GREEN BUILDING INFORMATION MODELLING TECHNOLOGY ADOPTION FOR EXISTING BUILDINGS: FACILITIES MANAGEMENT PERSPECTIVE

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DEDICATION

This effort may a dedication, To

my beloved family

To every individual who blessed me

Towards my success…….

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The success of this research is a result of many individuals' collaboration. My heartfelt gratitude is extended at each and every one who supported in numerous ways in making this a reality.

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ABSTRACT

GREEN BUILDING INFORMATION MODELLING TECHNOLOGY ADOPTION FOR EXISTING BUILDINGS: FACILITIES MANAGEMENT PERSPECTIVE

There is a manifest increase for the use of Building Information Modelling (BIM) techniques in the construction industry due to its evident benefits that facilitate the construction processes than traditional approaches. The need of incorporating BIM based techniques for building constructions has been increasingly acknowledged both at the academic research and industrial levels. Herein, Green BIM as one of BIM based technologies has been discussed in recent years in relation to sustainable and green concepts with its advanced technological features that help to accomplish sustainable goals. The fundamental advantage of Green BIM is the ability of generating advanced building performance analysis results that are important in optimizing energy consumption of buildings through improved decision making. The inherent benefits of Green BIM have been extensively discussed in literature especially considering its implementation during design and construction phases of building construction projects towards the energy optimization. Evidently, there are lack of research for the use of Green BIM for existing buildings even though there is a huge potential in optimizing energy during operation and maintenance phases of existing buildings. As discussed in literature, facilities managers are being faced numerous challenges in adopting Green BIM for existing buildings due to lack of necessary building data during the operation and maintenance phases of buildings discouraging the implementation of Green BIM for existing buildings. The aim of this research therefore, was to study the potential of adopting Green BIM for existing buildings from facilities management perspective.

To achieve the aforementioned aim, a qualitative research approach was followed which included a multiple case study analysis. The case study was conducted with two cases through the practical implementation of Green BIM. The practical implementation was mainly included creating the basic BIM models and running Green BIM techniques to analyse the performances of selected buildings. The Green BIM techniques used for the selected cases were solar analysis and energy analysis respectively. The experiences gathered during the study were analysed and discussed as the findings of the research. The findings include the challenges faced during the study when implementing Green BIM for the selected cases and the actions taken during the study were discussed with further recommended solutions. Finally, a framework was developed as a guidance to overcome the challenges of Green BIM implementation for existing buildings. The findings of this research emphasized the challenges that can be faced from facilities management point of view, over the implementation of Green BIM for existing buildings during the operation and maintenance phases. Thus, the framework provided in this study may significantly helpful for facilities managers to implement Green BIM for existing buildings that maintain with lack of data, towards the energy optimization through improved decision making.

Key Words: Building Information Modelling, Building Performances, Energy, Facilities Management, Green BIM.

TABLE OF CONTENTS

List of Figures

List of Tables

CHAPTER 01

1.0 BACKGROUND

Long-lasting challenges of today construction industry, energy consumption and co_2 emission have come to the forefront as construction industry is identified as one of primary contributors of greenhouse gas emissions and global warming (Hong, Chou & Bong, 2000; Liu, Meng & Tam, 2015). The United Sates Green Building Council has declared that buildings in the US account for thirty percent (30%) of world's total energy and forty percent (40%) of greenhouse gas emissions (Wong & Fan, 2013). Escalating energy consumption and issues of greenhouse gas emissions (GHG) are typically generated due to the operations of building sector which includes heating and cooling systems, operation of electrical and lighting appliances and other system operations (Schlueter & Thesseling, 2009). Thus, there is a growing concern to mitigate the increased demand of building energy consumption while enhancing efficient utilization of resources and environmentally sound industry practices (Autodesk, 2005). In addition to that, there is a challenge for industry professionals to assure a healthy and comfortable environment for building occupants (Hong, Chou & Bong, 2000).

In this context, sustainability has become a contemporary notion in building sector and many countries have prompted efforts in promoting sustainability for the reduction of environmental degradation while making better working environments (Wong & Fan, 2013). The concept of sustainability combines threefold speers of environmental, economic and social impacts and also refers to building performances (Luo & Wu, 2015). Many countries have established various rating systems in terms of sustainability to certify the buildings during last two decades. For examples, Leadership in Energy and Environmental Design (LEED), SBTool, CASBEE, Building Research Establishment Environmental Assessment Method (BREEAM) and Green Globes have been identified as systems which are used to rate the buildings in terms of sustainability (Fowler and Rauch, 2006). These standards are important to evaluate the overall performance of a completed building (Liu, Meng & Tam, 2015).

Though sustainability is a tremendous attempt, construction industry is perceived yet as the highest contributor for carbon emissions (Oduyemi & Okoroh, 2016). Further, according to statistical indications, construction sector is still being continued as the main energy consumer even though green strategies have been applied under the concept of sustainability (Wong & Zhou, 2015). Moreover, as explained by Liu et al., (2015) though the concept of sustainability is widely discussed and practiced while proving its actual benefits by real cases still there is a requirement to find out more effective ways to ascertain improved building performances during the buildings' lifetime. Thus, architects, designers and planners in the construction industry nowadays more conversant to optimize building energy performance through improved building operations and building performance analyses (McGraw-Hill Construction, 2008).

Building Information Modelling (BIM), as a novel technological approach, has been used for building performance analyses with a deeper and more profound uptake recently in the construction industry (Azhar, 2011). In this respect, new trends of integrating BIM and green building strategies have been emerged in a broader perspective of building performance analyses within the scope of sustainability. BIM is acknowledged as an innovative technology where digital building models are presented in a virtual space which enables efficient management of building operations throughout the buildings' life cycle (Chien, Wu & Huang, 2014). BIM has been originated appreciably in Architecture Engineering and Construction (AEC) sector empowering all stakeholders to design building infrastructure, monitor building operations and facilities in an integrated approach and through improved communication (Wong & Kuan, 2014). In contrast to the traditional paper based practice of the architecture, BIM enables stakeholders to effectively collaborate all over the buildings life cycle for the management of building information through 3D visualization which provides a reliable basis for decision making (Volk, Stengel & Schultmann, 2014).

Further, the systematic approach of BIM enabled management in buildings provides numerous opportunities to building owners, facility managers and decision makers for sustainable design improvements and energy efficient strategies through the use of multi-dimensional visualisation technology (Bank, McCarthy, Thompson & Menassa, 2010). Moreover, it is envisaged that BIM is a critical element to optimize building energy performance through enhanced building performance analysis and thus BIM could contribute for sustainable strategies and green building approaches (Wong & Fan, 2013). Meanwhile, Smith, (2007) asserted that BIM has been significantly appreciated due its ability to integrate with sustainable and green strategies. Among various green strategies integrated with BIM technology, energy analysis has been mostly focused on recently published papers (Niewoehner, 2010). According to Middlebrooks, (2008) integration of BIM with sustainable strategies could achieve prolonged benefits not only during the design stage but also over the whole life cycle phases of buildings including operation and maintenance, deconstruction and demolition.

Integration of BIM with sustainable strategies is acknowledged as the Green BIM technology which is an emerging trend in the AEC industry (Ilhan & Yaman, 2016). Green BIM is perceived as the use of BIM based sustainability tools which facilitates to achieve and evaluate improved building performances (McGraw-Hill Construction, 2010). Broadly, Green BIM is defined as a model based process which includes generation and management of building data during the project lifecycle to enhance energy efficiency of buildings while achieving desired sustainability goals (Wu & Issa, 2015). Similarly, Green BIM is identified as a tool or a technique which is used to make informed decisions in the early design stage to manage the building energy use and performance over a building project (Wong & Zhou, 2015). It is further emphasized that, application of Green BIM should extend over the entire lifecycle of buildings without bounding only to the conceptual and design phases (Alawini, Tanatanmatorn, Tucker, Tucker & Daim 2013).

As shown in recent publications, Green BIM has been widely discussed as a major breakthrough for various sustainable objectives of buildings (Ilhan & Yaman, 2016). The ideal benefit of Green BIM is the ability to perform comprehensive building performance analysis through building simulations precisely and efficiently (Azhar, Brown & Farooqui, 2009). As mentioned by Hong et al., (2000) energy performance of a building is not only depended over the individual performances of building envelope components and systems but also over the overall performance of entire building including all building operation systems, components and occupants. Furthermore, it is essential to understand the dynamic and complex interactions of buildings with its systems, plants and environment, to formulate the strategies towards the achievement of sustainability goals. The only technique available for building owners, architects and engineers for this consideration is building simulation and building performance analyses (Clark & Irving, 1988).

In the early stages, traditional CAD based tools have been used for building simulations with high involvement of skilled personnel resulting in high cost and time consumption (Ilhan & Yaman, 2016). Further, traditional tools are more prone to errors, less user friendly and can be tedious in preparing and handling input data and also less communication and integration with other programs and tools (Hong et al., 2000). However, the development of Green BIM tools with better integration of design model and simulations has overcome aforementioned issues since it enables handling vast amount of data within a single model which help to improve analysis through eliminating the errors of data handling (Kriegel & Nies, 2010). As described by Stumpf, Kim and Jenicek (2009) Green BIM tools provide completed building simulations more quickly than the traditional approaches. Hence Green BIM has been appreciated in recent years for comprehensive performance analysis through accurate building simulations (Azhar, Carlton, Oslen & Ahmad, 2011). From facilities management perspective, the use of Green BIM has been widely appreciated as it provides numerous benefits for operation and maintenance of buildings.

According to, Teicholz and Hoboken (2013), BIM ensures the availability of as built information, which is a critical requirement of FM, development of various maintenance schedules, opportunity to track and maintain lifecycle information about the building structure. Together with aforementioned benefits, Green BIM provides a significant opportunity to improve building performances which should be ensured by facilities manager within the management scope of FM (Eastman et al., 2011). The inherent techniques in Green BIM can be used for defect detection, energy usage analyses, renovation and demolition, firefighting, sustainability and safety in facility management (Kassem et al.,2015). Towards the aim of optimizing energy performance of buildings, Green BIM is a greater advance for a facilities manager during the operation and maintenance of buildings. As the longest phase of a building is the operation and maintenance phase, existing buildings considerably account for a high maintenance cost where facilities mangers' responsibility become more significant (Jung et al., 2014).

Hence, facilities managers can greatly contribute in making proper decisions for the improvements of existing buildings to mitigate the unnecessary energy costs of existing buildings. Nevertheless, the rate of Green BIM implementation for existing buildings to fulfill the facilities management requirements still appears as very less (Eastman et al., 2011).

As evident from recent studies, BIM has been considerably used for new building constructions including commercial, educational, residential and many other building types. Especially complex and larger buildings have been facilitated with BIM approaches (Gerber & Rice, 2010). According to recently reported data 30% of construction projects around the world have used BIM. Also, BIM usage has been increased from 28% to 71% in North America in 2012. Correspondingly, statistical data have demonstrated that around 97% of return on investment is attained from the use of BIM technologies to construction projects in countries including Canada, Japan, France and Germany (Jones & Bernstein, 2014).

Though above-mentioned studies reveal the widespread usage of BIM for construction projects as a novel technological advancement, the studies also demonstrated that still there are gaps and uncertainties in the implementation of BIM for existing building constructions. It is well proven by Volk et al., (2014) stating that though BIM is widely used for new constructions, existing buildings are not yet maintained and managed with BIM. Similarly, Gursel, Sariyildiz, Akin and Stouffs (2009) have mentioned that there is lack of efforts to use BIM for existing buildings than new constructions. With the same concern, Wong and Fan (2013) have highlighted that still there is a considerable shortage in applying BIM technologies for existing buildings. Further, Gu and London (2010) have stated that though there is an expanded usage of BIM, its practical effectiveness needs to be examined for existing buildings.

Several publications have discussed the risks associated with BIM implementation such as technological risks, risks for work process changes, shortage of skilled specialists and software handling (Eastman, Teicholz, Sacks & Liston, 2011). Compatibility issues of BIM softwares with other packages, interoperability issues, complicated models and procedures and lack of tools have been recognized as negative factors of BIM implementation for existing buildings (Bryde, Broquetas & Volm, 2013; Chien, Wu & Huang, 2014). Cost of software licenses is identified as another factor which impedes the BIM usage (Pelsmakers, 2013).

As the prevalence of Green BIM depends over the usage of BIM first, aforementioned issues also hinder the implementation of Green BIM for existing buildings. It is further proved in the reviewed literature that there are similar challenges causing less usage of Green BIM for existing buildings. For example, Wong and Zhou (2015) have mentioned that complicated models and lack of tools hinder the adoption of Green BIM. Further, McGraw-Hill Construction (2010) has indicated that, the availability of user friendly BIM tools is a major consideration for the energy simulations and analysis. Moreover, McArthura (2015) has clearly stated the challenges of Green BIM implementation for existing buildings as identification of required data from existing documentation, high effort required to create existing BIM models, transformation of data between existing monitoring systems and BIM, and elimination of uncertainty from missing and incomplete building information.

However, according to both BIM and Green BIM literature, the main challenge for the implementation of Green BIM for existing buildings is acquisition and management of required building data from incomplete and missing information sources of existing buildings. As proved by Giuda, Villa, Paolo and Piantanida (2015) the history of an existing building with detailed information of its construction is compulsory to be known for the application of BIM technology to existing buildings. Similar to McArthura (2015), proper identification of building information is necessary to obtain improved building performances through the application of BIM for building operations. Oti and Tizani (2015) have further emphasized that existing data are not comprehensive enough for the assessment of building sustainability. As explained by

Volk et al., (2014) there is still not any standard method to assess the data requirements of BIM technologies for existing buildings.

However, the above-mentioned literature provides merely the surface challenges of Green BIM implementation for existing buildings while the specific challenges that can be arised within the scope of FM are still unknown.

According to the literature, it is obvious that the issues pertaining to existing data is a challenge for the implementation of Green BIM for existing buildings. Moreover, there are challenges of data requirements to be considered in applying the Green BIM technology for existing buildings. However, still there are lack of studies focusing the implementation of Green BIM for facilities management requirements in existing contexts of buildings. Even though it was mentioned that Green BIM is challengeable when implementing for existing buildings, the actual and practical challenges that would be exposed for a facilities manager still exist as a question to be addressed. Also, though it is obvious that availability of data is crucial for efficient operation of facilities management, there is a clear research gap and critical need of conducting thorough investigations and studies aiming to determine the challenges of Green BIM implementation for existing buildings within the scope of FM, despite the general challenges given without any in detail analysis.

Hence, identifying this significant research gap in the prevailing literature, this study focused to determine the practical challenges of Green BIM implementation for existing buildings from the perspective of facilities management.

1.1 Problem Statement

Even though the importance of Green BIM technology is increasingly discussed in the literature, it is further discussed that still there are hurdles for Green BIM implementation for existing buildings (Jalaei & Jrade, 2014). As revealed by Daim, Oliver and Kim (2013), implementation of Green BIM technology for existing constructions could be complicated due to the scarcity of necessary input data for building performance analyses. In practical scenario, perhaps building data of design and construction phases are not available in the operation and maintenance phases of buildings. Moreover, Mousa, Luo and McCabe (2016) stated that lack of input data and documentation of existing buildings is attributed to lack of implementation of BIM for existing buildings.

McArthura (2015) highlighted that there is a risk in collecting and using existing building data and the uncertainty of such data could not be avoided without a comprehensive inspection of buildings. Besides, a risk of human errors also exists in recapturing and transforming existing data for BIM technologies (Wang & Cho, 2015). Further to Wang and Cho (2015), as-built data of existing buildings are not always available and will require manual collection of data with a risk of errors and high time consumption. Bryde et al., (2013) also emphasized that creating basic BIM model is a challenge through restructuring the drawings and specifications. However, there are limited literature available discussing the challenges of Green BIM for existing buildings focusing on facilities management perspective when there is lack of data available. Hence, it is vital to investigate the potential challenges that can be faced by a facilities manager when implementing Green BIM for existing buildings.

1.2 Aim and Objectives

The research is aimed to study the adoption of Green BIM for existing buildings from Facilities Management perspective. The established objectives for this aim are,

1. Identify Green BIM techniques, tools and data requirements for each tool
2. Analyse the status of availability and suitability of existing data
3. Identify the challenges of generating BIM data required for Green BIM
4. Develop a framework that could be supported to overcome the identified challenges for the implementation of Green BIM technology in existing buildings

1.3 Methodology

A qualitative approach was followed to achieve the research aim. As the preliminary stage of the research, a comprehensive literature survey was conducted to identify the Green BIM techniques, tools and data requirements for tools. Subsequently, this study followed a multiple case study approach to investigate the availability and suitability of data and challenges of generating BIM data that required for Green BIM, from existing sources of buildings. The selection criteria of the cases were based on the literature for the study and finally the analysis was conducted based on two case studies. The researcher was involved as the instrument of data collection in the methodology of this study. Accordingly, 1st objective of the research was achieved through the literature survey and 2nd, 3rd and 4th objectives were achieved through the data collection and analysis.

1.4 Scope and Limitations

The study intended to cover buildings which are currently in operation and has completed their defects notification period. The scope was selected to identify cases where no formal input for design and construction team are available. As per current information, Green BIM has not been in use in Sri Lanka. Thus, application of Green BIM in its natural implementation will not be available for the study. This will be the key limitation of this study.

1.5 Chapter Breakdown

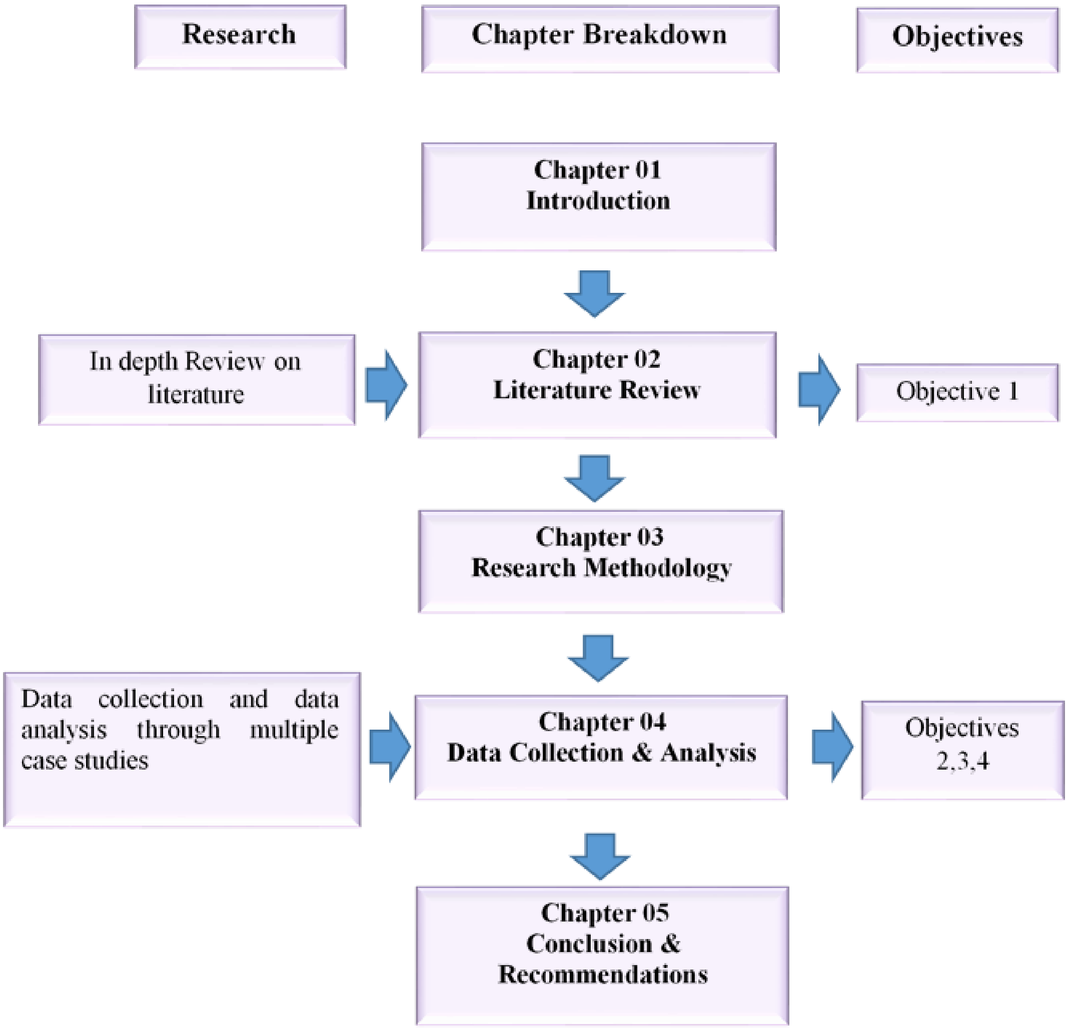


Figure 1: Chapter Breakdown

CHAPTER 02

2.0 LITERATURE REVIEW

2.1 Energy Consumption of Buildings

Buildings are identified as the major contributor of adverse impacts to the global environment due to high energy consumption (Hammond, Nawari, Walters, 2014). According to Hong, Chou and Bong (2000), around one third of primary energy is consumed in buildings. Escalating energy cost of buildings has increased public awareness to reduce energy consumption over the whole lifecycle phases of buildings (Wong & Kuan, 2014). As per Wong et al. (2013), highest energy consumption is encountered during the construction phase of building life cycle. However, operational phase of buildings has also been identified where there is a greater propensity for high energy consumption. As demonstrated in recent estimations, operational energy cost is five to seven times higher than the initial cost and three times the construction cost (Kelly, Serginson & Lockley, 2013). However, Bynum, Raja, Issa and Oblina (2013) stated that, energy consumption of construction processes is significant as operational energy consumption. Conversely, Hatamipour, Mahiyar and Taheri (2007), have argued that operational phase reports for a major portion of total energy consumtion over whole building life cycle. Proving the same opinion, Brady and Abdellatif (2017) mentioned that, the anticipated high energy consumption can be recognized during the operation stage of buildings which contributes for the largest impact on the environment.

Moreover, Wong and Zhou (2015), have stated 40% energy consumption for all residential and commercial buildings in United States (US) due to the operations of heating and cooling systems. It has further proven by Hong et al. (2000), saying that, it is important to optimize energy conservation through heating, cooling and lighting systems during the operational phase as it accounts for a major part of building's' energy use. With this regard, Park et al. (2012), have suggested sustainability as a great approach for the optimization of energy performance in buildings not even for the buildings' operational phase only, but for the entire life cycle phases.

