifications Program.* Accessed 07 12, 2018. http://blog.bradleycorp.com/bradleybim/2012/04/10/bradley-revit-family-library-joins-e-specs-integrated-specifications-program/.

Hukkinen, Jaan. 1999. *Institutions in Environmental Management. Constructing Mental Models and Sustainability, Routledge, London.* London: London; New York: Routledge, 1999. Accessed 05 13, 2018. http://www.worldcat.org/title/institutions-in-environmental-management-constructing-mental-models-and-sustainability/oclc/39763875.

IBC. n.d. "IBC Institute for BIM in ." Accessed 06 23, 2018. https://thebimhub.com/institute-for-bim-in-canada-ibc/.

Ilhan, B., & Yaman. 2013. *BIM and sustainability concepts in construction projects: A Case Study. Proceedings from SB13 - Oulu Sustainable.* Accessed 06 10, 2018. http://www.irbnet.de/daten/iconda/CIB_DC26632.pdf.

IPCC. 2007. " National Greenhouse Gas Inventory Guidelines." Institute of Global Environmental Stra tegies (IGES), Kanagawa, Japan. 20 pp, Japen. Accessed

05 20, 2018. https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch11s11-10-1-2.html.

IPCC. 2006. *National Greenhouse Gas Inventory Guidlines.* Kamiyamaguchi, Hayama, Kanagawa, JAPAN: : IGES, Japan. IPCC National Greenhouse Gas Inventories Programme Technical Support Unit, % Institute for Global Environmental Strategies,.

Jalaei, F., & Jrade, A. 2014. "An Automated BIM Model to Conceptually Design, Analyze, Simulate, and Assess Sustainable Building Projects. Journal of Construction Engineering, 2014." Accessed 06 12, 2018. http://www.hindawi.com/journals/jcen/2014/672896/.

Jordan. 2010. "BIM and FM: The Portal to Lifecycle Facility Management', Journal for Building Information Modeling." 13-16.

Juhola, Virve. 2011. *"Inland, Norway, Singapore, USA Lead Progress in Construction.".* Accessed 06 13, 2018. http://www.bimsightblog.com/finland-norwaysingapore-usa-lead-progress-in-construction-industry/.

K.M. Fowler and E.M. Rauch. 2006. *Sustainable Building Rating Systems Summary.* Accessed 05 14, 2018. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-15858.pdf.

Khemlani, L. 2015. *Architecture Engineer Construction bytes.* Accessed 06 12, 2018. http://www.aecbytes.com/review/2015/ArchiCAD19.html.

Krygiel, E., & Nies, B. 2008. "Green BIM: successful sustainable design with building information modeling. John Wiley & Sons." Accessed 05 12, 2018.

Ku and Taiebat. 2011. "'BIM Experiences and Expectations: The Constructor's Perspective', International Journal of Construction Education and Research." 175-197. Accessed 06 15, 2018.

Kymmell, W. 2008. " Building Information Modeling: Planning and Managing Projects with 4D CAD and Simulations, USA: McGraw Hill Construction ."

MacTavish, A., Turner, A., & Iqbal, N. 2013. "Resource efficiency through BIM: a Guide for BIM Users. WRAP." Accessed 05 03, 2018.

http://www.wrap.org.uk/sites/files/wrap/Resource%20efficiency%20through%20BIM%20-%20a%20Guide%20for%20BIM%20Users.pdf.

MacTavish, A., Turner, A., & Iqbal, N. 2013. "Resource efficiency through BIM: a Guide for BIM Users. WRAP." Accessed 06 03, 2018. http://www.wrap.org.uk/sites/files/wrap/Resource%20efficiency%20through%20BIM%20-%20a%20Guide%20for%20BIM%20Users.pd.

Mann, Samual. 2011. *Sustainable Lens: A visual guide.* NewSplash. Accessed 07 27, 2018. https://computingforsustainability.com/2009/03/15/visualising-sustainability/.

Mark Saunders, Philip Lewis, Adrian Thornhill. 2009. *Research methods for business students.* 5. Harlow: Pearson Education Limited.