2.2 Sustainability and Green Buildings

Sustainability has become a fast-growing topic in the research field in response to the rising cost of energy in buildings (Azhar, Brown & Farooqui, 2009). According to Diaz and Anton (2014), construction industry is turning more towards sustainability, to achieve energy conservation, minimum environmental impact and social and economic development. The awareness towards sustainable buildings has been increased considerably, as it provides high building performance and monetary savings. As defined by Azhar, Brown and Sattineni (2010), sustainability is the development of contemporary building designs and construction requirements without compromising the ability of meeting future needs. Further, sustainability is defined as which provides energy savings, quality of indoor environment and balanced investment expenditures with operational costs (Araszkiewicz, 2016). As asserted by Azhar, Carlton, Olsen and Ahmad (2011), there is a high demand for sustainability nowadays. The metrics of measuring sustainability are namely social, economic and environmental considerations (Chong, Lee, Wang, 2016).

Furthermore, Sheth and Malsane (2014), have mentioned green building concept as a new approach which momentarily grew up through sustainability. Green Building is defined, as an outcome of creating and practicing structures and processes which are environmentally sound and resource-efficient over a building life cycle (Bu, Shen, Anumba, Wong, & Liang, 2015). Further to Sheth and Malsane, (2014), green buildings ensure the optimized use of natural resources for building constructions to reduce pressures on environment and meet the sustainability criteria including maximization of daylighting, natural ventilation, indoor quality and controlled energy consumption. Compared to conventional buildings, better working environment, higher employee productivity, lower cost of operation and maintenance and improved health of occupants have been recognized as benefits of green buildings (HinHo, Rengarajan, & HanLum, 2013). Thus, Green Building apparoach has become a trend of energy efficient and environmentally friendly building designs (Chen & Nguyen, 2016).

2.3 Building Simulations and Performance Analysis

With the current emphasis on sustainability and energy efficiency, building simulations have been increasingly used to design buildings (Negendahl, 2015). As an essential part of designing energy efficient buildings, building simulations have become important and its ability to assess environmental and energy performance has been highly concerned (Hensen & Augenbroe, 2004). As explained by Hong et al. (2000), building simulation has increasingly been discussed with the demand for green buildings and it is an applicable technology for whole building life cycle including design, construction, operation and maintenance. In 1960's building simulation has been first introduced and become a popular practice in 1970's. It has been realized as a key technology to create and manage energy efficient and environmentally sound built environments through improved building performance analysis. Consequently, the core purpose of building simulations was building performance analysis which is important for decision makers for better visualization of building performances and to quickly address the issues of energy efficiency (Wang & Cho, 2015).

The term building performance analysis or in other words sustainability analysis, has been discussed for various assessments which determine buildings' environmental performance including energy analysis, daylighting analysis, building orientation and massing (Azhar et al., 2010). Further to Azhar et al. (2010), building performance analysis engaged with functional aspects of buildings including lighting, ventilation, temperature control, energy consumption and structural integrity (Jalal & Jrade, 2014). It has clearly stated that such various performance aspects of buildings are interrelated with each where change of one aspect could impact other performance aspects (Liu, Meng and Tam, 2015). According to Kim and Anderson, (2013), building performance analyses support to determine the actual energy use of buildings by comparing and analysing input energy requirements with building systems. Thus, building performance analysis is vital to improve life cycle cost of buildings and to enhance comfortable environments for employees through the improved quality of indoor workspaces (Lindahl, 2004).

In traditional method, basic computer-aided documentation (CAD), design, drafting and computer-aided simulation have been undertaken for performance analysis of buildings. While documentation and drafting of technical drawings are basically performed using 2D CAD software, simulations are done using engineering tools. Engineering tools comprise series of simulation software including DOE-2, ESP and TRNSYS (Hong et al., 2000). However, as reviewed in literature, traditional method used for building performance analysis has been encounted various inefficiencies and deficiencies. (Asl, Zarrinmehr, Bergin & Yan, 2015).

2.4 Issues of Traditional Building Performance Analysis

Traditional practice of building performance analysis basically involved two steps, as preparing of building geometry first using 2D CAD software and secondly simulation and analysis. Prior to the simulation and analysis, building geometry was exported first from CAD software to simulation software and simulation was done by several professionals separately. More individuals are involved for the decisions of performance analyses since simulations are resulted in lack of clarity, evident and less understandable. In this background, different view definitions and decisions are generated from different individuals for the performance analysis of same building. This has been a common issue as different people bear different views based on the level of knowledge and skills, experience and understanding, complexity of building geometry and available resources. Consequently, Bazjanac (2008), has mentioned that traditional simulations and analysis are subjected to illogical decisions. Furthermore, Mills et al. (2004), explicated that quantitative results of traditional methods are reliable only under special circumstances since it is resulted in over predicted energy performance of buildings.

Moreover, traditional building designing and evaluations of building performances using CAD systems, require considerable human intervention resulting high cost and time (Azhar, Brown, Farooqui, 2009). Besides, such simulations and anlysis are associated with challenges of data exchanges and processes, complex data formats and massive variables of representing building systems (Wu & Issa, 2012). Further, it has also been stated that traditional method provides slight understanding to the operational phase (Elmualim & Gilder, 2013).

In addition to the above deficiencies, Araszkiewicz (2016), has mentioned that, traditional method requires extensive and comprehensive information for sustainability analysis. Apart from the informational issues, Bank, McCarthy, Thompson and Menassa (2010), stated that, traditional performance analysis also hinders the comprehensive assessments of sustainability issues resulting specious sustainable designs. Subjective to the sustainable perspective, it has further been argued saying that, traditional CAD based simulations lack the ability of performing sustainability analysis at the early design stages (Azhar, Khalfan & Maqsood, 2012). Intending the same Kraatz, Sanchez and Hampson (2014), have mentioned that CAD based systems unable to perform sustainability analyses at the early design stage, as well as pre construction stages.

Thus, Wu and Issa (2012), asserted that, utilization of inefficient traditional 2D CAD based systems need to be quickly replaced by more powerful analysis tools. For example, Building Information Modelling (BIM) has been realized with its rapid development and innovative capabilities to overcome aforementioned deficiencies. Proving the same opinion, Chen, Shang-Hsien and Hsieh (2013), mentioned that, the current 2D CAD based methods will be replaced in the forseeable future by 3D BIM approach.

2.5 Building Information Modelling (BIM)

According to Hungu (2013), BIM has emerged as a 3D approach opposed to conventional 2D design. Arayici (2008), has mentioned the principal difference of BIM and 2D CAD as 2D drawings involve sections, elevations, plans with graphical entities of circles, arcs and lines, and require to update all when editing one of these, resulting considerable errors. However, since BIM involves intelligent semantic BIM models, elements and systems with walls, spaces and beams, it avoids the potential errors of 2D CAD based method. More importantly, BIM has offered an opportunity to produce same drawings as in CAD systems, more accurately and efficiently than CAD designs, with the advantage of parametric change technology and to manage any change effectively. Thus, BIM allows to maintain the consistency of building information model at all times and avoids unnecessary human intervention to update drawings contrasting to the traditional method (Azhar and Brown, 2009).

As described by, Wong and Fan (2013), BIM comprises entire building information in an integrated database and thus, all information are parametric and interconnected. Hence, in case of any change of an element object within the model, all other related objects, assemblies and connections are automatically updated with relevant information as it already contains all necessary information. Additionally, Park et al. (2012), have reviewed that, BIM has the ability to improve accuracy level of performance analyses of buildings while making considerable time savings compared to the CAD based method. Notably, BIM is a solution to eliminate the issues of traditional CAD based analyses, as it allows to link building models with analysis tools for performance evaluations and thus avoid the requirement of separate analysis involved in traditional method. For further proof, Eastman, Teicholz, Sacks and Liston (2008), have stated that, though CAD system lack the ability for accurate building performance analysis due to lack of detailed information, BIM provides reliable information representing both graphical and non-graphical aspects of buildings through a standard database, at any given time. Thus, as a modern technology, BIM has opened a new episode for the AEC industry, revising the traditional approaches while announcing innovative technologies.

2.6 Evolution of Building Information Modelling

Emergence of BIM has been discussed in late 1970s from the concept of semantic data models (Schlueter and Thesseling, 2009). The purpose of designing the semantic models has been indicated as to connect logical and physical information. As identified by Li et al. (2012), BIM models have first been developed based on “Building Description System” in 1975. The purpose of BIM was to support design concepts from the early stages of project to preserve the project through construction documentation (Sheth & Malsane, 2014). According to Volk et al. (2013), BIM has been introduced for pilot projects in early 2000s and consequently, major researches have been focused on pre- design, visualization, clash detection, costing and data management. Afterwards, other basic functionalities including scheduling, structural analysis, job site safety and progress tracking have been incorporated. However, as stated by Eastman et al. (2011), BIM technology has been originally developed in

1980s in retail and manufacturing industries through object-based parametric modelling.

While it is uncertain in realizing the real instance of conceptualized BIM, Eastman et al. (2011), have recapitulated the evolution of BIM from early 3D modelling, mainly along three different combined technologies which have drastically developed BIM technology. These technologies are shown in figure 02 as Solid Modelling, Assembly Modelling and Parametric Object Modelling.

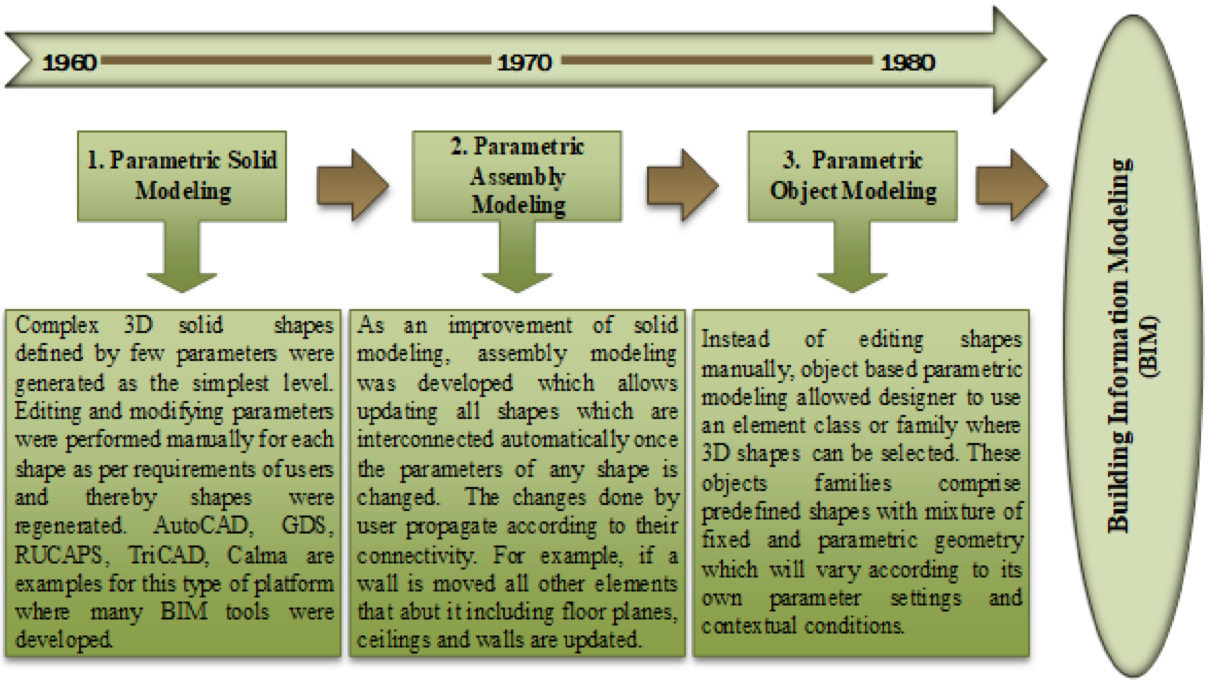


Figure 2: Evolution of BIM

Source: Adopted from; BIM Handbook, 2011

Known as parametric solid modelling, new 3D representations have been first developed in 1960s, through designing initial polyhedral forms with predefined parameters. These polyhedral forms are designed with limited set of parameterized, scalable and complex shapes. These shapes have been further developed as volume-enclosing shapes with the ability to easily edit and modify as required by designers and users. Boundry representation approach was one of basic methods used to create these shapes (Eastman, 1999). This method has been used to represent shapes as a closed, oriented set of bounded surfaces and a shape was always a set of bounded surfaces which defines a set of volume-enclosing criteria of orientation, connectedness and surface continuity (Requicha, 1980). With the use of computational functions different 3D shapes with variable dimensions have been created including parameterized boxes, spheres, boxes, pyramids, extrusions and revolves. CAD platforms have been first incorporated with parametric solid modelling. As the first attempt of 3D modelling, solid modelling was gradually developed between 1960 and 1970 and as an incremental improvement, parametric assembly modelling was resulted.

Assembly modelling was developed allowing update of entire shapes in any layout automatically, by changing any parameter of a shape, and thus eliminate the need of editing and modifying shapes separately in a layout. Consequently, if any shape was changed, all other shapes bounded it determine their changes of connectivity and automatically changed. Thus, the geometry of other related shapes is not separately defined, but generally propagated according to the entire connectivity. Any errors of auto changes are allowed to be manually corrected by the designers. Assembly modelling has been first utilized in creating stairways and that is realized as the development of 3D AutoCAD. However, when building designs become more complex with more shapes or objects, assembly operations have been cumbersome and impractical and the need of effective way to rebuild building designs has been realized. Thus, parametric object modelling was found which allows to select building objects from a family class or element class instead of designing objects separately. In parametric design, objects are early created and categorized separately in a family class with predetermined parameters and include set of rules to control the parameters by which an element can be generated. Thus, user allows to generate designs easily without creating objects manually and unlike solid modelling and assembly modelling, parametric modelling automatically adjust any errors of designing. Thereupon, parametric object modeming has been developed from 1970s to 1980s and by 1990s parametric building model applications were expanded 3D model beyond vectorial data including complementary data such as physical characteristics, quantity take-offs, unit costs and more. Most of current BIM applications have been grew out from the development of parametric object modelling capabilities and later included innovations created what is now recognized as BIM (Eastman et al., 2008).

Accordingly, BIM technology has made new inroads through 3D parametric modelling to make the fundamental change of building representation from human readability to machine readability opening broad opportunities to enhance and facilitate building design and construction (Mitchell, 2011). The current BIM software including Autodesk Revit, Bentley, Graphisoft, ArchiCAD, Gehry Technology's Digital Project, Nematschek, Vectorworks, Tekla Structures and Structureworks have been developed from object-based parametric modelling and upgraded first for the mechanical systems designs in 1980 (Anderl & Mendgen, 1996).

Further, Khosrowshahi and Arayici (2012), have demonstrated BIM maturity in BIM implementation along threefold basic stages including object-based modelling, model based collaboration and integrated practice as shown in figure 04.

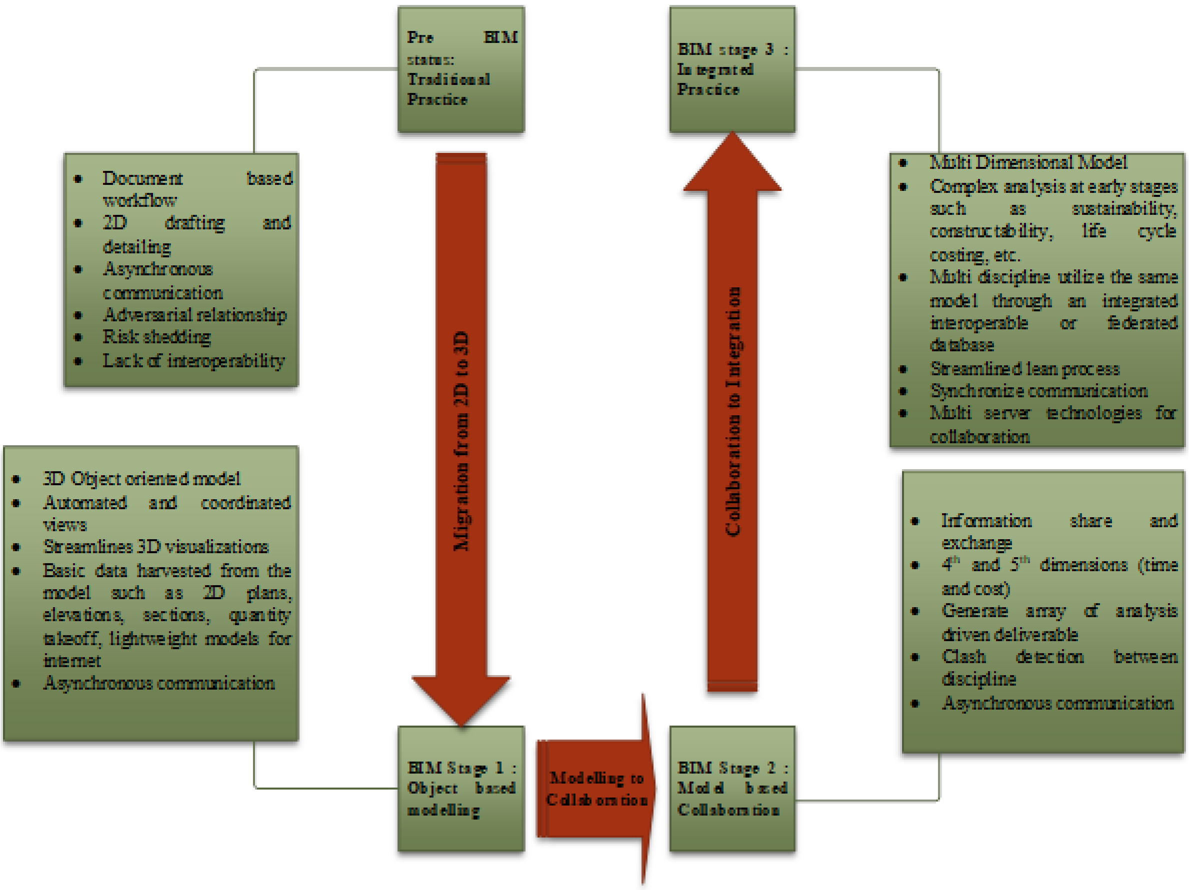


Figure 3: Development of BIM

2.7 Definitions of Building Information Modelling

In concept, BIM is simply defined as "single source of truth" (Pittard & Sell, 2016). Particularly, the consensus meaning of BIM has been put forward in different ways by different individuals, communities, businesses and industries. Thus, definitions of BIM provided in literature have been summarized in table 01.

Table 1: Definitions of BIM

Definition of BIM	Cited By
A digital representation of physical and functional characteristics of a facility	National Institute of Building Sciences (NIBS, 2007)
A shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward	Smith (2014)
A revolutionary technology and process which transform the way of buildings are designed, constructed and managed	Hardin (2009)
A methodology to manage essential building design and project data in digital format throughout the building life-cycle	Succar (2009)
A technology which allows to collect multiple information from multiple disciplines, companies and project phases over a collaborative process	Grilo and Jardim-Goncalves (2010)
Parametric modeling of buildings which has made opportunities to virtually design and construct buildings. It has not been regarded just as a	Suermann and Issa (2009)

2.8 Integration of Building Information Modeling for Building Performance Analysis and Environmental Sustainability

BIM integration to sustainability and building performance analysis has been widely discussed in recent researches. Azhar et al. (2009), have mentioned that, BIM can ensure better integration with building performance analyses for an optimized sustainable design and BIM based sustainability analyses, which has a significant impact over time and cost savings than the traditional methods. Nguyen, Shehab and Gao (2010), have also mentioned that BIM has number of attributes to enhance the sustainability of building design, construction and operation. Further, as explained by Azhar et al (2011), BIM can be used to facilitate complex procedures of sustainable design including daylighting and solar access.

Further, Ilhan and Yaman (2016), mentioned that BIM can play a significant role in building performance. As explicated by Azhar et al. (2010), combination of BIM and sustainable strategies has the potential to produce more efficient high-performance buildings than the traditional design practices. With the same intention, Kamaruzzaman et al. (2016), stated that BIM technology can be incorporated for sustainability and building performance analysis to improve the overall building performance and has the potential to produce greener buildings. Similarly, Kolekar (2015), stated that BIM can aid complex building performance analyses to optimize sustainable designs. In addition to that, Azhar and Brown (2009), explained that the ability of BIM for performance analyses simplifies the difficult analyses and allows architects easy access to get immediate feedback on design alternatives. It has also been reviewed that BIM Model can report areas and quantities within the model for various parameters which contribute to sustainability of projects including water conservation, energy analysis and daylighting analysis (Siddiqui, Pearce, Ku, Langar, Ahn & Jacocks, 2009). Furthermore, according to Jrade and Jalaei (2015), BIM facilitates experimental analysis of structure, environmental controls, construction method, use of new materials and systems. Thus, BIM has been realized which is associated with numerous benefits for sustainable analysis and design throughout the project (Kamaruzzaman et al., 2016). According to Zanni, Soetanto, Ruikar, (2014), BIM contribution to sustainable building design has been discussed along two perspectives as integrated project delivery and design optimization.

2.8.1 Integrated Project Delivery

It has identified that there would be numerous problems when handling a building project, from its inception to completion due to the involvement of various stakeholders. Every project stakeholder takes a part for the project and due to clashing opinions and miscommunications of information, many of redundancies could be occurred throughout the project. As in the traditional practice, when resolving all these redundancies through the documentation process, frequency of cycling documents among stakeholders would be high due to many of refinements, resulting in high costs, mistakes, delays and inefficiencies. As BIM allows an integrated approach for the project team, many of redundancies could be eliminated through the improved communication. Traditional design process has been demonstrated in figure 05.

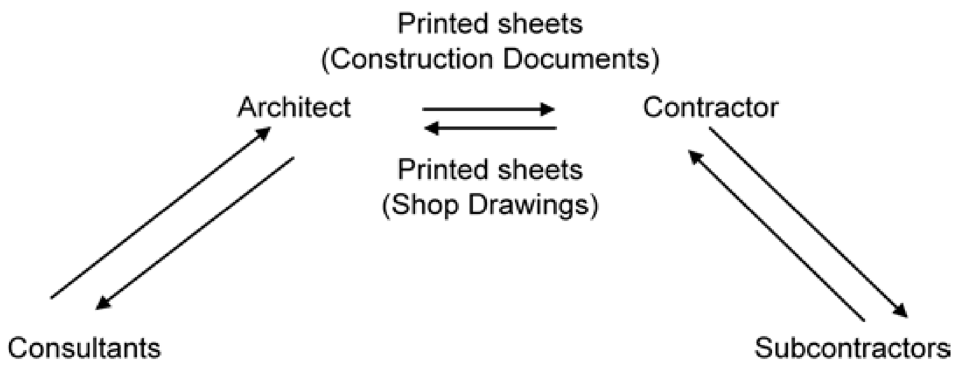


Figure 4: Integrated Project Delivery

Source: Kregel and Nies, 2008

2.8.2 Design Optimization

Design optimization has involved two steps as creating basic models using appropriate BIM software (eg: Autodesk Revit) and exporting models to BIM based analysis software (eg: EcoTest) for various sustainability analyses (Jalaei & Jrade, 2015). These analyses have integrated with various functional aspects of a building including structural integrity, temperature control, lighting, ventilation, circulation, energy distribution and consumption (Moakher & Pimplikar, 2012). Hence, there is an obvious opportunity for the sustainability measures and performance analysis of buildings (Tae, 2012).

According to the reviewed literature, BIM has been widely accepted to manage building performance during the lifecycle as an integrated framework and many researches have been conducted with the aim of integrating BIM with sustainability based applications (Kasim, Li, Rezgui & Beach (2013). Similarly, Biswas, Wang and Krishnamurti (2013), have mentioned that recent researches have been focused on integrating BIM for sustainability at the early design and pre-construction stages. For an example, Azhar et al. (2009) has developed a conceptual framework of BIM-based Sustainability Analysis for construction companies as presented in Figure 6. The left side column shows the project phases, middle column indicates various sustainability analysis features and right side indicates the interaction of external entities such as customers or project partners.

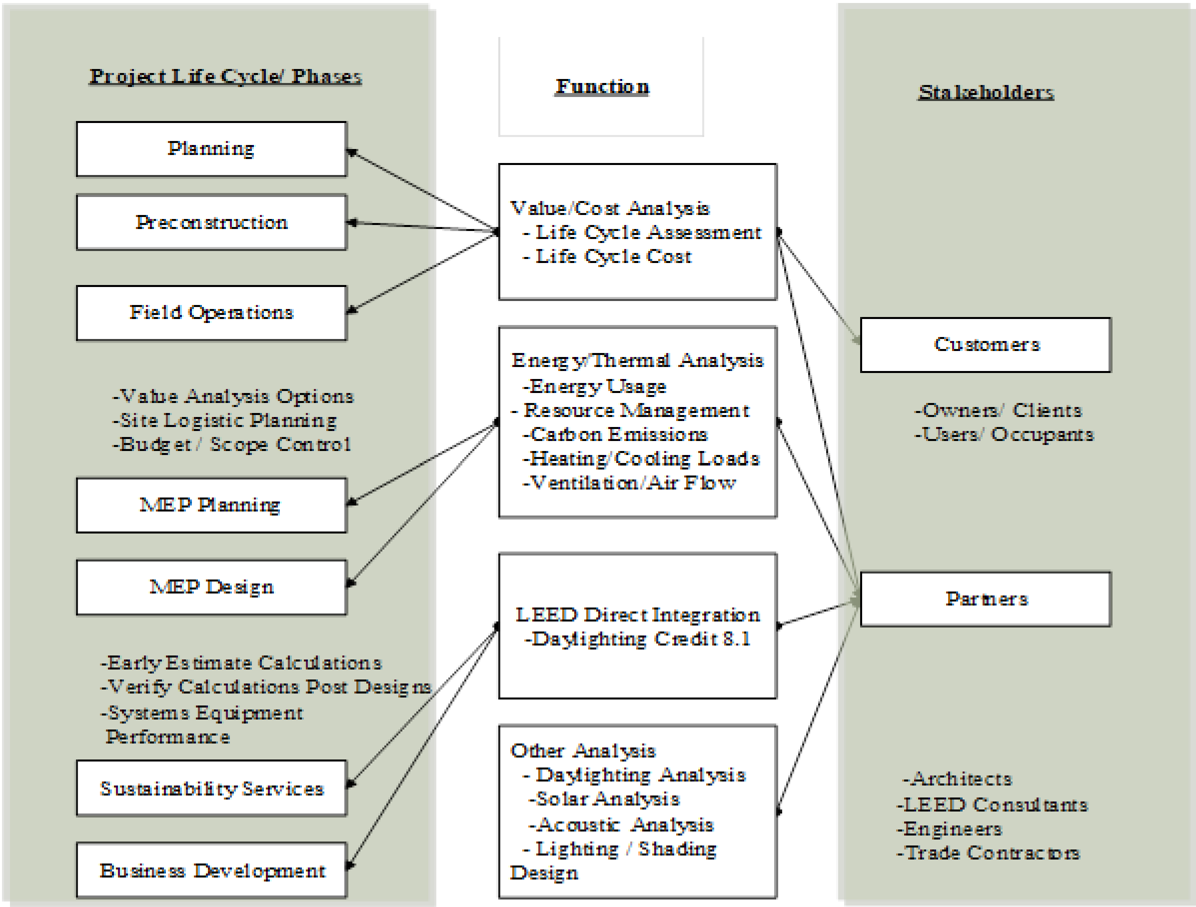


Figure 5: Conceptual Framework for BIM Based Sustainability Analysis

The above framework has been proposed to facilitate the design process and integrated energy analysis. This indicates that BIM can surely facilitate tedious process of traditional sustainable design. This study has explored BIM capabilities in performing various tasks including solar studies, material take-offs, and cost estimation. Azhar et al. (2009), have also indicated a conceptual framework for BIM based sustainability analysis of a project as illustrated in Figure 07.

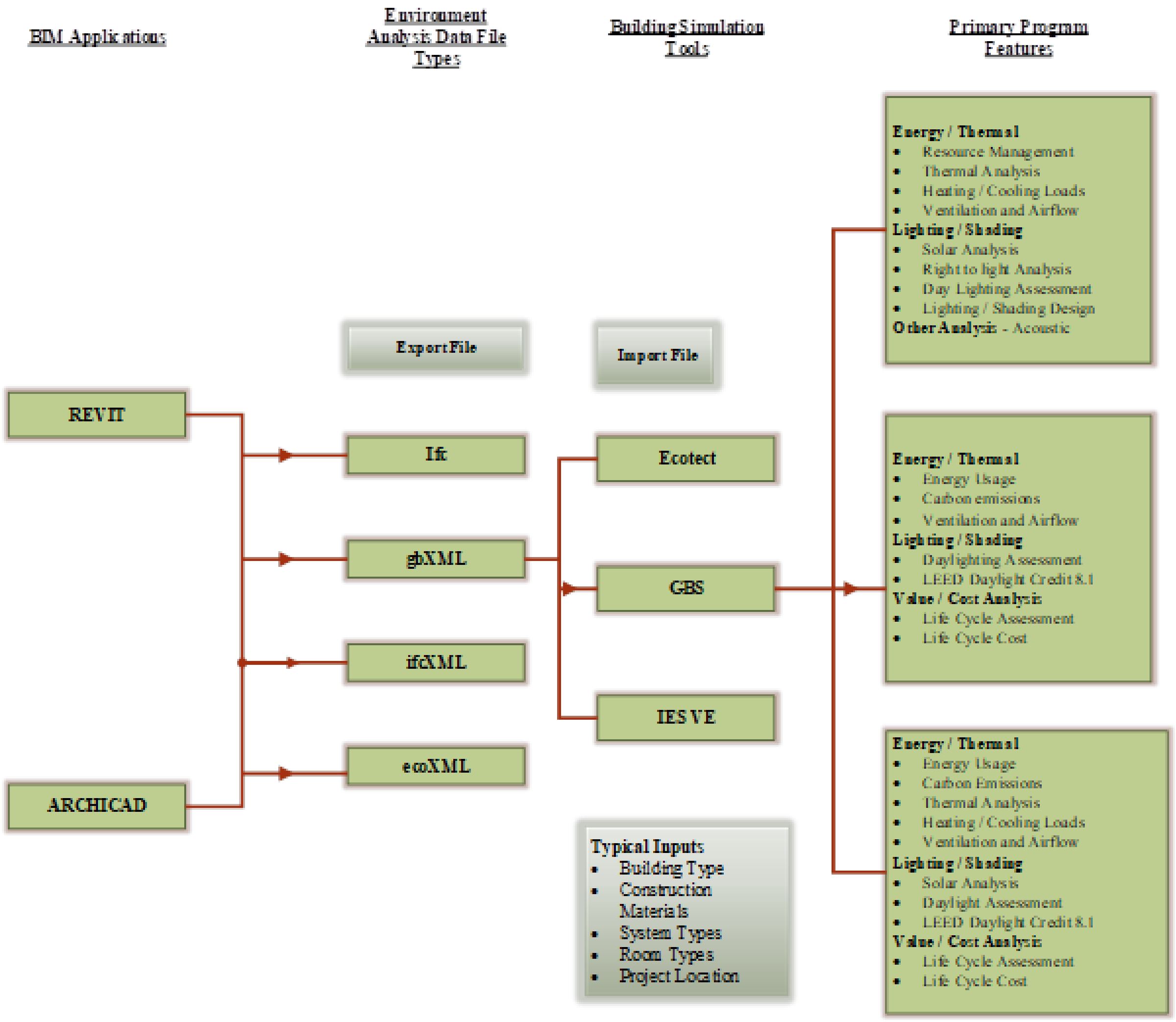


Figure 6: Conceptual Framework for BIM based Sustainability Analysis

As revealed by Chen and Nguyen (2016), Green building and BIM have rapidly transformed the building design and construction industry in this era. An increasing awareness has been created recently in AEC industry to integrate sustainability principles with BIM in green building projects (Sollar, Ismail, Elbeltagy & Yunus, 2016). The professionals in AEC industry more conversant with BIM and green building strategies with the increase in demand for better building performances (Wu & Issa, 2013). Bryde et al. (2013), have highlighted the benefits of BIM, especially in the nature of BIM analysis and simulation abilities corresponding with the objectives of Green Buildings. According to McGraw Hill Construction (2010), there is an increasing awareness in the industry towards the adoption of BIM for green building projects. As asserted by Sheth and Malsane (2014), since the inherent capabilities and characteristics of BIM has been appreciably used for complex building projects, it is significantly appropriate for the development of green building environment.

Ceranic, Latham and Dean (2015), mentioned that, there is a growing trend of green building projects for BIM based simulations during the design phase, to make informed decisions through analysing and simulating various design scenarios to achieve desired green objectives. Further to Lee (2012), the potential applicability of BIM technology into green design projects, has been recently realized from surveys and results have demonstrated 78% of expected growth for green simulations using BIM. The results also demonstrate 88% of expected growth for small green retrofit projects.

Consequently, the use of BIM based green simulations and analysis have become more important in green building design projects (Lee, 2012). As the green building movement matures, such simulations and analysis help designers and architects to have a better understanding of their designs and overall performance with the changes of various design views (Villella, 2010). As identified by Wong and Zhou (2015), promoting benefits of BIM including efficient building operations, improved quality for customers, improved safety performance and reduced resource waste have been identified as leading factors for the creation of green buildings.

While recent publications are widely discussed BIM integration to green buildings in various aspects, some of the researches have defined the same principle behind BIM and green buildings highlighting as Green BIM concept. As revealed by (McGraw-Hill Construction, 2010,), integration of BIM and sustainable principles has gained a growing interest last few years by means of implementing the Green BIM concept. According to Gandhi and Jupp (2014), 'Green BIM' has been coined to describe the convergence of green building design and BIM.

2.9 Green BIM Technology

Ghandi and Jupp (2013), have identified Green BIM as an emerging trend of project design and delivery, which is based on convergence of sustainable buildings and BIM.

Broadly, Green BIM has been defined mainly focused on threefold conceptual pillars as,

- An integrated design processes and building systems supported by object – based modelling and analysis tools,
- Environmentally sustainable design principles and
- Optimization of green buildings certification credits

The construction practitioners in US have considered Green BIM as a tool which provides significant savings of time and cost in design improvements (Azhar, 2011). As pointed out by Wu and Issa (2012), green BIM is the synergies of BIM and green building, which leads to achieve green objectives to improve sustainable outcomes of buildings. Similarly, Liu et al. (2015), have stated Green BIM as the use of BIM tools with the aim of achieving improved building performances. Green BIM has integrated with the structure model and simulations which in turn reflects its impact on the environment, and supports to improve performance analysis while eliminating potential errors of data handling (Motawa and Carter, 2013). From the industrial perspective, Green BIM has been defined as a tool which integrates BIM with sustainable design and construction techniques to make a greater impact on building energy performance and improve making informed decisions at early design stages. Similarly, Bonenberg and Wei (2015), have mentioned green BIM as a tool that is created to integrate sustainable principles in building design industry especially for the energy efficiency application.

However, as per the given definition by Liu et al. (2015), Green BIM is a model-based development of generating and managing coordinated and consistent building data over the lifecycle which helps to accomplish the desired sustainability goals. However, due to the limited research findings of Green BIM in prevailing literature, a precise definition for Green BIM is still mysterious. Thus, considering the existing Green BIM delineations, a definition for Green BIM is given in this research. Accordingly, "Green BIM is a standardized approach and an integrated process where BIM design software and BIM based sustainability software are interacted to perform comprehensive sustainability analysis of buildings, through the use of enriched building data and to optimize building performances".

As stated by Gandhi and Jupp (2014), projects followed with Green BIM has reported considerable life cycle cost savings and proved its economical feasibility for the use. For example, Columbia campus of the University of South Carolina has shown approximately $900,000 savings over the next 10 years with the use of Green BIM (Azhar & Brown, 2009). Hence, property developers and investors also expect that green BIM will serve to achieve high energy efficiency, to evaluate the investments on green buildings and thereby reduced energy costs and sustainability benefits for tenants (Wong & Zhou, 2015). Besides, significant time savings can be achieved through the use of Green BIM since it avoids the recreation of building models, once the model is imported to simulation tools (Ham & Golparvar-Fard, 2014).

As recognized by Bonenberg and Wei (2015), Green BIM has been incorporated with sustainable design methods which are used to examine the impacts of green buildings, with all necessary aspects including lighting, energy efficiency, sustainability of materials and other building performances. Additionally, benefits of Green BIM have been identified as lower material wastage, lower life cycle cost and environmental impacts of construction and enhanced asset value. Siddiqui et al. (2009), have argued that Green BIM has the potential to lead more sustainable projects at different levels, supporting the sustainability assessment of facilities. Further, as reported by McGraw-HillConstruction (2010), Green BIM has increasingly been discussed for more sustainable outcomes. Thus, 'Green BIM' has become a tremendously popular concept in building and construction sector during the last few years.

2.9.1 Green BIM Techniques

Mainly four simulation and analysis areas of BIM which used to achieve green objectives have been identified as energy performance, lighting analysis, HVAC design and green building certification (Lee, 2012). Additionally, BIM software such as Revit has included several green strategies known as building orientation and appropriate degree of massing. Building orientation for sustainable design is identified as positioning of building on site, relative to the path of sunlight since it has a huge impact on energy consumption of buildings and comfort of occupants. This would be essential to identify the heat gain and day lighting aspects inside the building and for optimal design of heating and cooling plants which lead to minimize the total energy cost (Bonenberg & Wei, 2015). In addition to that, Azhar and Brown (2009), have also mentioned several BIM based analysis types including contextual analyses, such as daylighting, building massing and site orientation, solar analysis, and water consumption analysis as well as internal analyses such as optimization of building's HVAC system.

Basic techniques of Green BIM have been identified including energy and thermal analysis, lighting and shading analysis, value and cost analysis, acoustic analysis, water harvesting, space simulation and system simulation as summarized in table 02. The features and output results of each technique are further included.

Table 2: Green BIM Techniques, Features and Outcomes

Green BIM Techniques/ Simulations	**Features**	**Outcomes**
• **Energy and Thermal Analyses**	• Energy Usage • Carbon Emissions • Resource Management • Thermal Analysis • Heating/Cooling Loads • Ventilation and Air Flow • Heat loss calculations • Simulation of indirect environmental	• Energy use intensity • Renewable energy potential • Annual carbon emissions • Annual energy cost and consumption • Building heating and cooling loads • Breakdowns of energy use for major electric and gas components such as HVAC and lighting

Green BIM Techniques/ Simulations	Features	Outcomes
	effects such as atmospheric pollutants associated with building energy use	• Energy end use charts
• **Lighting and Shading Analysis**	• Solar Analysis • Day lighting Assessment • Shading Design Analysis • Lighting Design Analysis • LEED Daylight credit 8.1 • Radiance analysis	• Calculations of solar energy absorption • Glare and discomfort spaces • Spaces where solar directly enters • Cooling and heating energy consumption • Solar orientations for the building
• **Value and Cost Analyses**		• Life Cycle Assessment • Life Cycle Cost
• **Acoustic Analysis**		• Noise dispersion and its effect inside the building

Green BIM Techniques/ Simulations	Features	Outcomes
		• Amount of sound energy a specific building material absorbs
• **Water Harvesting**		• Monthly non- potable water usage • Monthly potable water usage • Monthly water savings • Total water reuse potential • Building water demand • Rain water capture from the roof
• **Space Simulation**		• Comparisons of alternative indoor air quality levels • Comparisons of alternative windows and shades • Dimensioning of air conditioning equipment

Green BIM Techniques/ Simulations	Features	Outcomes
		• Analysis of temperature problems of the building
• System Simulation		• Comparisons of alternative HVAC systems • Optimization of zones for AHUs • Dimensioning of cooling equipment based on actual cooling loads

Adopted from: Azhar and Brown (2009), Azhar et al. (2009), Azhar et al. (2010), Azhar et al. (2011), Chen, Chen, Li and Chiu (2017), Aksamija (2013), Wu and Clayton, 2013, Osello et al. (2011), Douglass (2010), IDM (2010), Bahar, Pere, Landrieu and Nicolle (2013), Moakher and Pimplikar (2012) and Malin (2007).

Among the Green BIM techniques summarized in table 02 space simulation would be impractical or difficult to conduct for existing buildings as buildings are already constructed. For instance, where an existing building is under renovations or refurbishments, space simulation is important to redesign the workspace. System simulation performance is possible if the required system information is available. In typical buildings, sometimes these information is not available if the building has long been used. In such instance, system simulation is also impractical due to the unavailability of required information. In overall, energy, lighting, value and cost analysis and water harvesting probably could conduct for existing buildings compared with other analysis and acoustic analysis become important for buildings with high noises. Hence, factories, garment industries and other different manufacturing organizations which are highly machine-oriented and noise generated may require acoustic analysis while other organizations have a less requirement for acoustic analysis.

In recent research publications, authors have proposed a basic process to conduct Green BIM techniques especially for energy and thermal analysis. For example, Kim and Anderson (2013), have indicated a research framework for energy analysis including seven steps as shown in figure 08.

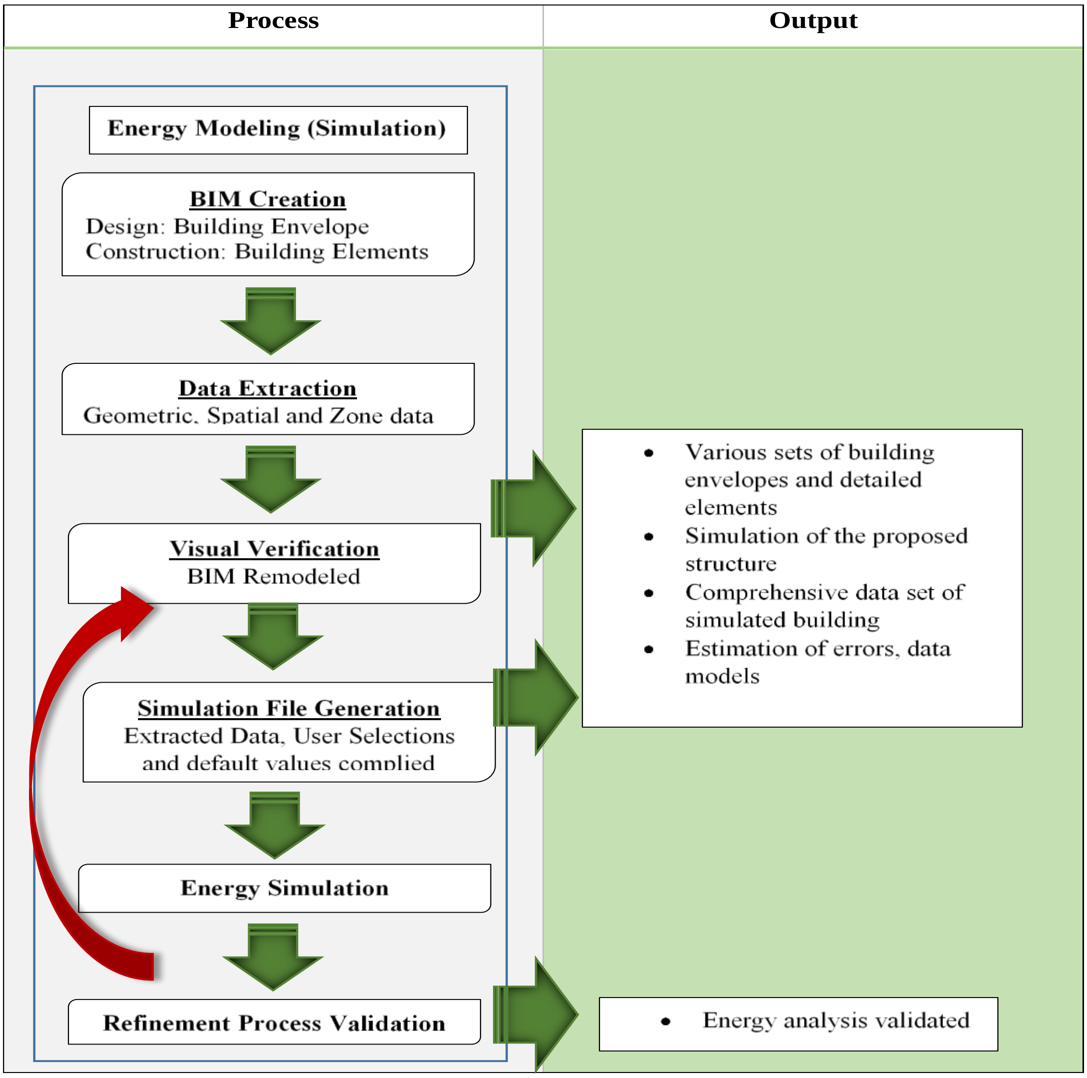


Figure 7: Green BIM Process

According to the figure, as the first step, BIM model of the building is created using modern 3D building design software and exported as an ifcXML file. Data extraction determines the exported file and the system passes geometric and spatial information from the ifcXML representation of the BIM model. As the third step visual verification (optional) is determined after extraction and transformation of information of building model and verify the completeness and accuracy of the model. Together with extracted information additional user input data including system type, occupancy type, duration, location and some default values required for the system are included and get compiled to an energy simulation input file. Finally, energy simulation is performed and results are achieved for the proposed building model, and analysis results are validated through a refinement process (Kim &Anderson, 2013).