Masood. 2007. "Postmodernism and Architecture." Accessed 06 14, 2018.

Milne, M. 1996. "On sustainability; the environment and management accounting." Accessed 06 15, 2018. https://www.researchgate.net/publication/223295234_On_sustainability_the_environment_and_management_accounting.

MustafaYılmaz and AdemBakış. 2015. "Sustainability in Construction Sector." Accessed 06 05, 2018. https://doi.org/10.1016/j.sbspro.2015.06.312.

Newton, R. S. 2004. "'Inadequate Interoperability in Construction Wastes 415.8 Billion'." *13, Article 342.* Accessed 06 04, 2018. AECNews.com.

OECD. n.d. *Environment Policy Committee, Design of Sustainable Building Policies: scope for improvement and barriers, Organization for Economic Cooperation Development.* 2002. Accessed 05 15, 2018. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?doclanguage=en&cote=env/epoc/wpnep(2001)5/final.

Operations, SEC. n.d. "Orgon Solar Energy Conference." Accessed 07 21, 2018. https://drive.google.com/file/d/1ZYbQzuFhtLFUWxGenR5TwIgWMzz-Q5GM/view.

1990. *Our Common Future.* Australian edn, Oxford University Press, Melbourne, p. 87. Accessed 04 21, 2018. https://www.uow.edu.au.

Parkin, S. 2000. "Contexts and drivers for operationalizing sustainable development." *Proceedings of the Institution of Civil Engineers - Civil Engineering*, May 25. Accessed 05 5, 2018.

Peakstoprairies. 2005. "Sustainable Design and Construction." Accessed 06 25, 2018. www.peakstoprairies.org/p2bande/skigreen.

Pinske, J., and Marcel D. 2008. "Overcoming Barriers to Sustainability: an Explanation of Residential Builders' Reluctance to Adopt Clean Technologies, "Business Strategy and the Environment." January. Accessed 06 04, 2018. www.interscience.wiley.com.

Plessis, Chrisna du. 2001. " Sustainable Construction. Agenda 21 For Sustainable." Brezil. Accessed 05 28, 2018.

Plessis, Du. C. 2002. "Paper for the 9th ENTAC." Brazil: 2002. Accessed 06 24, 2018.

Preview, ISO 15392:2008. n.d. "Technical Committee: ISO/TC 59/SC 17 Sustainability in buildings and civil engineering works ." Accessed 05 10, 2018. https://www.iso.org/standard/40432.html.

Rafael Sacks, Lauri Koskela, Bhargav A. Dave 3 and Robert Owen 4. 2009. "The Interaction of Lean and Building Information Modeling in." Accessed 06 12, 2018. http://usir.salford.ac.uk/9356/6/Interaction_of_Lean_and_BIM_in_Construction_plus_Figures.pdf.

Recreation, The Campus. 2012. *sonoma.* Accessed 07 14, 2018. https://web.sonoma.edu/campusrec/sustainable/.

RICS. 2016. *BIM rises in the United States.* Accessed 06 12, 2018. https://resources.rics.org/content/bim-rises-united-states.

Rosenberg. 2007. *Building Information Modeling.* Accessed 06 01, 2018. http://www.ralaw.com/resources/documents/Building%20Information%20Modeling%20%20Rosenberg.pdf.

Rubenstone, J. 2010. "'Autodesk Steers Users Toward the Cloud With Expanded Subscription-based Services', Engineering News Record." Accessed 06 06, 2018.

Sacks, R., Treckmann, M., & Rosenfeld, O. 2009. "Visualization of Work Flow to Support Lean Construction. Journal of Construction Engineering and Management, 135." Accessed 05 16, 2018.

Salman Azhar, Michael Hein, and Blake Sketo. n.d. "Building Information Modeling (BIM):." Accessed 06 02, 2018. http://ascpro.ascweb.org/chair/paper/CPGT182002008.pdf.

Schlueter and Thessling. 2008. "Building Information Model-based energy/exergy performance assessment in early design stages', Automation in Construction." 153-163.

Simon Elias Bibria and John Krogstie. 2016. "Smart sustainable cities of the future." Accessed 05 16, 2018. https://www.sciencedirect.com/science/article/pii/S2210670716304073.