2.9.2 Green BIM Tools

Simply, BIM tool is a BIM software. The term BIM tool is broadly defined as an application used for a specific task which produces a specific standalone outcome including drawing production and model generation, specification writing and cost estimation, clash detection, energy analysis, rendering, scheduling and visualization. In some instances, tool outputs are exported to another tool application for example, quantity take-offs to cost estimation, BIM models for sustainability analysis and structural information for more detailed software applications.

Regarding Green BIM, it is important to identify BIM design tools and BIM based sustainability tools or simulation tools separately. BIM design tools are used to design the basic BIM model of buildings and BIM simulation tools are used for various sustainability analysis. These analyses are undertaken by exporting the developed BIM model from design tool to simulation tool via data exchange formats. It is further proven by Sheth and Malsane (2014), saying that, BIM tools can support sustainable building designing and exporting building information and data related to materials, room volumes, via data exchange formats such as green building extensible mark-up language (gbXML) and Industry Foundation Classes (IFC). Use of these tools involve less time-consuming process while making complex analysis easier to evaluate. Accordingly, popular BIM design tools and BIM simulation tools are reviewed in this research, as shown in figure 10.

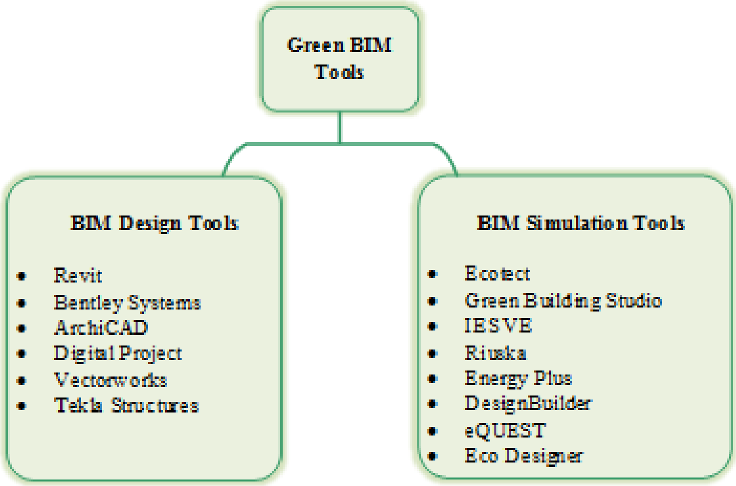


Figure 8: Green BIM Tools

2.10 BIM Design Tools

2.10.1 Revit

Revit has been introduced in 2002 by Autodesk and currently it is the best-known architectural design application of BIM. Drawing capability of Revit has been highly recognized in the industry as it allows strongly associative model generation with standardized functions. Revit comprises a large set of product libraries of design objects. Revit is an accessible and usable tool as it allows to import models from Sketchup, McNeel Rhinoceros and AutoDeSys and support to exchange data through DXF, DWG, DGN, SAT, FBX and ADSK. Even though Revit is used mainly for designing of BIM models, latest versions have been incorporated with simulation features and also with direct plug-ins to BIM simulation softwares.

2.10.2 Bentley System

Bentley system has been identified as a building modelling and drawing production tool and comprises a standard set of predefined parametric objects. As a tool it supports to import external objects and allows clash detection, and offers a broad range of modelling tools. However, this application has been identified as less user friendly, lack of integration and data consistency. Bentley supports data exchange formats including DWG, DXF, 3DS, PDF, VRML, 3DM, U3D, CGM, IGES and ACIS SAT.

2.10.3 ArchiCAD

ArchiCAD has been identified as the oldest marketed BIM tool for the architectural designs which was first introduced in 1980s. Drawing generation, user friendliness and well-crafted interface have been reviewed as strengths of this tool. ArchiCAD comprises a large set of predefined parametric objects and modelling capabilities for site and interior planning and space planning. Minor limitations have been identified in parametric modelling for large projects.

2.10.4 Digital Project

Digital Project has been a premier tool in automative and aerospace industries for parametric modelling. Generally, requires a powerful platform to operate well and also able to model large and complex projects. It is a multifaceted tool and usable for fabrication issues and also a file based application. Mainly, supports data exchange formats including DWG, DXF, VRML, CGR, 3DXML, IGES, STL and HCG.

2.10.5 Vectorworks

Vectorworks has been introduced first as a MiniCad tool in 1985. As a tool, currently it comprises parametric modelling capabilities as in other tools. Vectorworks has been identified as a user friendly tool and provides wide range capabilities for modelling. Data exchange formats for this tool have been realized including DXF, DWG, IGS, 3DS, SAT and STL.

2.10.6 Tekla Structures

Tekla Structure is a tool introduced in 1990s for building and construction, infrastructure and energy. As a tool basically supports precast concrete designs, steel and timber designs and reinforced concrete designs for structural engineering. Good functionality, ability to model structures including structural materials and large projects, have been determined as system capabilities. Complexity and expensive use have been identified as limitations of this tool (Eastman et al., 2011).

2.11 BIM Simulation Tools

According to Azhar (2011), "The development of Green BIM tools which integrates design model and simulation can analyse multi-disciplinary information in a single model which improves the analysis and eliminates errors of data handling". The intelligent information created by the BIM model could conduct building energy analysis, simulate performance, and visualize appearance (Motawa & Carter, 2012). The most commonly used BIM based sustainability analyses tools have identified as Autodesk ECOTECT, Autodesk Green Building Studio (GBS), Integrated Environmental Solutions (IES) Virtual Environment (VE) Energy Plus and DeST (Wong & Fan, 2013).

2.11.1 Ecotect

Ecotect owned by Autodesk, is an energy simulation tool which is compatible with BIM software (eg: Autodesk Revit Architecture) and used to perform comprehensive building energy performance analysis. Ecotect comprises thermal, lighting and acoustic analyses, resulting natural and artificial lighting levels, hourly thermal comfort, monthly space loads, project costs, acoustic reflections, reverberation time and environmental impact (Shoubi et al., 2014). It has recognized as a complete building design and environmental analysis tool which covers a wide range of simulation and analysis functions allowing designers to work easily in the 3D context (Wong & Fan, 2013). According to Moakher and Pimplikar (2012), new Ecotect Analysis includes an expanded array of environmental analysis and simulation capabilities including shadows and reflections, shading design, solar analysis, photovoltaic array sizing and load matching, lighting design, right-to-light analysis for neighbouring buildings, acoustic analysis, thermal analysis, and ventilation and airflow. However, most of Ecotect features specially lighting simulation features have been currently incorporated for the Revit.

2.11.2 Green Building Studio

Green Building Studio, also owned by Autodesk has been identified as an energy analysis tool to evaluate the environmental impact of individual building components, in the life cycle process of buildings. The lighting and shading analyses are used to assess day lighting and include the LEED Daylight Credit 8.1 feature. The value and cost functions have determined the lifecycle assessments and lifecycle costs (Azhar et al., 2010). GBS is popular as an analysis tool, which allows to perform whole building energy analysis. The model should be created by another design software which can export to the gbXML format. GBS does not support the ifc format but provides easy interoperability with BIM tools and other softwares including Autodesk Revit, ArchiCad, Ecotect, eQuest, and EnergyPlus. gbXML and VRML are some supported file formats for GBS (Bahar et al., 2013).

2.11.3 Integrated Environmental Solutions' Virtual Environment (IES <VE>)

VE (Virtual Environment) has been developed by IES (Integrated Environmental Solutions) in

Scotland. Integrated Environmental Solutions' Virtual Environment software has been identified as an integrated building performance analysis tool. Analyses are addressed the issues of solar, lighting, energy, costs and many others (Hua, 2009). The energy/thermal functions include energy usage, carbon emissions, thermal analysis, heating/cooling load evaluation, and ventilation. The lighting and shading analysis includes solar analysis, daylighting assessment, and LEED Daylight Credit 8.1 feature. The value/cost analysis functions are included lifecycle assessment and lifecycle costs (Azhar, 2011). It is an integrated system that operates all building simulations from a central building model. It allows the assessment of performance and provides feedback on building energy consumption and carbon dioxide emission. IES VE mainly supports gbXML and dxf files and can import files from Revit, ArchiCad and as a plug-in of Google SketchUp (Bahar et al., 2013).

2.11.4 Riuska

This tool is used for compliance checking, comparison of indoor climate quality levels, analysis of problematic spaces, energy consumption of buildings and building systems (Peng, 2016).

2.11.3 Energy Plus

Energy Plus is a building energy simulation program which supports architects, engineers and building owners to reduce the energy usage and cost. It is used to optimize the building energy usage of heating, cooling, lighting and ventilation by the simulation. It improves the simulation of entire building approaches through cost and energy savings and indoor environmental quality (Moakher & Pimplikar, 2012).

2.11.4 Design Builder

Design Builder has been introduced as an interface to Energy Plus and thus allows to input all the data of Energy Plus. As a tool it is used for alternative design analysis and parametric analysis of different design parameters and allows compliance for energy certificates. With the ability of importing 3D architectural designs from Revit and ArchiCAD it provides a range of simulations for environmental performances including daylighting analysis. Basically allows data exchange for gbXML and dxf formats (Design Builder, 2013).

2.11.5 eQUEST

This tool is identified as an energy simulation software which calculates heating and cooling usage of buildings. It enables importing of dwg files, exporting of analysis results for excel formats and importing of building geometry via gbxml format (Hirsch, 2013).

2.11.6 Eco Designer

Eco Designer is a tool combined with ArchiCAD and enables basic energy analysis and carbon checking functions, and not as comprehensive as Ecotect (Bahar et al., 2013).

2.12 Application of Green BIM for Existing Buildings

BIM processes have been widely applied for new buildings, while the majority of existing buildings is not yet maintained, refurbished or deconstructed with BIM (Volk et al., 2013). Wong and Fan (2013), have also mentioned that BIM has been widely used for the design phase of building projects. Similarly, Godager (2011), has stated that BIM has been mostly focused on new building projects though there is a considerable need of BIM usage for operation and maintenance of existing buildings. At the same time, Wang and Cho (2015), have indicated that even BIM is available for design and construction phases, BIM is not always available for existing buildings. Further, it has revealed that most of industry professionals have still not seen the real need to develop BIM models for the existing buildings. It has also been mentioned that, keeping and updating a BIM model is a challenge while building is operated and thus, a manual process will be required which is very time consuming and labor intensive. With the same opinion Bonanomi (2015), have stated that, designing BIM model for an existing building to support building maintenance is a challenge.

However, Wang and Cho (2015), have stated that, in order to comply with growing needs of sustainability improvements, existing buildings need to meet modifications and renovations. Proving this statement, Hammond et al. (2014), have mentioned that there is an ideal opportunity in existing buildings to improve building performance since it provides a broad market for green renovations. Essentially, Wong and Zhou (2015), have pointed out that, building owners and managers need to find out ways to improve sustainability of their existing buildings to improve the energy efficiency. As further mentioned by Wong and Zhou (2015), apart from energy efficiency, incorporating sustainable design attributes, reducing operational costs, limiting environmental impacts and increasing building resiliency have also become priorities of retrofitting existing buildings. As per Khaddaj and Srour (2016), use of BIM technologies for energy-driven refurbishments of existing buildings, help building owners to achieve sustainability certifications within a short period of time. In light of this, number of studies have recently begun for the use of BIM for existing projects with the aim of achieving sustainable outcomes.

However, though number of studies have been conducted to simplify the incorporation of BIM for sustainable achievements of existing buildings, recent literature reveals that still there is a need to investigate more possibilities to integrate BIM technologies for existing buildings. It is further proven by Khaddaj and Srour (2016), stating that, still there is an increasing awareness and need to explore special techniques to integrate BIM for existing buildings. On the basis of aforementioned literature, it can be mentioned that, since prevailing studies still have remained the requirement to integrate BIM for existing buildings, the application of Green BIM for existing buildings is also less. Even though, there are few studies focusing on the integration of BIM for existing buildings from sustainability perspective, still there is a gap in incorporating Green BIM for existing buildings. According to literature, application of BIM technologies for existing buildings is mainly hindered by the fact, that there are issues of input data requirements of BIM applications when applying for existing buildings. Hence, the need of input data requirements in integrating Green BIM for existing buildings is discussed in this research.

2.13 Data Requirements for the Application of Green BIM in Existing Buildings

Incorporation of Green BIM for existing structures involves modelling of the building first in BIM design software before simulations. However, it is a quiet challenge as BIM modelling requires set of information of building design and construction. Such information should be updated appropriately when buildings pass its life cycle from planning to maintenance stage. In general, it is difficult to get reliable updated information from existing buildings as buildings are already constructed and also it is hard to make models when building drawings are misplaced or destroyed (Godager, 2011). Similarly, in order to perform various sustainability analysis for existing buildings, consistent and reliable information should be entered for simulation software. Such additional information includes thermal zone layouts, local weather data, HVAC system types, lighting types and appliances, operating schedules, occupancy and utility rates (Ham & Golparvar-Fard, 2014).

Figure 11 shows typical input data requirements exchanged between BIM design software and simulation software in BIM-based building performance (or sustainability) analyses.

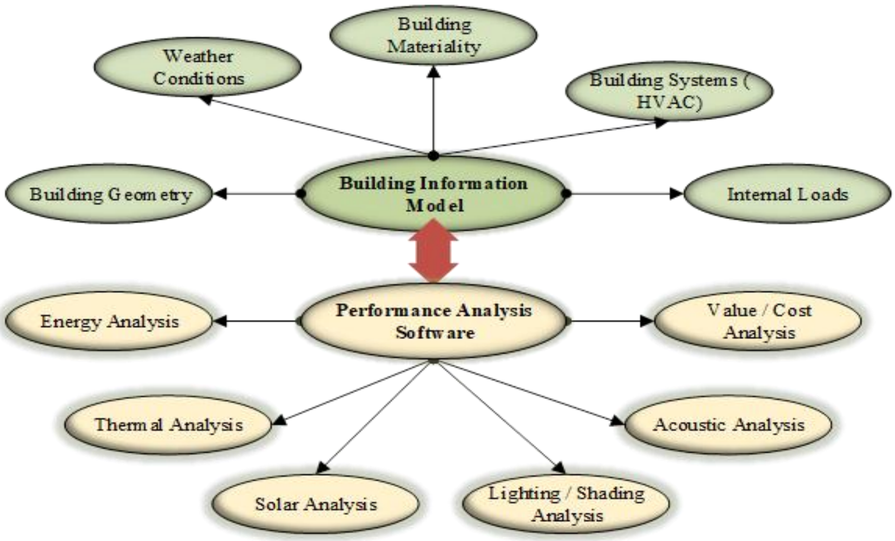


Figure 9: BIM Based Sustainability Analysis

According to Liu et al. (2015), two main categories of input data are required to be included for simulations, as initial design of the building with corresponding building materials and project based information including location of the project, local climate information, and the surrounding situations like number and height of the architectures around and shape of the construction site. Further, input data required for Ecotect lighting simulation have been mentioned as daylight factor, illuminance level, number of working days, total amount of working hours per day, total amount of artificial lights and electricity consumption of artificial lights. For Ecotect life cycle assessment construction cost, operation cost, time value, inflation rates and real interest rates have been identified.

However, it is important to categorize required input data considering the different type of tool as each tool may require different input data for the simulations. Table 05 summarizes required input data for Ecotect, Green Building Studio, IES VE, Energy Plus, Eco designer, eQUEST and Design Builder respectively which are often used for simulations.

Input Data	Green BIM Tools						
	Ecotect	GBS	IES VE	Energy Plus	Eco-Designer	eQUEST	Design Builder
▪ Building Geometry	✓	✓	✓	✓	✓	✓	✓
▪ Building orientation	✓	✓	✓	✓	✓	✓	✓
▪ Weather data	✓	✓	✓	✓	✓	✓	✓
▪ Building envelope constructions	✓	✓	✓	✓	✓	✓	✓
▪ HVAC type	✓	✓	✓	✓	✓	✓	✓
▪ Building type/function	✓	✓	✓	✓	✓	✓	✓
▪ Glazing type	✓	✓	✓	✓	✓	✓	✓
▪ Lighting power density	✓	✓	✓	✓	✓	✓	✓
▪ Equipment power density	✓	✓	✓	✓	x	✓	✓
▪ Occupancy Schedule	✓	×	✓	✓	x	✓	✓

▪ Lighting Schedule	✓	×	✓	✓	x	✓	✓
▪ Equipment Schedule	✓	×	✓	✓	x	✓	✓
▪ Fuel type	✓	×	✓	✓	✓	✓	x
▪ Operable windows	✓	×	✓	✓	✓	✓	✓
▪ Operable window schedule	✓	×	✓	✓	✓	✓	✓
▪ System energy efficiency	✓	×	✓	✓	✓	✓	x
▪ Roof Reflectance	✓	×	✓	✓	x	✓	x
▪ User-defined glazing specifications	✓	×	✓	✓	✓	✓	✓
▪ User-defined envelope construction properties	✓	×	✓	✓	✓	✓	✓
▪ MEP BIM Model	×	×	✓	x	x	x	×
▪ Water efficient fixtures	×	×	✓	x	x	✓	×
▪ HVAC Component sizings	×	×	✓	✓	✓	x	×

▪ Customizable occupancy schedule	✓	×	✓	✓	x	✓	x
▪ Customizable lighting schedule	✓	×	✓	✓	x	✓	x
▪ Customizable equipment schedule	✓	×	✓	✓	x	✓	x
▪ HVAC fan power	✓	✓	✓	✓	x	✓	x
▪ Interior temperatures	✓	✓	✓	✓	x	✓	x
▪ Utility Rates	✓	✓	✓	✓	x	✓	x

Table 3:Input Data for Green BIM Tools

Source: Reeves, Olbina & Issa (2015), (Francis, 2016)

Moreover, the types of building geometry data mainly required for creating the basic BIM model in Green BIM, have been identified in this section as mentioned below (Rathnasiri, Jayasena & Madushanka, 2017).

- Floor Plan Details
- Doors and Windows Details
- Specification Details
- Elevation Details
- Roof Plan Details
- Sectional Drawings
- Foundation Details
- Beams and Columns Details

In addition to that following data have been mentioned as required input data for BIM based simulation tools (Reeves, Olbina & Issa, 2015; Francis, 2016).

- Heat recovery systems
- Automated lighting controls
- Geographic location
- HVAC schedule
- Heating / cooling set points
- Types of building materials
- Volume of materials

2.14 Level of Detail / Development (LOD)

Level of Development is a concept which addresses the level of development of model elements in different phases of buildings. It provides a conceptual framework to describe the relative development of model elements throughout the building life cycle. Creating model elements in a scale of LOD indicates how much it is depended for the decision making process. LOD specifies required building information for the model development in BIM context including LOD 100, LOD 200, LOD 300, LOD 400 and LOD 500 respectively as in figure 13.

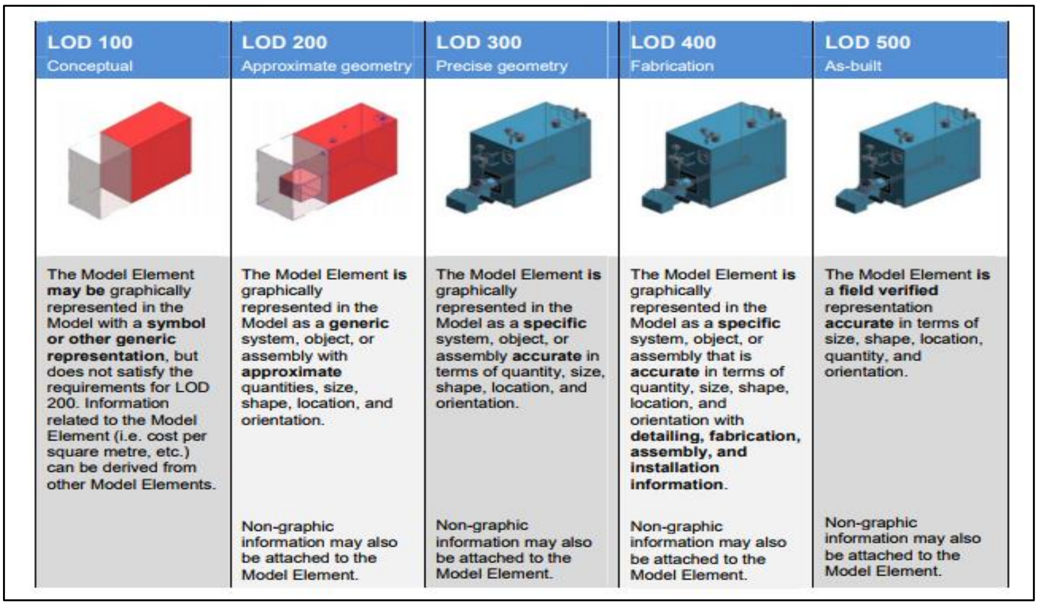


Figure 10: LOD Scales

Source: (BIM Paper, 2013)

Simply it is a metric to clearly define the approximate model development. As defined by American Institute of Architects, the "*Level of Development describes the minimum dimensional, spatial, quantitative, qualitative and other data included in a model element to support the authorized uses associated with such LOD*" (BIM Forum, 2015).

Over the Green BIM perspective, Aksamija (2012) and Wu and Issa (2015) have presented LOD for BIM based sustainability analysis including energy analysis, detailed day lighting analysis, solar position, site context/shadow analysis, shading analysis and solar exposure analysis. Types of input data specified under LOD scales prior to each Green BIM analysis have been further discussed in table 06.

LOD	Types of Data		Depth of Analysis	
	Day Lighting Analysis	**Energy Analysis**	**Day Lighting Analysis**	**Energy Analysis**
LOD 100	Surrounding buildings, building form and massing	Site location, building orientation, massing	Solar Position Site Context / Shadow Analysis	Assessments of design alternatives
LOD 200	Building form, openings, interior spaces, windows, shading elements, floors, walls, dimensions	Building geometry, preliminary layout, construction, mechanical equipment	Shading Analysis Solar Exposure Analysis	Evaluate design schemes, intermediate analysis, preliminary code compliance

LOD 300	Building form, openings, interior spaces, windows, shading elements, floors, walls, dimensions, interior partitions, material properties	`Building geometry, detailed layout, detailed construction and envelope design, mechanical equipment, building controls and detailed assumptions	Detailed Day Lighting Analysis	Estimate final design energy analysis

Table 4: Input Data for BIM Simulations Under LOD Scales

Source: Adopted from; Aksamija (2012) and Wu and Issa (2015)

2.15 Challenges Over the Application of Green BIM for Existing Buildings

BIM has associated with the whole building's design life. The difference of BIM projects used for existing constructions has been identified as getting the BIM into whole life cycle phases of the building (Succar, 2010). Adopting BIM for existing buildings makes a need to adopt BIM for the operational phase. McArthur (2015), has mentioned key challenges that must be overcome to develop BIM for sustainable operations management as,

- Identification of critically required information,
- High level of effort to create new or modify existing BIM models for the buildings,
- Management of information transfer between real-time operations and monitoring systems and the BIM model, and

- Handling of uncertainty based on incomplete building documentation.

However, analysing the availability of data in existing buildings, Rathnasiri, Jayasena and Madushanka (2017), revealed that the required data are available up to some extent, in new buildings and green accredited buildings. In addition, Lavy (2008) has mentioned that buildings managed with facilities management divisions are maintained with proper information of the building to ensure the optimised FM practices. Further, according to Hedstrom (1997), maintaining building record keeping systems are important and such organisations are managed properly with the available desired information for day to day operations of buildings.

However, as explained by Godager (2011), it is important to create the 3D BIM model using paper drawings or digital drawings. Further, according to**,** Ham and Golparvar-Fard (2014), the information is generally obtained from drawings, specifications, photos or any other available materials and the accuracy of such information is one of the most important factors need to be considered.

In other hand, taking a responsibility for updating such information to ensure its accuracy involves a great deal of risk (Azhar et al., 2012). The use of appropriate data can only save time in the creation of 3D digital models and the lack of consistency of data has become an ongoing issue in the management of a facility (Sabol, 2008). Moreover, problems such as missing data can also destroy the credibility of BIM results (Jun, Kim, Lee & Kim, 2014).

Further, documentation is a critical factor for building maintenance. Sometimes, though the information really exists, the acceptable quality is unknown or not easily accessible which can result in unnecessary duplication efforts or losses. Chien, Wu, Huang (2014), have also summarized risk factors of BIM implementation as insufficient and incorrect design information and unclear specifications. With this intention Wu and Issa (2012), have stated about the lack of data management during project life cycle, as a key barrier for BIM adoption. The availability of data is another significant fact since the information often remains in paper format rather than in the digital format. Thus, it is important to ensure the compatibility of both formats if available.

According to McArthur (2015), proper identification of information is critical for the creation of BIM models and sustainability analysis. Motawa and Carter (2012), have mentioned that, the use of BIM for sustainability analysis of existing constructions results in unreliable and overestimated measures. Wu and Issa (2012), have also indicated the need of variety of information as a major hurdle for the integration of BIM and LEED certification.

However, there is a growing concern for generating and managing building data, as integration of BIM into sustainability heavily depends on reliable information. As a result, cloud-based technology has been developed which can simplify the data capturing from existing buildings (Cooley & Cholakis, 2013; Konig, Drinbek & Stankovski, 2013).

Apart from point cloud technology, to facilitate the data acquisition from existing information, advancements of energy audit technologies including Building Automation Systems (BAS) and Building Energy Management and Control System (EMCS) have also been proposed (Xu, Chan & Qian 2011; Cooper, Daly, Ledo; 2012). Nevertheless, as mentioned by Arayici (2008), use of these technologies are impractical and inefficient with regard to time, cost, accuracy and usefulness.

On the basis of currently available literature, it can be proved that still there is a gap in integrating Green BIM technology for existing buildings due to the challenges of data requirements in BIM standards. The aforementioned literature reveals the issues associated with existing building data which commonly exists. Nevertheless, the actual challenges which can be practically aroused in recapturing BIM data from existing building information are hidden and unknown as it has not been proven through any practical experiment. As this study focuses on facilities management perspective, the reviewed literature can be demonstrated with the research gap, where application of Green BIM for existing buildings in FM perspective is not reviewed. In overall, Green BIM is not adopted for existing buildings due to various challenges, however focusing FM, there is no real challenges have been determined. Thus, the real challenges, solutions and directions to overcome the challenges of Green BIM implementation for existing buildings which could arise in the practical nature still remain with a question. This statement is further proven by Godager (2011), saying that, future attempts will be directed to more successful processes to facilitate the recapturing of as built information of existing buildings. Thus, literature ends with highlighting the gap of what are the challenges of existing building information and solutions to overcome such challenges for the appropriate adoption of Green BIM for existing buildings in FM perspective.

Based on the literature review findings, a theoretical framework was adopted to reflect the existing research gap of this study. The framework basically demonstrates how Green BIM concept has become to the building construction industry with the need of energy optimization of buildings. Main considerations of Green BIM have been identified as Green BIM techniques and Green BIM tools. Attributes of Green BIM were listed as ability for comprehensive building performance analysis, standard information management system, proper integration for all project stakeholders, improved decision making and optimized building environmental performances. As identified from literature, these attributes directly provide benefits for facilities managers and thereby enhance FM functions in existing buildings due to the opportunity for energy optimization.

However, the literature reveals the challenges which discourage the implementation of Green BIM for existing buildings. These challenges have been gathered in the framework. Nevertheless, in relation to FM scope, the specific challenges of facilities managers for the lack of implementation of Green BIM for existing buildings have not yet been recognized where the research gap of this study become obvious.

CHAPTER 03

3.0 RESEARCH METHODOLOGY

Research is identified as a quest for undiscovered knowledge (Goddard & Melville, 2004). In one hand, research is to provide an answer to a prevailing question which is unanswered or to be answered. This chapter is expected to provide a systematic approach which was used to accomplish the aim and objectives of the research to answer the research problem. Importantly, it explains the research methodology used for the research in detail, including research approach and research process. According to Kothari (2004), the importance of research methodology is identified through the steps adapted by the researcher to study the research problem with the relevant logic behind them. Hence, the purpose of this chapter is to provide a comprehensive idea about the methodology of this research.

3.1 Research Design

Research design is a logical blueprint which can be implicit or explicit (Yin, 2009). According to Tan (2002), research design is defined as the plan for moving from the research question to the conclusion. It basically includes the principles and procedures of logical thinking processes which apply to a scientific investigation (Fellows and Liu, 2008). The selected task could be performed easily in an organized manner with the help of research design. Then the actual work of the research could be initiated after completing the research designing (Senarathna, 2005). The outcome of any research heavily depends on the research design; thus, it is important to develop an appropriate research design to the research study. The design of this research includes an initial study, literature survey, case study and analysis, development of a framework and validation of the findings respectively.

3.2 Research Approach

Research approach is identified as the process which leads to achieve the research objectives. Mainly, it is to monitor in organizing research activities in a way that achieving research aim satisfactorily (Smith, Thorpe, & Lowe, 2002). Further to, Smith, Thorpe and Lowe (2002), research approach assists in organising research activities including the data collection to achieve the research objectives. The two main research approaches are identified as qualitative approach and quantitative approach (Kothari, 2004). Quantitative approach relates to positivism and seeks to gather factual data (Fellows and Lui, 2008) whereas qualitative research is undertaken through a deep contact with live situations (Miles & Huberman, 1994). Moreover, qualitative research is of subjective nature and consists of non-quantitative data such as assessment of attitudes, opinion and behaviour (Kothari, 2004; Naoum, 2007). In other hand, a quantitative research is of objective nature and gathers quantitative data (Fellows & Lui, 2008).

3.2.1 Quantitative Research Approach

As mentioned by Amaratunga, Baldry, Sashar and Newton (2002), quantitative approach enables the advantages including allowable comparison and replication, reliability and validity more objectively than qualitative techniques and reducing the complexity to facilitate the analysis. Nevertheless, Yin (2011) argued that, the approach is restricted since it limits the establishment of necessary research conditions, difficulties in drawing sample respondents, obtaining higher response rates and devotes to study past not the ongoing events.

3.2.2 Qualitative Research Approach

Berg (2001) has defined the Qualitative approach as, “Adequacy of any procedure resulting in nominal than numerical types of data.” Further, Yin (2013) has emphasized, the advantages of qualitative approach as an in-depth study on broad topics, focus on specific set of people, representation of views and perspectives of people and greater latitude in selecting topics. However, the selection of the approach is rested upon the nature of the research problem (Noor, 2008). The aim of this research was to identify the challenges of regenerating BIM data from existing building information for the use of Green BIM technology. In order to achieve the objectives of this study a qualitative research approach was followed.

3.3 Research Process

Research process explains the sequence of steps that should be followed to achieve the aim and objectives of the research in an efficient and effective manner (Kothari, 2004). Further to Kothari (2004), it describes the linkage of literature review, data collection and data analysis in achieving the research objectives. The research process adapted to achieve the research aim in this study has been discussed below.

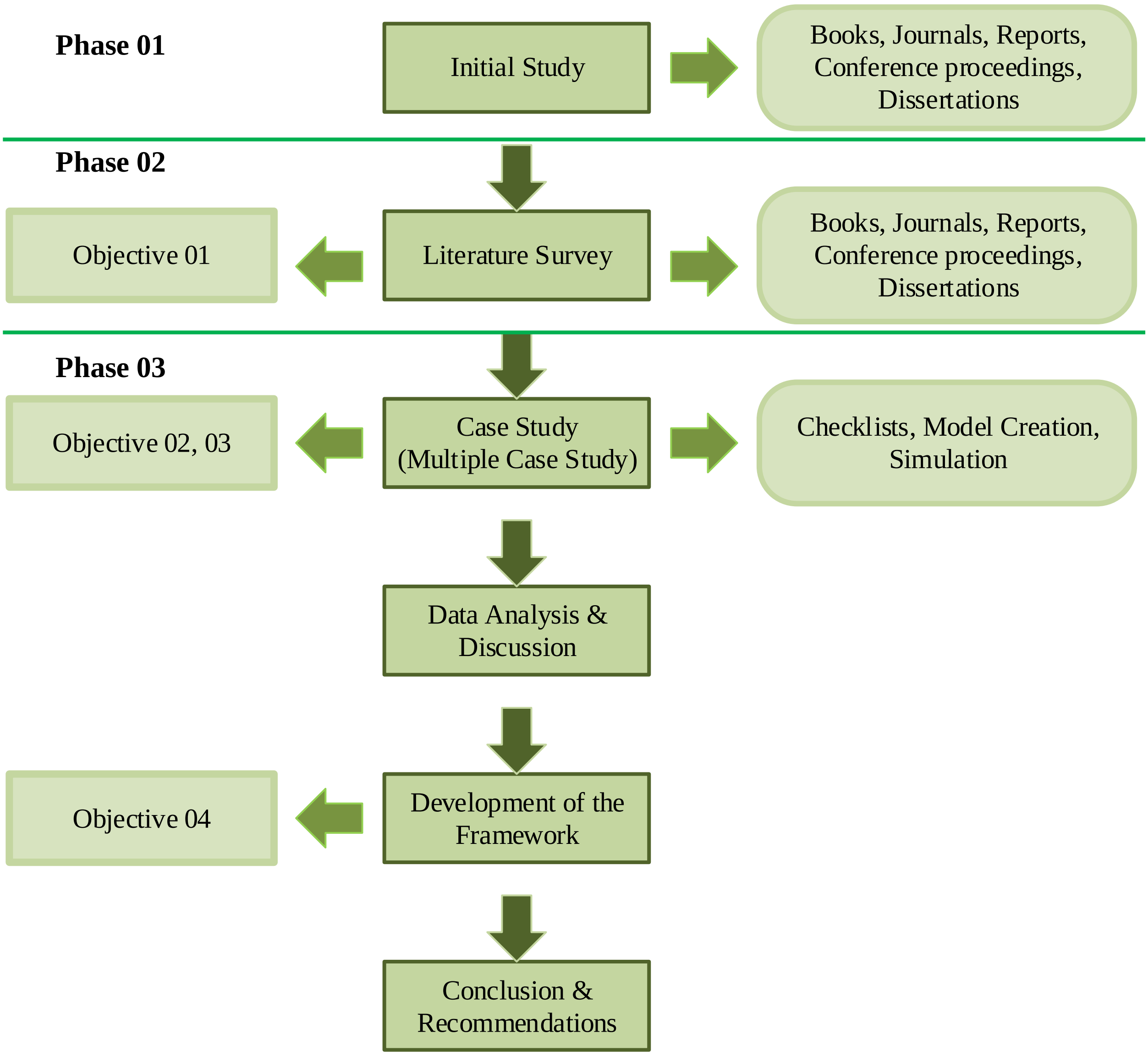


Figure 11: Research Process

3.3.1 Phase 01 - Initial Study

An initial study was conducted first for the purpose of establishing the research problem, aim, objectives as well as the research background. Alongside, scope and limitations of the study were also identified. Research background was established by referring journal articles, books, reports, unpublished dissertations and conference proceedings. Finally, the research gap was identified for further continuation of the research.

3.3.2 Phase 02 -Literature Survey

The purpose of literature review was to study the research problem in detail in order to gather the required knowledge for data collection and analysis process. Accordingly, a comprehensive literature review was conducted to identify the term BIM, Green concept and further, the synergy in Green BIM and existing knowledge and principles regarding Green BIM. Books, journal articles, conference papers, reports and unpublished dissertations were referred in gathering required information. The first objective of identifying Green BIM techniques, tools and data requirements for tools were identified through literature review. Hence, literature review was important in establishing the base for Green BIM implementation in existing buildings.

3.3.3 Phase 03 – Multiple Case Study

According to Schramm (1971), case study tries to come up with a decision or set of decisions of; why they were taken, how they were implemented, and with what result. Ethnographies or participant observations and experiments are regarded as different perspectives of case study strategy. Case study method is not just a form of qualitative method and it can include or limited to quantitative evidence as well. In some circumstances, case study research may include as a mix of both quantitative and qualitative evidence and may be conducted and written with many different motives (Yin, 2011). Further to Yin (2013), case studies may be conducted as single case study or multiple case study.

These two instances have distinguished advantages and disadvantages and however, multiple case study is identified as which is more significant in having analytical benefits compared to single case designs. Further, it is mentioned that single case studies are more vulnerable as it needs to "put all eggs in one basket". Hence, the evidential results of multiple case studies are considered as more compelling results and overall study is more robust (Herriott & Firestone, 1983). Besides, multiple case studies are important in arriving broad generalizations than the individual cases (Yin, 2011). Thus, multiple case study method was selected for this research and accordingly, two cases were conducted for the study by practically applying Green BIM technology for selected two cases. Application of the technology was involved conducting checklists, creation of BIM models and simulations. This is further discussed at the end of this chapter.

3.3.3.1 Unit of analysis

Unit of analysis may be a project, process, an individual or an organisation based on the requirements of a particular research. For the purpose of this research an existing building was selected as the unit of analysis.

3.3.3.2 Triggers of the study

This research is a further continuation of a previous study; thus, the findings were fundamentally used and triggered for the in-detail analysis of this research. The previous study was to basically identify the applicability of Green BIM technology for green buildings which are during the operation and maintenance phase. The scope of study was considered within the Sri Lankan context and findings demonstrated the potential of Green BIM application for green buildings in Sri Lanka. The research was undertaken conducting a single case study selected among the population of green buildings. Especially, existing green buildings were considered which have been accredited under LEED certification. Four types of LEED certification were considered including new constructions and renovations, operation and maintenance of existing buildings, design of commercial interiors and building core and shell development. The selected case was a green building certified under operation and maintenance of existing buildings.

However, findings revealed that all above building categories have an accepted level of input data required for Green BIM while the selected case demonstrated a highest data availability. Based on the availability of data, the case study was conducted by applying Green BIM technology for the selected building. The findings during the study verified that, though the data are adequately available, accuracy of data is vital for the proper implementation of Green BIM for existing green buildings. However, this study was just an effort to identify the possibility of Green BIM application for buildings which have not been designed using BIM. Depend on this, findings of this study concluded that, there is a potential for the application of Green BIM for green buildings even though BIM has not been used at the early stages. Further to research findings, this possibility is entirely depended upon the availability of accurate data relating to the design and construction details of the building. Thus, further research directions were suggested to investigate the potential of Green BIM application for buildings which operate with less data availability. Selected green buildings showed a sufficient data availability as green buildings are updating such information periodically with the renewal of LEED certifications. However, literature revealed that existing buildings which have not accredited green rating systems are often lacking the data required for Green BIM. Accordingly, the findings of this previous research and practical experience gained were considerable benefits and a base which laid a foundation for the new focus of research study.

3.3.4 Selection of Cases for the Multiple Case Study

The aim of this research was to identify the challenges of regenerating BIM data from existing building information for the implementation of Green BIM technology in existing buildings. Thus, the study focused to conduct an in-depth analysis using two existing cases to identify the specific challenges in each case. The difference of the two cases was considered where one case need to be available with new conditions while the other case need to be available with old conditions to compare the differences in BIM environment. Therefore, considering the overall perspective for the requirement of the cases, the preliminary focus was to select two existing buildings which was constructed years ago and a building which was constructed recently. The previous study of this research revealed that the BIM data are adequately available in newly constructed green buildings. Based on that, this study focused to identify the challenges of recreating BIM data from available limited information in existing buildings. Hence, due to the nature of this research, it was important to select a building with less data availability which is either not entirely data available or not any data available (zero). To compare the differences of challenges in the two existing contexts, other case was needed to select with required data availability and thus a recently constructed building was considered based on the literature.

In addition to that, the access for getting building information including drawings and specifications of the building was also needed to be considered as a major requirement for the selection of cases, since the organisations are restricted in permitting such information for external parties. However, keeping the verification of cases later, first, two existing buildings were selected based on the aforementioned requirements and boundaries. The criteria for the selection of cases were established first based on the literature findings as prerequisites. The case 01 specified a building which was constructed years ago while case 02 specified a building constructed recently. These criteria are indicated in table 07.

Table 5: Criteria for the Selection of Cases

Criteria	**Case 01 (specified as aged)**		**Case 02 (specified as new)**	
	Accepted	**Not Accepted**	**Accepted**	**Not Accepted**
Whether building has accredited any green certification (If Yes)		√		√
Whether building has been recently built or years ago (If recently built)		√	√	
Whether there is a facilities management department or a maintenance department in the organization	√		√	
Is the organization following any documents keeping and management systems	√		√	

As mentioned previously, the literature findings reviewed that desirable, up to date, complete data are available in buildings which have been recently built and/ or achieved green accreditations. Thus, such cases were disregarded for the selection of case 01, since the challengeable contexts not persist in such situations due to the availability of data requirements. In light of this, it was necessary to assure the limited data availability in case 01 for the identification of challenges which impede the potential for the application of Green BIM. To attend this, it was important to verify that building is available with minimum data availability of building geometry data, instead of non-availability of data. Hence, for the verification of minimum data availability, the remaining selection criteria were established considering the existence of FM department or maintenance department in the organization and organisations maintained with any record keeping or documents management systems. If one of these criteria was fulfilled, it was regarded as a positive factor for the selection of case 01. Importantly, the second criterion was established to separately identify the condition of the building; whether building has been built years ago or recently.

For the selection of case 02, first criterion was again disregarded to simplify the comparison between the two cases. Thus, green accredited buildings are avoided considering it as a different category though there were recently built new buildings accredited with green certifications. The remaining criteria were similarly identified to select a building which is recently built and to confirm the data availability.

Accordingly, two existing buildings were selected which were educational buildings. The buildings selected for case 01 and case 02 have been constructed in 2005 and 2016 respectively. Accordingly, the existing building used for the study as the first case was 13 years old while the second selected case has passed 2 years after its construction and both buildings were currently occupied and during the operation and maintenance phase. Besides, the selected cases were not accredited any green certification while managing with a facilities management department and thus fulfilled the minimum and maximum data availability within the boundaries. Furthermore, the present condition of the selected two cases were obviously different in terms of building design, construction, condition of building envelope materials, quality and also the appearance. It was aimed to identify the different challenges of implementing Green

BIM in these existing buildings as both buildings have not been constructed using BIM during the design and construction stages.

3.3.5 Data Collection (Multiple Case Study)

This study was conducted by implementing Green BIM for the selected cases within the scope of facilities management. Consequently, the methodology of this study involved the researcher as the instrument for the data collection. Accordingly, as main findings of this study, practical challenges and solutions were discussed based on the experiences of the researcher in implementing Green BIM in each of the case. This method was adopted because there had been no known Green BIM implementation in the country, and the challenge was overcome by researcher who is from facilities management background implementing it in two real life buildings (i.e. two cases). Accordingly, the researcher as a facilities manager has revealed the challenges that could be experienced during the practical implementation of Green BIM for existing buildings. The method offered rich firsthand data for analysis.

3.3.6 Data Analysis (Multiple Case Study)

Analysis is the challenging and exciting stage of entire research process (Ritchie et al., 2014). Qualitative analysis was considered for this research. Basically, findings were identified during the practical implementation of Green BIM for selected two cases. To conduct the multiple case study, a process flow diagram was developed first after the selection of cases. Along with this process it was intended to practically implement Green BIM techniques for the selected cases. In order to facilitate this implementation, the framework was developed with necessary steps. The purpose of this was to identify the actual challenges that can arise in the practical context of Green BIM implementation for existing buildings and to recognise the solutions to overcome them. With the findings that achieved during the study, the process flow diagram was revised and further improved for a framework so that it can be used to implement Green BIM for existing buildings successfully.