Smith and Tardif. 2009. "Building Information Modeling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers, NJ: John Wiley and Sons."

Sosa, E. N. 2014. "Modelado de Información para la Edificación en BIM y su aplicación frente a las exigencias de la demanda energética con LIDER Y ECOTECT." *Universidad Politecnica de Cataluña.* Accessed 05 23, 2018. http://www.bimforum.cl/wpcontent/uploads/2016/01/PFG_MEMORIA.pdf .

Standard, The America National BIM. 2007. *Project Structure - Tetralogy of BIM.* Accessed 06 17, 2018. https://www.nationalbimstandard.org/tetralogyofbim.

Stine, J.D. 2011. "Design Integration Using Autodesk Revit® 2012, Mission, KS: SDC Publications."

The subcommittee, the WBDG Aesthetics. 2016. "Engage the Integrated Design Process." Accessed 05 17, 2018. https://www.wbdg.org/design-objectives/aesthetics/engage-integrated-design-process.

Susan Dzifa Djokoto, Kumasi Polytechnic, Faculty of Built and Natural Environment, 2014. "Barriers to Sustainable Construction in the Ghanaian Construction." *Barriers to Sustainable Construction in the Ghanaian Construction* (published by the Canadian Center of Science and Education 2014). Accessed 05 03, 2018. http://dx.doi.org/10.5539/jsd.v7n1p134.

n.d. *sustainable development.* Accessed 06 26, 2018. www.iisd.org/topic/sustainable-development.

TayyabAhmad, Muhammad JamaluddinThaheem. 2017. "BIM-based Iterative Tool for Sustainable Building Design: A Conceptual Framework." May. Accessed 05 15, 2018. https://www.sciencedirect.com/science/article/pii/S1877705817317460.

Tekla. n.d. *An open approach to BIM connects different stakeholders to each other.* Accessed 06 http://www.tekla.com/company/building-construction, 2018.

The Computer Integrated Construction Research Group. 2010. *Building Information Modeling Execution Planning Guide.* Accessed 05 16, 2018. https://vdcscorecard.stanford.edu/sites/default/files/BIM_Project%20Execution%20Planning%20Guide-v2.0.pdf.

Thompson and Miner. 2007. "e-Construction: Don't Get Soaked by the Next Wave', The Construction Law Briefing Paper." Accessed 05 26, 2018. http://www.minnlaw.com/Articles/68553.pdf.

TRADA. 2012. "Construction Briefings: Building Information Management." *High Wycombe: Timber Research and Development Association.* Accessed 05 25, 2018. http://www.exovabmtrada.com/getmedia/15c92265afa6-4e6f-889a-37c16b0b6340/building-management-information.pdf.

Wei, W., & Issa, R. R. 2014. "BIM execution planning in green building projects: LEED as a use case. Journal of Management in Engineering, 32." Accessed 05 16, 2018. http://ascelibrary.org/doi/abs/10.1061/(ASCE) ME.1943-5479.0000314.

Weygant. 2011. "BIM Content Development: Standards, Strategies, and Best Practices, NJ: John Wiley and Sons ."

Williams, Roger. 2010. *Design as a Tool for Architectural + Social Development: the Kalighat Women's Resource Center.* Accessed 06 04, 2018. Roger Williams University, lbrugger096@g.rwu.edu.

Wong, J. K., & Zhou, J. 2015. "Enhancing environmental sustainability over building life cycles through green BIM." Accessed 06 02, 2018.

Works, Q. d.o.p. 2016. "Smart and sustainable design objective, s. l; queens land department of public works." Accessed 04 15, 2018.

http://www.hpw.qld.gov.au/construction/Sustainability/SustainableHousingLaws/ClimateZones/Pages/default.aspx.

Yong Han Ahn, Annie R. Pearce, Yuhong Wang & George Wang. 2012. "Drivers and barriers of sustainable design and construction: The perception of green building experience." 09. Accessed 04 02, 2018. https://www.tandfonline.com/doi/full/10.1080/2093761X.2012.759887?src=recsys.