Consequently, once the cases are selected, the study intended to investigate the drawings and specifications of selected buildings to analyse the data availability, as the first step of the process. Availability of the data in each case was analysed through checklists which were used as the data collection mode including the data identified from literature. The findings of data availability analysis were subjected for the verification of selected cases. This was also supported to decide the appropriate scale of Level of Development (LOD) for the study. Subsequently, the study analysed the suitability of identified data in selected cases to introduce the data requirements which should be updated to comply with the actual condition of the building. This was mainly involved the designing of basic building models and simulations in BIM software environment. Designing of building models was performed using Autodesk Revit BIM designing software while simulations were done using inherent Green BIM features of Revit and Green Building Studio. As the simulations, energy analysis and day lighting analysis were conducted using simulation software. The combination of software represented the potential real-life context as Revit was the commonly found modelling tool and GBS was freely available on web, making them the most accessible tools for a Facilities Manager in Sri Lanka.

The above discussed process flow diagram for the study is presented in figure 15.

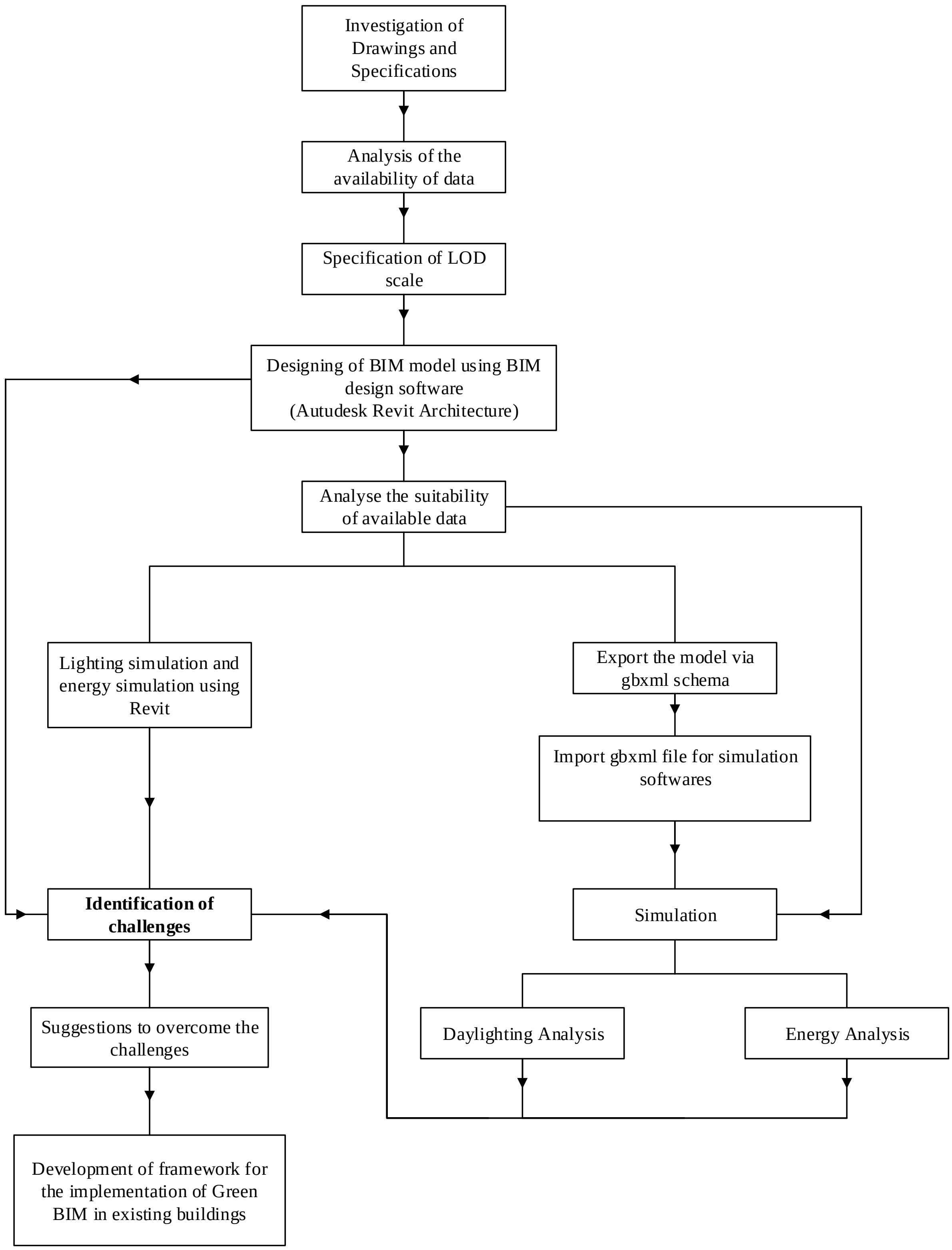


Figure 12: Process Flow Diagram Developed for the Study

3.3.7 Development of the Framework

As the final objective of the research, the developed process flow diagram was revised and re-developed for a framework including the challenges and suggestions to overcome the identified practical challenges during the implementation of Green BIM in existing buildings. This framework provides guidance for facilities managers to implement Green BIM for existing contexts of buildings.

3.3.8 Conclusion and Recommendation

Finally, conclusions were given based on the findings of the study highlighting research objectives and further, recommendations were provided. At the end of this chapter, further research directions and limitations were briefly discussed.

3.3.9 Chapter Summary

This chapter focused to provide the overall methodology and process which followed to achieve research aim and objectives. Importantly, this chapter discussed the research design, research approach and research process comprehensively with the discussion of data analysis techniques. Further, triggers of the study and the positionality which was based for the study were explained. Also, the sequential process of the research was graphically presented.

CHAPTER 04

4.0 DATA ANALYSIS AND DISCUSSION

This chapter includes the findings gathered from data collection and analysis and interpretation of the analysed data. Data collection and analysis were entirely based on two case studies. First the data availability was analysed to verify the selected cases for the study and further, suitability of data was analysed as the study focused on existing buildings where required data need to be updated for the real-life context. Through the case study approach, an in-depth analysis was done to identify the challenges of translating existing data to relevant BIM data and challenges of generating BIM data when existing data are not sufficient. The identified challenges were discussed and interpreted extensively in this chapter and subsequently, a framework was developed with suggestions to overcome the identified challenges which arises during the practical implementation of Green BIM for existing buildings.

4.1 Overview of the Project

This project was conducted through multiple case studies, according to the theoretical framework developed for the study. The experiences gathered during the project are explained sequentially as the findings of the case studies which also fulfilled the requirements of second, third and fourth objectives of the research. Challenges confronted when progressing through different stages of the project and the solutions or the steps taken to complete the project are explained sequentially as the outcomes of third and fourth objectives respectively. One of the major challenges faced during the initial stages of the project was the unavailability of BIM data of the selected case study buildings. However, later the relevant drawings were gathered from the contractor of the buildings. This chapter along with several other key findings, explains the barriers that were faced due to the lack of BIM data at the early stages of the project and the changes made to the developed model after obtaining the drawings through the contractor.

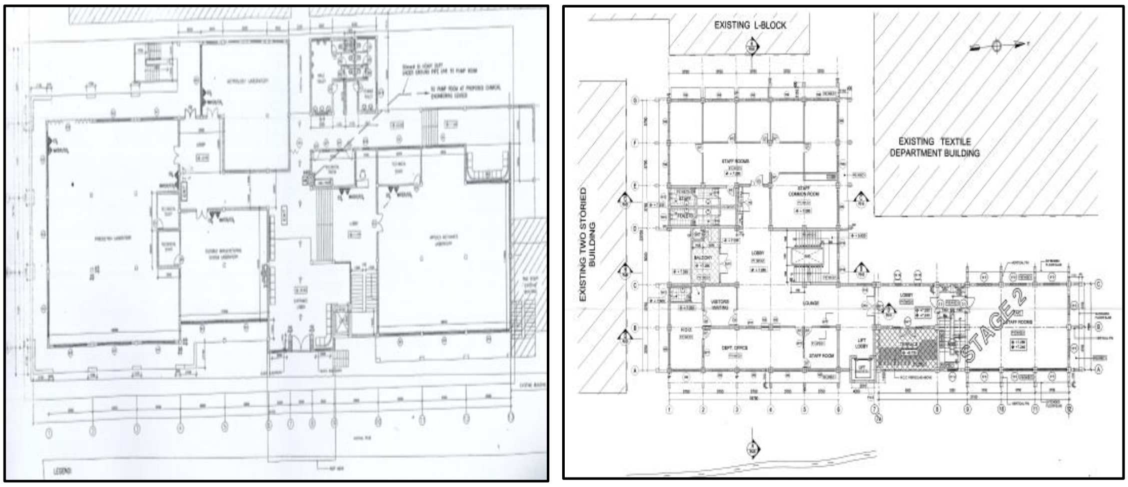
4.2 Multiple Case Study Analysis

After developing the process flow for the case studies, it was conducted with the active participation and integration for the selected two cases while exposing social, environmental and technological aspects as discussed in chapter 03 of the research. Hence, it was important to consider the way of using the language to describe the experiences gathered within these different environments. Moreover, Sharon, Ravitch, Nicole and Mittenfelner (2016) have suggested the use of first person writing to signify the role and the exposure of the researcher. Thus, all findings, experiences and discussions have been described according to the researcher's point of view based on autobiographical writing (writing in first person).

4.2.1 Investigation of Drawings and Specifications

As the first step of the case study, available drawings and specifications were investigated for the selected two cases. However, there were number of obstacles in finding appropriate drawings. As the both cases were educational buildings in a university, drawings and specifications had to be found from the same place, in this study from the maintenance department of the university. However, I was not able to acquire architectural drawing for the buildings at the very first time, due to the issues of getting permission from the officials of the maintenance department. Hence, it was important to get the permission first from an authorised personnel at the maintenance department. Even though, the importance of research and the necessity of collecting data to successfully conduct the research was explained, I was not able to acquire the information. I was not even informed whether the necessary drawings are available or not at the department. Thus, it was very difficult to obtain the information for the study without any support from officials. Hence, the next step was to find out whether there were any other responsible personnel with the authority to grant permission to access the information that was required for the study.

Accordingly, I was able to contact and discuss with the facilities manager of the university after discussing with the research supervisor. The importance and the purpose of the research was comprehended by the FM, as the study directly leads to enhance the operation and maintenance of buildings which is under the purview of FM. Therefore, with the support and approval from the facilities manager, access for the information was permitted from the maintenance department. As requested by maintenance managers, I was provided the assistance with lower level managers and employees to obtain the drawings and other necessary information. Nevertheless, it was delayed several times due to their less awareness and inadequate collaboration. Finally, only the drawings of building's fire system for case 01 and architectural floor plan drawings for case 02 were received. Any of architectural drawings or as built drawings were not found for the case 01. However, since case 02 was a building constructed recently, architectural drawings were available at the maintenance department. Due to the incapacity to influence the maintenance staff to find out more drawings for case 01, I had to continue the study using the available drawings. Accordingly, fire drawings and floor plan drawings were analysed for case 01 and 02 respectively.



Case 01 **Case 02**

Figure 13: Ground floorplan of Case 01 and Case 02

Both cases were three- storey buildings and figure 16 show the case 01 fire system drawing of the ground floor and case 02 floor plan of the ground floor. The drawings were obtained for all the three levels of the building.

4.2.2 Analysis of the Availability of Data

As the availability of building data is critical from the FM perspective, it was important to accentuate the level of actual data availability in this project. Thus, after the review of drawings and specifications, data availability was analysed using the available drawings for both cases. Prior to the analysis of the available data, the study had to be limited to the received fire drawing for case 01. However, architectural drawings received for case 02 were analysed in detail compared to the literature findings. The data required for this project were mainly categorised as geometry data and simulation data as identified from the literature. Accordingly, available and non-available geometric data were analysed first, under this section. Table 08 indicates the available geometry data for both cases.

Table 6 : Analysis of Geometry Data Availability

Required Data (Building geometry data)	**Available Data**	
	Case 01 (As identified from the fire drawing)	**Case 02** (As identified from architectural drawings)
▪ Floor Plan Details	✓	✓
▪ Doors and Windows Details	×	✓
▪ Specification Details	×	×
▪ Elevation Details	×	✓
▪ Roof Plan Details	×	✓
▪ Sectional Drawings	×	✓
▪ Foundation Details	×	✓
▪ Beams and Columns Details	×	✓

For the case 01, floor plan details or the minimum geometry data requirement were identified, since the dimension details of the building are indicated in the fire drawing. Therefore, Case 01 was verified as BIM model of the building could not be created even without building floor plan. However, remaining required geometric could not be ascertained, as all other details were related only to fire system. On the other hand, all geometric data were available for the case 02 except for the specification details. Conversely, as case 02 indicated a higher availability of geometry data compared to case 01, case 02 could also be verified for the study.

Afterwards, the next step was to analyse the availability of simulation data for both cases. A checklist was used as the data collection mode and the data were gathered from the FM department. Table 09 indicates the availability of simulation data in each case.

Table 7: Analysis of Simulation Data Availability

Required Simulation Data	Available Data	
	Case 01	Case 02
▪ Building orientation	✓	✓
▪ Weather data	×	×
▪ Building envelope constructions	×	×
▪ HVAC type	✓	✓
▪ Building type/function	✓	✓
▪ Glazing type	×	×
▪ Lighting power density	×	×
▪ Equipment power density	×	×
▪ Occupancy Schedule	✓	✓
▪ Lighting Schedule	✓	✓
▪ Equipment Schedule	×	×
▪ System energy efficiency	✓	✓
▪ Roof Reflectance	×	×
▪ User-defined glazing specifications	×	×
▪ User-defined envelope construction properties	×	×
▪ MEP BIM Model	×	×

▪ Water efficient fixtures	×	×
▪ HVAC Component sizings	×	✓
▪ Customizable occupancy schedule	✓	✓
▪ Customizable lighting schedule	✓	✓
▪ Customizable equipment schedule	×	×
▪ Interior temperatures	✓	✓
▪ Utility Rates	✓	✓

According to the analysis, similar availability level for the simulation data could be identified in both cases. Among the simulation data, weather data, was disregarded for the analysis as such data are applied automatically from the simulation software. However, though the analysis was relied on the FM department to gather necessary data, all necessary simulation data were not available for the study. As identified, the data including building envelope construction, glazing type, equipment schedule, roof reflectance, user-defined glazing specifications, user-defined envelope construction properties, lighting power density, equipment power density, MEP BIM model, customizable equipment schedule and water efficient fixtures were not available for both cases. Conversely, data including HVAC types, system energy efficiency details, HVAC components' measurements and capacities, occupancy schedule, lighting schedule, interior temperatures and utility rates were available at the FM department. Though the cases were verified based on the geometric data, level of availability of simulation data was not adequate for both cases.

4.2.3 Specification of LOD Scale

As the next step of the study, specification of LOD scale was identified based on the level of data received for each case. The importance of identifying LOD is to determine the appropriate level in which BIM model can be designed and the extent to which simulations can be performed from the available data. Moreover, for this study, identification of LOD was important to recognize the degree to which the study can be extended in terms of designing the model and simulations depending on the received information. Importantly, it helped to clearly identify the potential challenges of Green BIM application from available information. In this study, as day lighting analysis and energy analysis were expected to be done; the required data for those two analysis were considered to identify the possible LOD scales for simulations.

Since LOD 100 is basically used to evaluate the design alternatives of buildings during the design stage, it was disregarded for the study. Thus, LOD 200 was considered first as it was the applicable level for building operation and maintenance. Besides, LOD 400 and LOD 500 were disregarded as they require specific and accurate as built data for all building elements. Though these scales (LOD 400 and LOD 500) are applicable for the operational phase, it was impractical to identify and measure the accurate data for each and every building element separately in the two cases. For the creation of building model in BIM, LOD 200 represents approximate dimension details, while LOD 300 represents accurate dimensions of the building. Hence, LOD 200 was an applicable scale as the approximate dimensions of the buildings are available. Applicability of LOD 300 was doubtful as the accuracy of dimension details could not be predicted at this stage. Thus, I focused on LOD 200 for the creation of BIM models of the selected cases.

In light of the simulations, for daylighting analysis, LOD 200 specified data including building form, openings, interior spaces, windows, shading elements, floors, walls and dimensions. As the types of lighting analysis, shading analysis and solar exposure analysis are included in LOD 200 with respect to the mentioned data. LOD 300 entails detailed day lighting analysis with additional data including interior partitions and material properties. However, for the selected two cases, material properties were not available and thus such values were used based on assumptions. With respect to the energy analysis, LOD 200 requires data including building geometry, preliminary layout, construction and mechanical equipment while allowing the outcomes including evaluation on design schemes, intermediate analysis and preliminary code compliance. For LOD 300, data including building geometry, detailed layout, detailed construction and envelope design, mechanical equipment, building controls and detailed assumptions are needed. Further, LOD 300 provides simulation results of final design energy analysis. According to the availability of simulation data for both case 01 and case 02, LOD 200 was applicable. Further, LOD 300 was applicable for the case 02 as the detailed dimension details are available, while it is not applicable for the case 01. Thus, based on the availability of simulation data of both cases, I focused on LOD 200 for the simulations as well.

4.2.4 Designing of BIM Model for the Selected Cases

After specifying the appropriate LOD scale for the cases, designing of BIM models were done for case 01 and case 02 using Autodesk Revit BIM designing software. Case 01 was the mechanical engineering building of the university while case 02 was the building of transport and logistics management. The study basically focused to design the architectural model of buildings since all the drawings of building services were not available. However, it was a challenge to design the architectural model of case 01 building as only the fire drawings were available.

This step of the case study intended to identify the challenges of BIM model creation prior to the Green BIM application for existing buildings. Thus, the designing of BIM model for the buildings was the first attempt to identify such challenges. To design the BIM model of case 01 building, it was necessary to extract the dimension details of building plan. The available fire drawings for all three levels of case 01 building were first used to identify the dimensions of building's floor plan. There were number of challenges in identifying necessary details of the building due to the errors of drawings and lack of required information.

Even though architectural drawings were available for case 02, several challenges were confronted when designing the model for case 02 as well. All the challenges confronted in relation to the two cases are discussed in section 4.7.

The BIM models created for case 01 and case 02 buildings are shown in figures 17 and 18 with images of the actual buildings.

Figure 14: Actual Building

Case 01

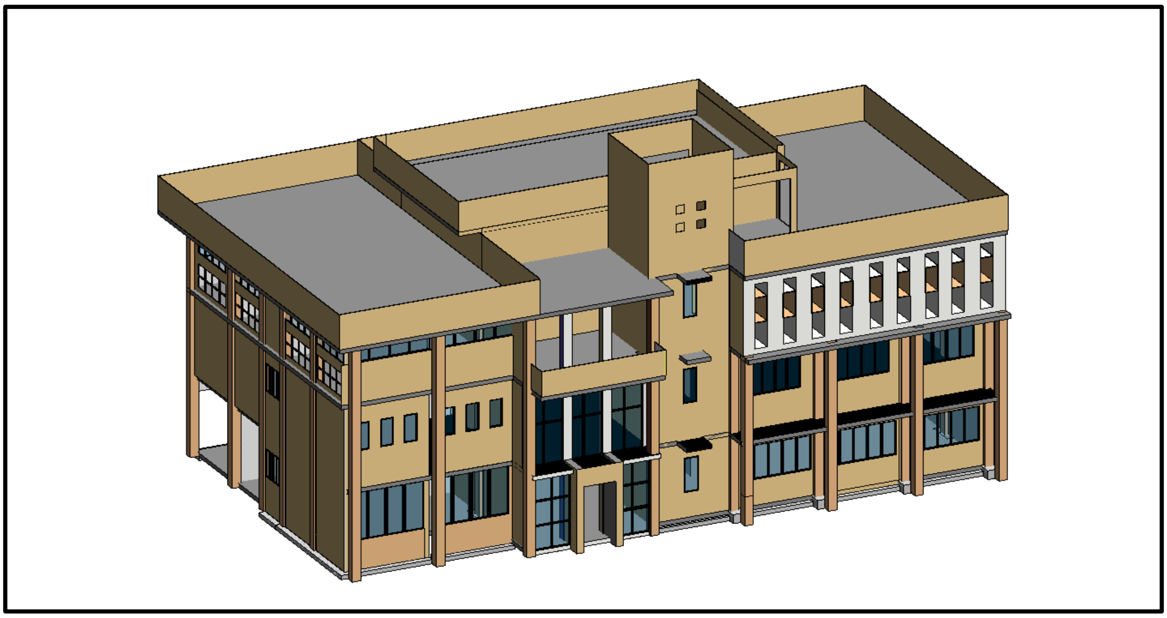


Figure 15: BIM Model of Case 01

Case 02

Figure 16: Actual Building of Case 02

Figure 17: BIM Model of Case 02

4.2.5 Simulation Results of the Cases

In accordance to the theoretical framework developed for the case study, Autodesk Revit BIM software was used first to conduct the lighting simulation and energy simulation for the cases. For the lighting simulation, solar analysis was performed in Revit. However, I was unable to conduct the detailed day lighting analysis since detailed day lighting features were not found in Revit as a direct plugin of Ecotect.

However, Autodesk Insight direct plugins for Revit was available on internet as a new feature added to BIM technology, especially for sustainability analysis, and thus I was able to install Insight plugins for Revit software.

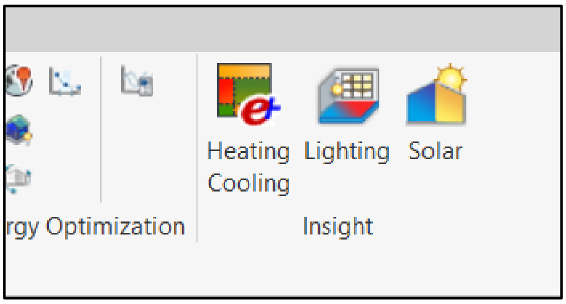


Figure 18: Insight Plug-ins in Revit

As the first attempt, solar analysis was conducted using Revit sun settings and Insight plugins for Revit. Though I conducted solar analysis, I was not able to conduct the detailed day lighting analysis again using Insight day lighting feature as the service was not available. An error message was appeared as shown in figure 22. As the same error occurred as previously, I inquired from several experts who are specialized in the field of information technology, to overcome the issue. However, I was unable to get any instruction to solve the error and thus, I further inquired in a Revit forum about the issue. The opinion I got was, perhaps, original Revit features are not given for countries like Sri Lanka, even for licensed versions. Though it was not verified through Autodesk, any of solutions were not given from anyone to correct the issue.

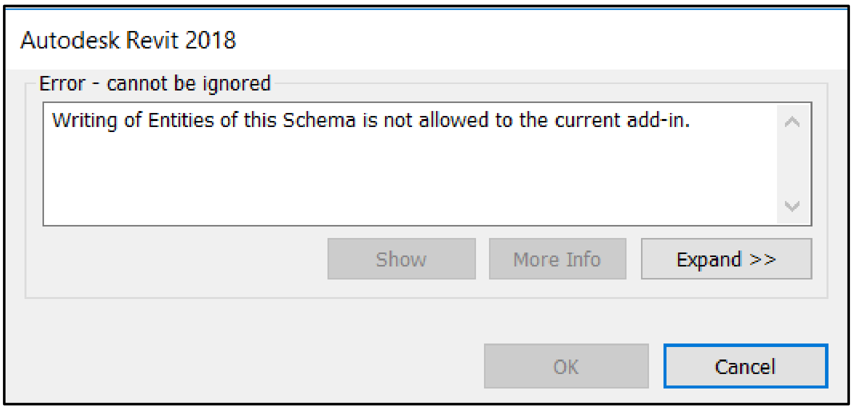


Figure 19: Technical Error Message

Hence, I performed only the solar analysis using both Revit and Insight plugins. The captures of analysis in Revit are shown in below figures for case 01 and case 02 respectively.

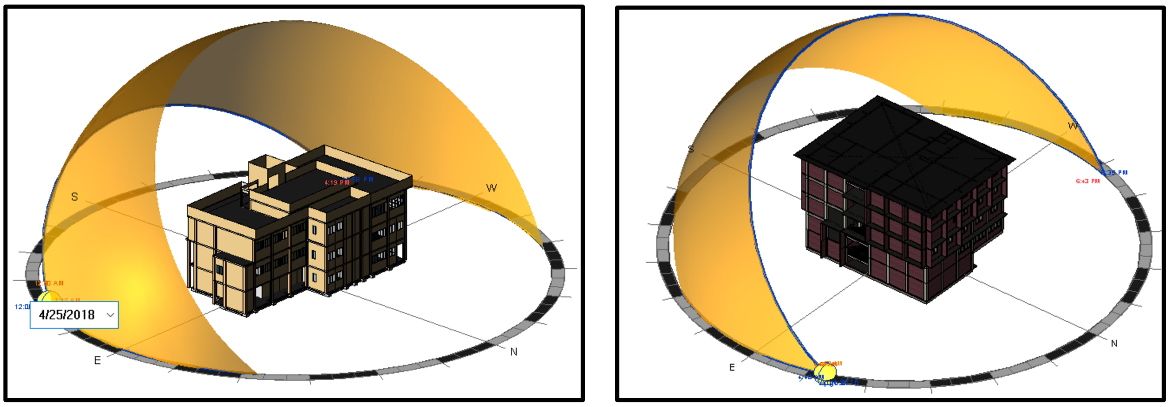


Figure 20: Solar Analysis

Above figures show the solar exposure and shading analysis for the building for a specific day. This analysis helps to identify how building facades is exposed to solar radiation in each orientation corresponding to the sun path. Accordingly, shading areas and solar exposed areas can be easily determined. Secondly, solar analysis was done using Insight software plugins, selecting two study types of Insight analysis. First the cumulative insolation results were achieved selecting the custom study type for both cases. To conduct the analysis, first the location of buildings and criteria of type of simulation surfaces had to be specified as shown in figure 24. Final simulation results demonstrated the cumulative insolation of selected building surfaces.

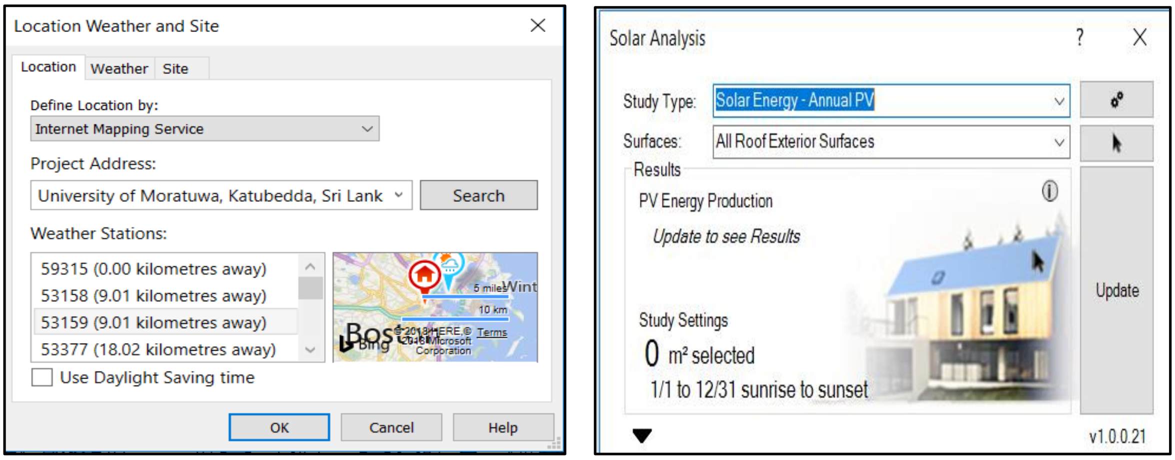


Figure 21: Interface for Location and Type of Simulation

Results of solar simulations are indicated in figure 25 and 26 for case 01 and case 02 respectively. The values show a high solar insolation for case 02 compared to case 01 for a same specified time. These results were achieved by selecting the building surfaces; thus, the results were basically depended on the number of surfaces selected in the two cases.

Figure 22: Images of Lighting Simulation

The above figures present how the solar intensity is applied on different surfaces of building's exterior façade varies. Building surfaces with yellow color represents the surfaces where intensity of solar radiation is high (refer the scale). Green coloured surfaces also represent high solar intensity and such surfaces are also widely exposed to the solar radiation. As per the scale, surfaces indicated in purple colour represent less solar intensity as exposure of those surfaces to solar radiation is very less.

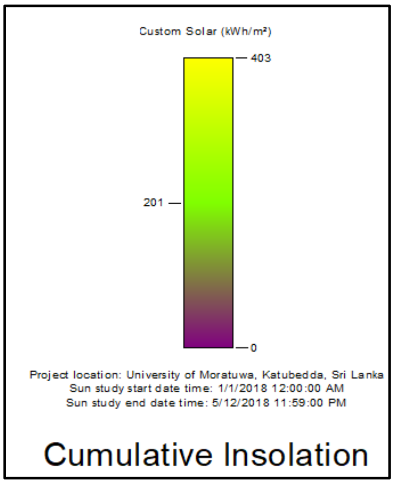


Figure 23: Scale of Cumulative Insolation

The simulation results also indicated the potential of photovoltaic (PV) energy production by exploiting the exposure of exterior surfaces of buildings to solar radiation with the subsequent values of energy savings and payback durations. To get the values it is needed to input the data including electricity cost per kwh, panel type, surface area and payback limit under the study settings.

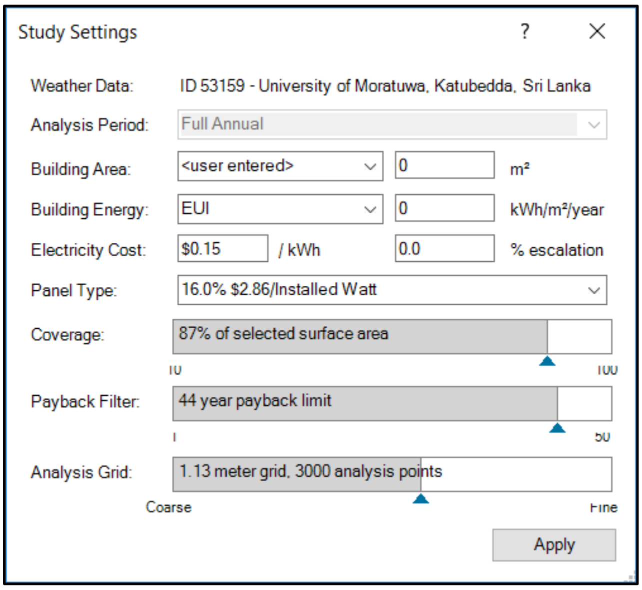


Figure 24: Study Settings for Solar PV Analysis

Simulation results of PV energy potential are presented in figures 28 for case 01 and case 02 respectively. The results indicated the PV energy production per year with the potential energy savings achieved from the produced photovoltaic energy. The required PV panel area to achieve that level of energy production, was also obtained in square meters. Finally, the period of payback to recover the initial cost of PV installation was obtained. To calculate this value only the roof area was selected where solar panels should be placed. Ability of generating this information automatically is substantially important as manual calculation is time consuming and complicated.

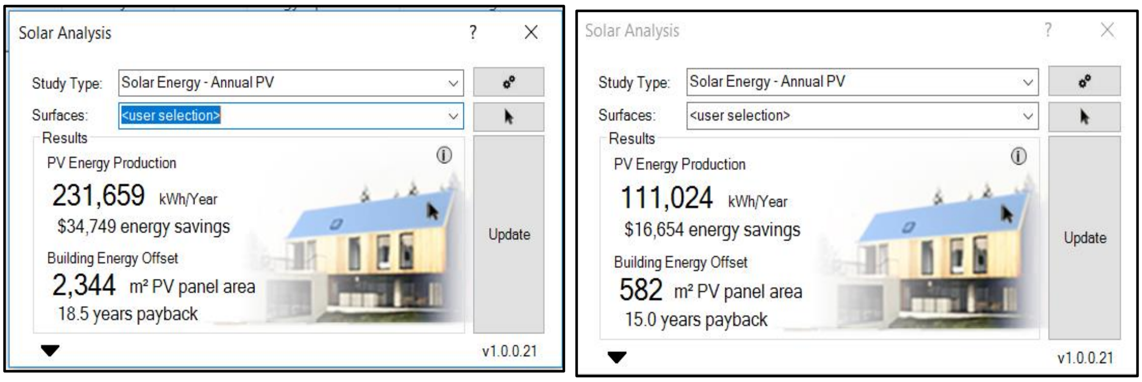
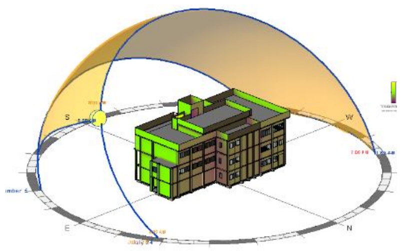
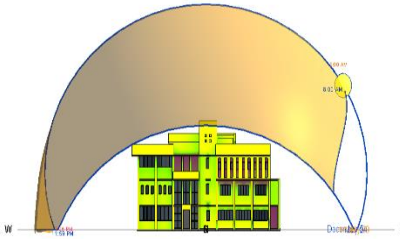
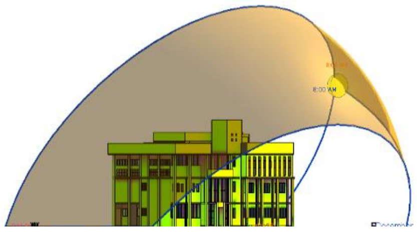
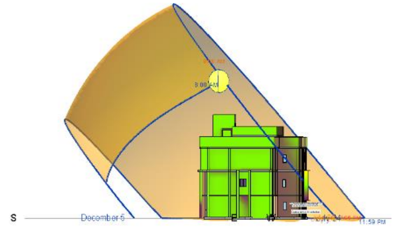
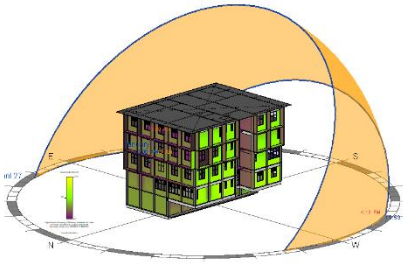
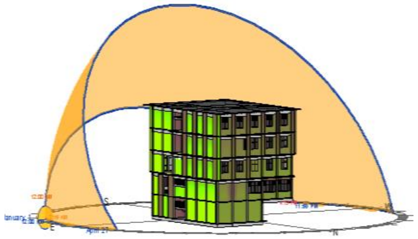
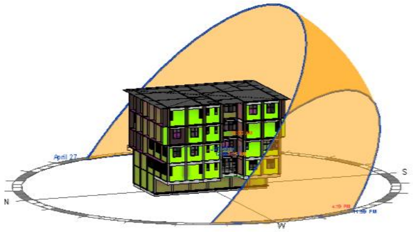
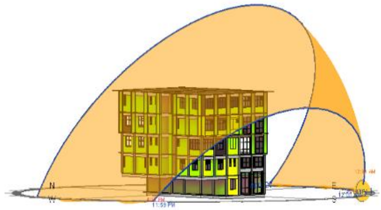


Figure 25: Solar PV Analysis

After analysing the separate simulation results, Revit solar analysis and Insight solar analysis were done correspondently to identify and compare the simulation results done separately to each case. Table 10 shows the intensity of solar exposure for different orientations of both buildings. According to the analysis, the surfaces of each building which are exposed for solar radiation are demonstrated with high solar intensity in yellow and green colours while the areas which are not considerably exposed to solar radiation in purple colour. The surfaces exposed to high solar radiations can be identified as the areas where heat is highly penetrated in to the building. Both buildings have been included with aluminium framed glass windows and thus such areas absorb considerable heat in to the building through windows. Hence, cooling demand of the whole building is increased resulting high energy costs. Hence, by analysing these simulated areas, energy retrofit techniques can be implemented for such building façade element to reduce the energy consumption.

Section 4.3 discusses energy saving retrofits which can be suggested as energy saving strategies to optimize the energy in both buildings. These strategies are identified by analysing the building facades where high solar intensity was shown in solar analysis results.

Table 8: Summary of the Analysis

Cases	Building Orientation			
	01	02	03	04
01				
02				
	Cumulative Insolation	**PV Energy Production**	**Energy Savings**	**Payback Period**
Case 01	463,825 kwh	231,659 kwh/year	$34,749	18.5 years

Case 02	480,538kwh	111,024 kwh/year	$16,654	15 years

4.3 Potential Energy Saving Strategies for Walls

4.3.1 Thermal Insulation

Thermal insulation of walls is an effective way to reduce the energy demand of buildings. For the exterior walls of both buildings in this study which are resulted with high solar intensity, thermal insulation can be proposed to reduce the heat gain. Thermal insulation can be provided for the exterior walls resulted with yellow and green colours with high solar intensity as shown in above figures in the table. Vacuum insulation panels (VIP), gas-filled panels (GFP) and aerogels can be identified as modern insulation materials for thermal insulation of walls. These materials comprise a lower level overall heat transfer coefficient (U value), which help to resist heat flow through building envelope (Al-Homoud, 2005).

4.3.2 Solar Shading Elements

Solar shading elements have the potential to reduce the energy demand of electrical lightings of buildings by increasing the day lighting potential into buildings. As heating loads have a greater impact on energy consumption of buildings, shading elements could be introduced to restrict the penetration of solar radiations into buildings. Both buildings of this study are not insulated with solar shading elements considerably and thus the simulation results showed high solar intensity over the exterior walls especially in east, west and south orientations. Accordingly, as external shading elements, movable shading elements can be proposed as it could control and balance the impacts of solar exposures on both visual and thermal aspects of buildings (Kim, Lim, Lim, Schaefer, & Kim, 2012).

4.4 Window Retrofits

4.4.1 Solar Control Low-E Application

Windows can be identified as the most important building element since the heat transfer coefficient of windows (U value) are about five times greater than the other elements (Lee, Jung, Park, Lee & Yoon, 2013). As per the simulation results of the buildings in this study windows are highly exposed to solar radiation and since the windows are aluminium framed glass windows, building’s energy is considerably wasted through windows. Aluminium is a material which highly absorbs heat of solar radiation. To avoid the penetration of solar radiation through windows low-emissivity (low-e) coatings could be proposed for both buildings. Low-e coatings can reduce the amount of ultraviolet and infrared lights when passes through the glass without compromising the amount of visible lights that is transmitted to the inside of buildings. Further, low-e coatings reduce the penetration of solar radiations to the buildings by reflecting near infrared radiation from the sun. Thus, low-e applications which are suitable for hot climates can be suggested for the buildings of this study, which reduce the radiative heat transfer in to the building. This can be added to the windows in both buildings even after the production in the form of foil products or spray coatings.

4.4.2 Multi Pane Glazing

Multi plane glazing is identified as which consist multiple layers of glass. This can reduce both radiative and conductive heat transfer into the building. As multi pane windows comprises number of panes including stationary air layers in between glass layers, overall heat transfer coefficient is decreased by impeding the heat flow into the building. Besides, the thickness of multi pane glass layers is considerably high and thus it also allows to reduce the heat gain (Mingotti, Chenvidyakarn & Woods, 2013). Hence, this can be proposed for the windows which are highly exposed to solar radiation as per the simulation.

4.4.3 Vacuum Tube Window

Vacuum tube window is another technology which consist a less U value and spaces of two panes of multi pane window which is filled a set of evacuated tubes of optimized diameter. The heat transfer by convection is reduced by filling argon gas between tubes and panes and thus reduce the heat gain to the building (Cuce & Cuce 2016; Cuce & Riffat, 2015).

4.4.4 Renovation of Window Frames

The window frames of both buildings in this study has been made of aluminium which significantly causes to increase the heat gain. The number of windows is increased the heat gain through window frames are also increased as considerable window area is taken by window frames. This is also caused to increase the total energy consumption of buildings and thus, renovation of window frames could be proposed with materials which has good insulation properties. As examples, materials including polyvinyl chloride (PVC) and glass fibre reinforced polyester (GFRP) could be proposed as an alternative for aluminium frames (Appelfeld et al., 2010; Basarir et al., 2012).

4.5 Roof Retrofits

4.5.1 Roof Insulation

As roof is entirely exposed for the solar exposure, the heat gain through roof materials is also significant. According to the solar analysis of two buildings in the study, roof can be identified for the direct solar radiations and thus the heat gain is considerably high. Hence, roof insulation can be identified as an energy retrofit technique for the roof. Roof insulations prevent the transmission of heat gain through the roof due to low heat transmission of insulation materials. Sprayed polyurethane (PUR), expanded polystyrene (EPS), extruded polystyrene (XPS) and stone wool can be proposed which are commonly used as thermal insulation materials for roof insulations (Asadi et al., 2012).

4.5.2 Green Roof Application

Green roof application is identified where a flat or some low sloped roofs are fully or partly covered with a vegetated substrate. Green roof reduces the solar radiation reaching to the building as the plants of green roofs absorb a significant proportion of solar radiation for the biological functions including photosynthesis, transpiration, respiration and evaporation. There are two major categories of green roofs as extensive (with soil thickness less than 10-15 cm) and intensive (with soil thickness more than 15-20 cm) green roofs (Niachou, Papakonstantinou, Santamouris, Tsangrassoulis, & Mihalakakou, 2001). Semi-intensive green roofs are also identified as a third category where both extensive and intensive green roofs are combined (Bianchini & Hewage, 2012). However, as the impact to structural capacity is negligible extensive roofs are mostly preferred over intensive roofs for retrofitting onto existing buildings (Castleton et al., 2010).

4.5.3 High-albedo Roof Paintings

High -albedo roof painting is an application which increase the reflective power of roof surfaces and thereby reduce the energy demand of buildings by reflecting some solar radiations (Coutts, Daly, Beringer, & Tapper, 2013). It is a cheap alternative to the thermal insulation especially for warm climates. However, as per the Friedman et al. (2014) the coating should be renewed after every five years to achieve the maximum benefits from albedo roofs.

After conducting available lighting simulation features, the study focused on energy simulations for the cases. According to the theoretical framework, Revit was used first to perform energy simulations for the buildings. However, the same error message appeared as in the detailed lighting simulations. Thus, I was not able to conduct energy simulations using the inherent features of Revit and Insight plug-ins. Hence, a separate BIM simulation software was used only to conduct the energy simulation for the cases. Accordingly, Autodesk Green Building Studio (GBS) was used for energy simulation as it was freely available on web. It was required to create a gbxml file of the BIM model to export model data to GBS, and two instances were allowed to create the gbxml file. First instance was to create an energy model of the building and second was to create spaces or rooms separately for each building model. Both instances were used to identify any potential issue in these two instances. However, none of issue was realised in creating gbxml files for each building model. Before exporting the model to gbxml, it was required to specify the building type, location, ground plane, export category and project phase as indicated in figure 29 and 30.

Case 01

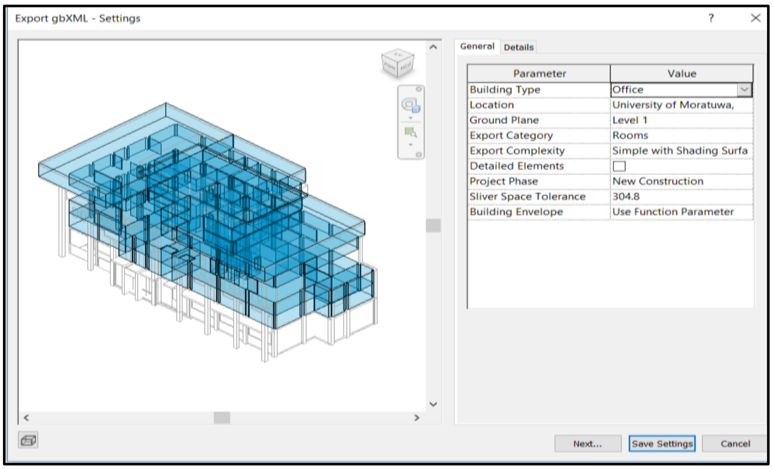


Figure 26: gbxml File for Case 01

Case 02

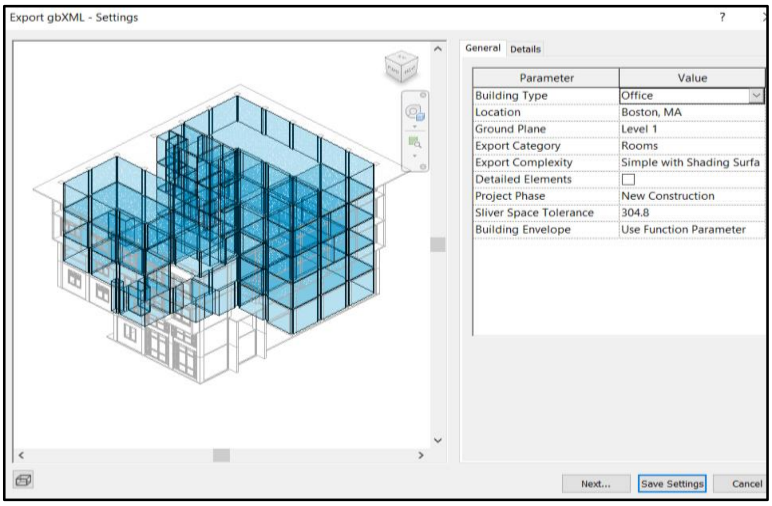
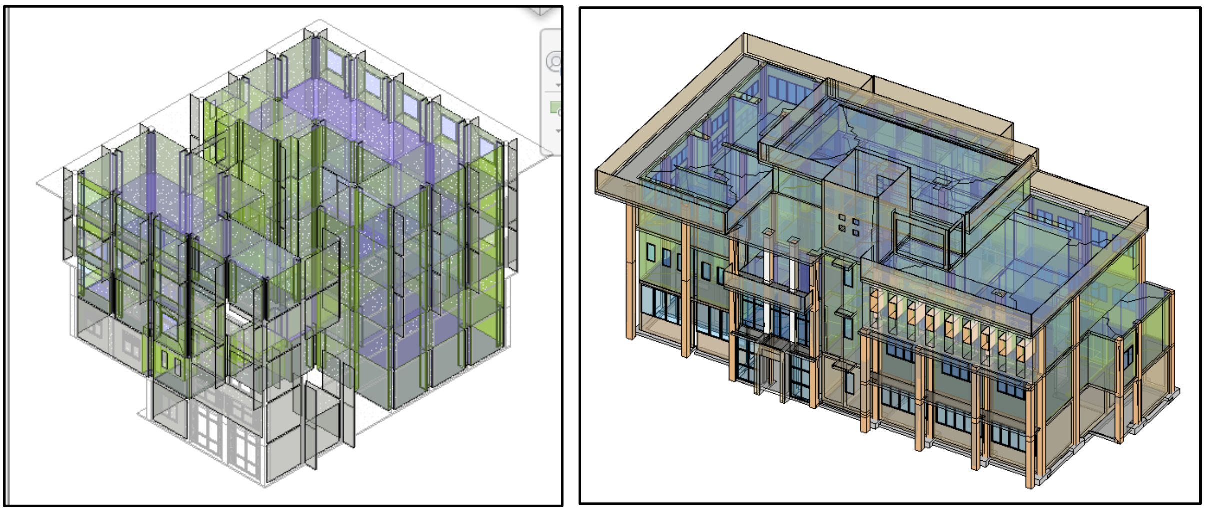


Figure 27: gbxml file for Case 02

Moreover, the energy model created for case 01 and case 02 are also presented in figure



31.

Figure 28: Energy Model for Case 01 and Case 02

After creating the gbxml file for both cases, it was exported to GBS simulation software and the analysis was done through the online interface/platform. Before exporting the gbxml file, the locations of buildings were specified first for GBS software. Further, following details had to be entered for the simulation. Table 11 presents the simulation data specified for the two cases for simulations.

Table 9: Project Defaults

0.1 Project Defaults		
Condition Type		
	Case 01	**Case 02**
HVAC Vented	✓	✓
Space Type		
Class Room/ Lecture Room/ Training penitentiary or multipurpose	✓	✓
Lighting power density	13 W/m^2 1.2 W/ft^2	13 W/m2 1.2 W/ft2
Equipment power density	11 W/m^2 1.0 W/ft^2	11 W/m2 1.0 W/ft2
Area per person	0.6m^2	0.6m^2
Sensible heat gain	-	-
Latent heat gain	-	-
Design temperature	-	-
Zones		
Cooling on set point	27	27
Cooling off set point	25	25
Heating on set point	-	-

Heating off set point	-	-
Outside air per person	0	0
Surfaces		
Roof type - Concrete roof deck (flat roof)	✓	✓
External walls - Concrete walls with poured course	✓	✓
Ceiling - Interior drop ceiling tile	✓	✓
Internal walls - Metal Frame only	✓	✓
Interior floor - Slab area	✓	✓
Doors - Defaults	✓	✓
Windows - Glass	✓	✓
Openings		
U values and R values of door elements	Default values	Default values
HVAC equipment capacities – Split AC capacities	✓	✓
Hot water heater capacities	-	-
02. Project Details		
Name	Project 01	Project 02
Building type	University	University

Project Type	Actual Project/ Existing building	Actual Project/ Existing building
Address	Katubedda, Sri Lanka	Katubedda, Sri Lanka
City	Colombo	Colombo
Province	Western	Western
Postal code		
Country	Sri Lanka	Sri Lanka
Time zone	West Asia Standard Time	West Asia Standard Time
Currency	LKR	LKR

Condition type was specified as HVAC vented and space type was selected as class room/ lecture room or training penitentiary or multipurpose, for both cases. Lighting power density and equipment power density is measured in watts per square foot or square meter. However, such values were not found in both cases as the relevant records were not available. Moreover, since it was impractical to calculate such data, due to time constraints and difficulty in manually calculate such values by using records of lighting appliances and equipment of whole building, such values were assumed using the standard values given by the US Green Building Council and Energy Star certification. Area per person was also specified according to the standard values. Sensible heat gain, latent heat gain and design temperature were not included as such values cannot be assumed. It is necessary to find such values through complicated calculations of HVAC systems which should be done by HVAC system designers.

Values of cooling on and off set points were entered as average values as specified by the facilities management department. Since heating systems were not used such values were disregarded for the heating systems. Further, value of outside air per person (fresh air intake) was zero in both cases as the buildings were installed with split air conditioning systems. Types of surfaces were selected as included in the table and U values and R values were selected with default values as such values have already being imported from the modelling details of Revit. HVAC system capacities were specified as per the available BTU values and heating system capacities were disregarded. Furthermore, project details needed to be included as indicated in the table and finally, utility information had to be included using the default values since it was restricted to change the values within the trial of simulation. Similarly, I was not able to change values for heating systems due to the use of trial version.

After specifying the required values and parameters, gbxml files were exported for the GBS software and energy simulation was started. Following results were achieved after the energy simulation of the two buildings.

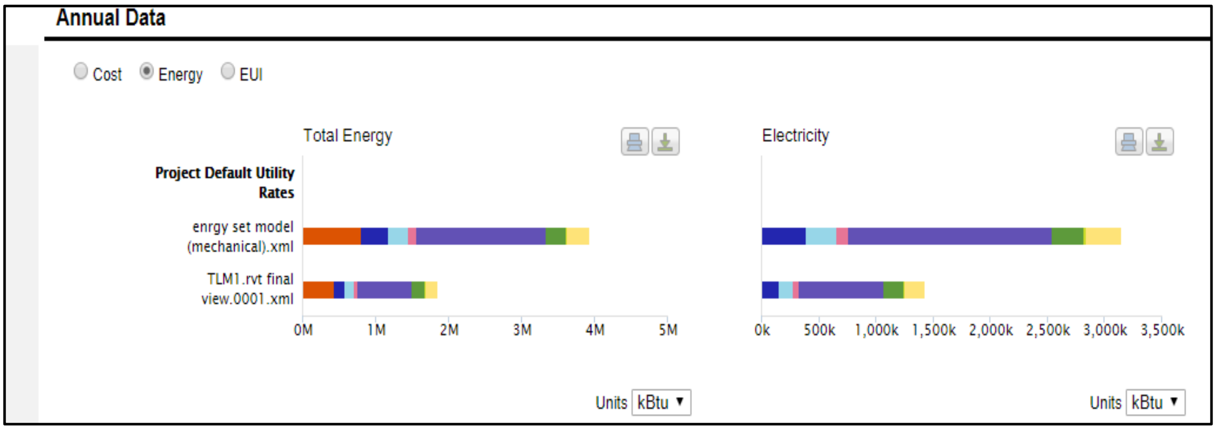


Figure 29: Annual Electricity Demand

Figure 32 shows the annual electricity demand and total energy demand of case 01 and case 02 obtained through the simulation. Criterions of energy calculations are presented in figure 33.

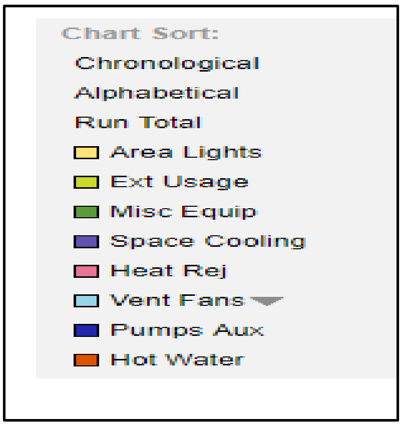


Figure 30: Energy Criteria

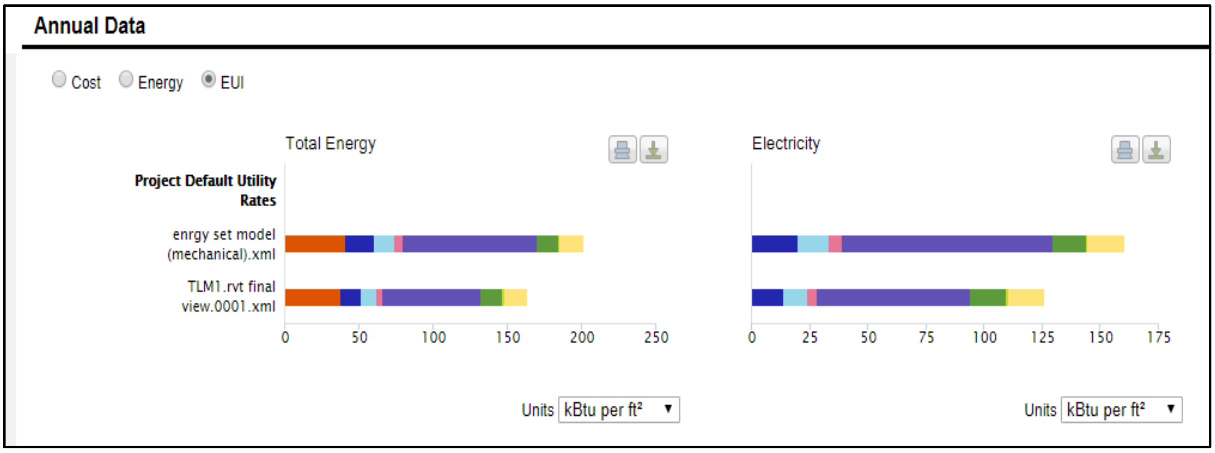


Figure 31: Electric Use Intensity

Further, the amount of annual electric use intensity was also obtained as in the figure 34. Figure 35 presents the annual cost of total energy and electricity of the building as per the default values of utility information.

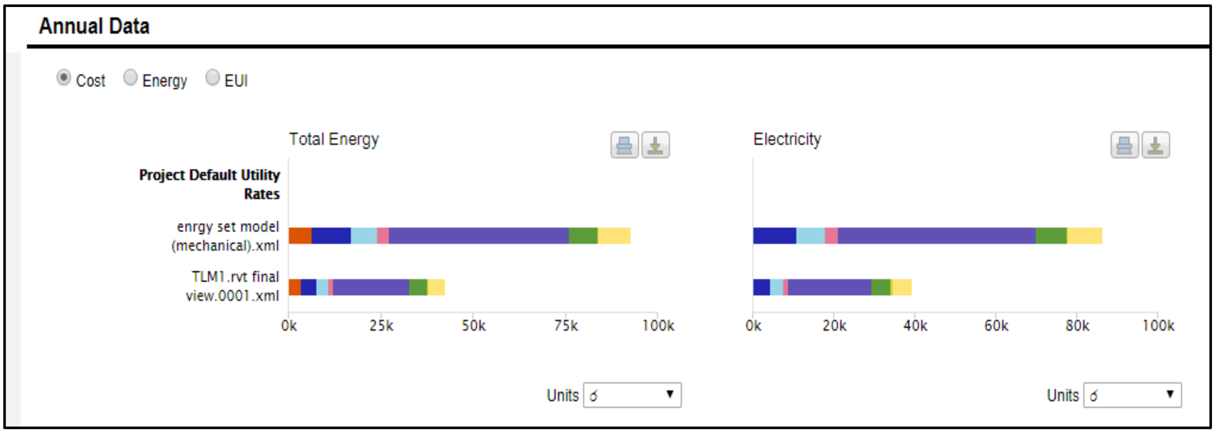


Figure 32: Annual Costs Results

Moreover, figure 36 and 37 show the monthly data of energy consumption and cost of total energy of the case 01.

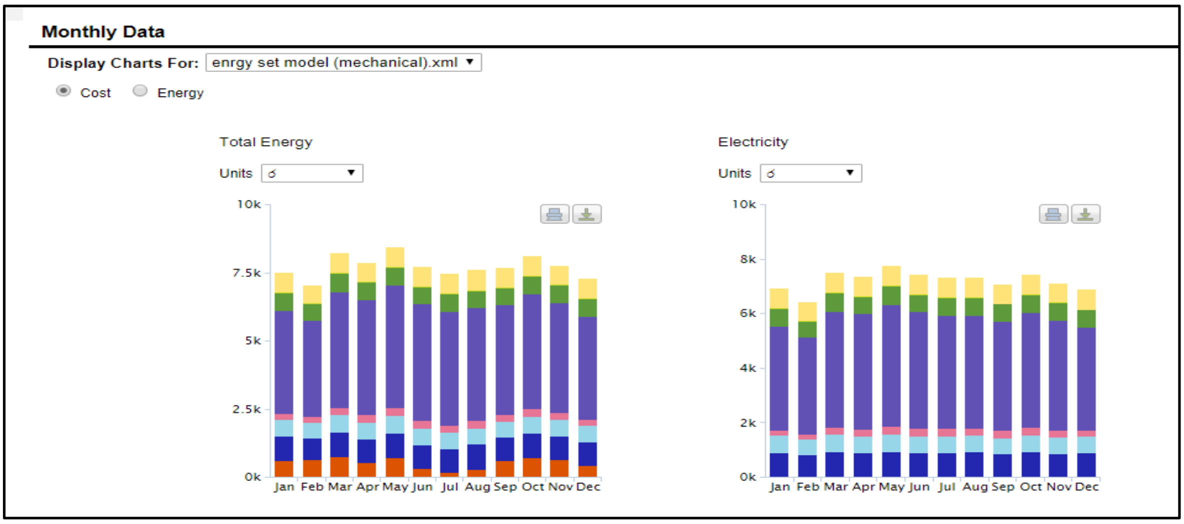


Figure 33: Monthly Cost Data for Case 01

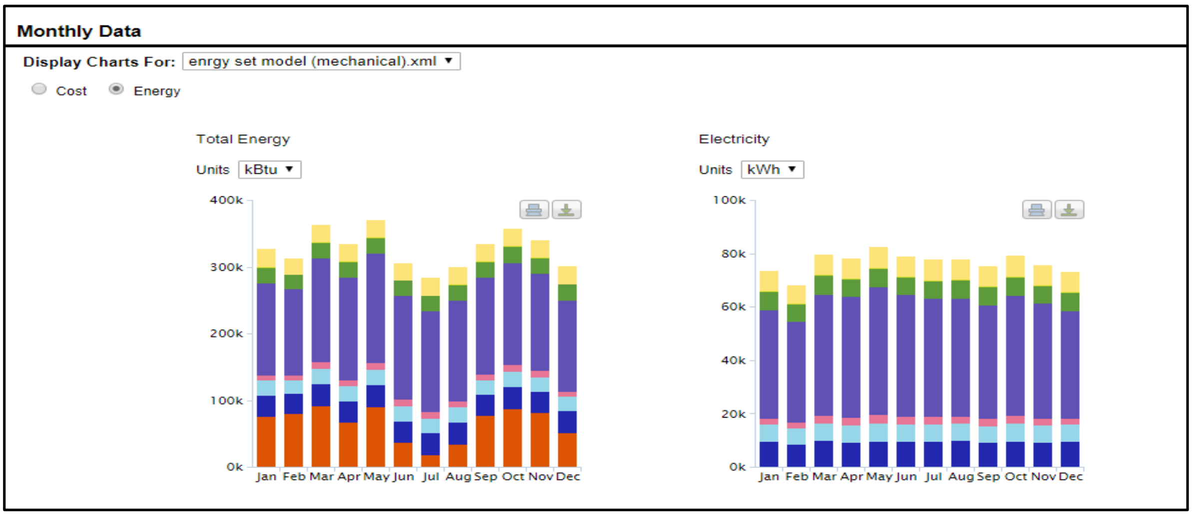


Figure 34: Monthly Energy Data for Case 01

Monthly data of energy consumption and cost of total energy of the case 02 presented in figure 38 and 39.

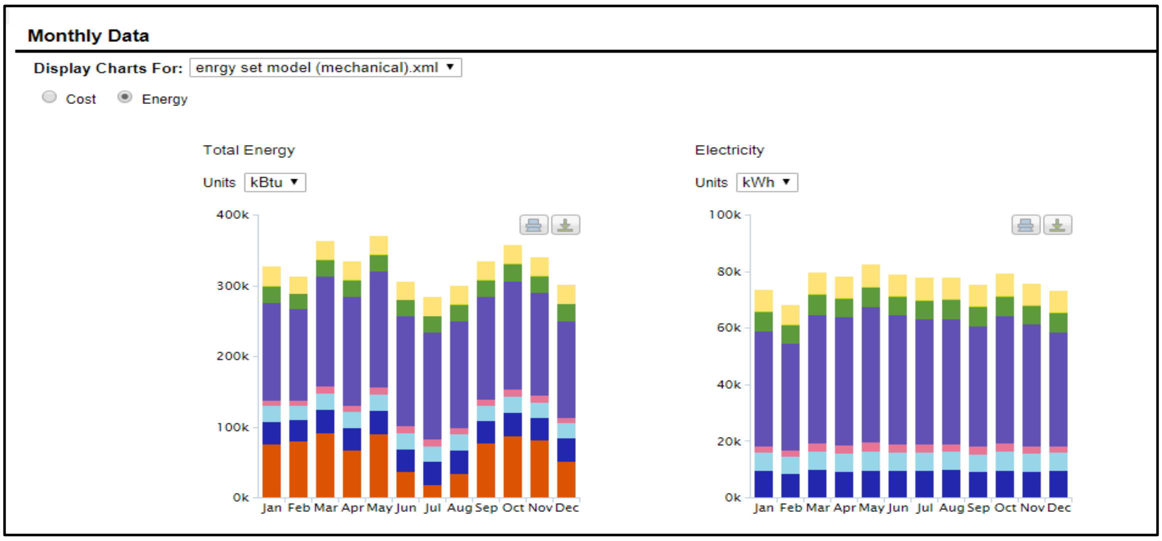


Figure 35: Monthly Energy Data for Case 02

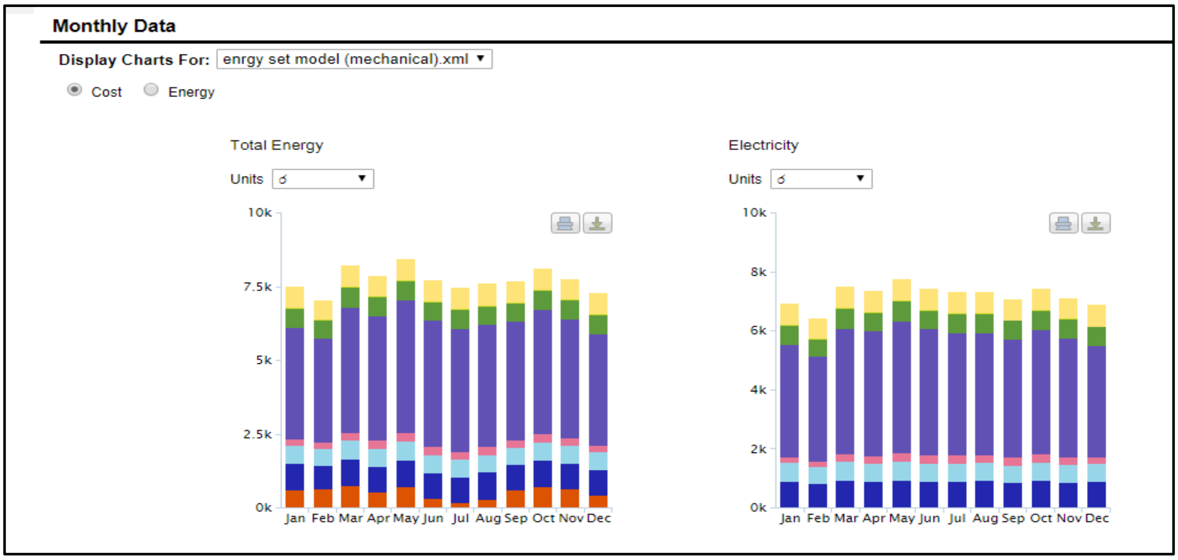
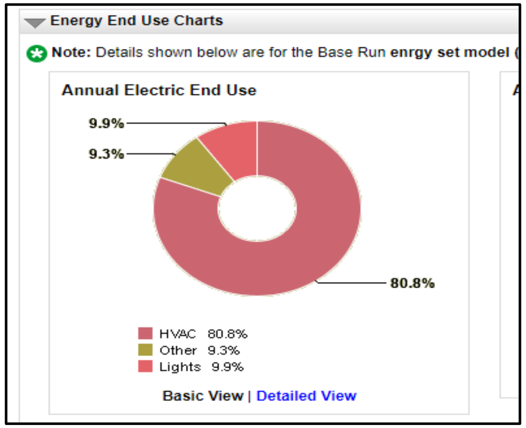
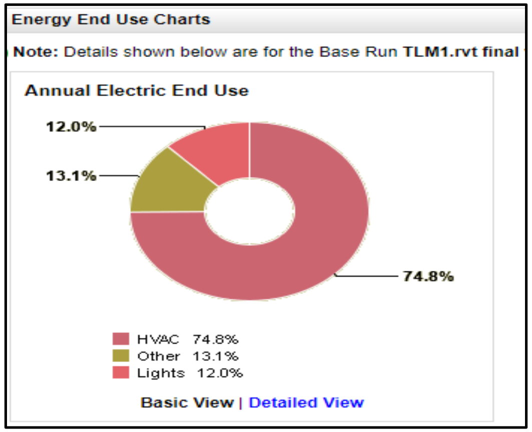


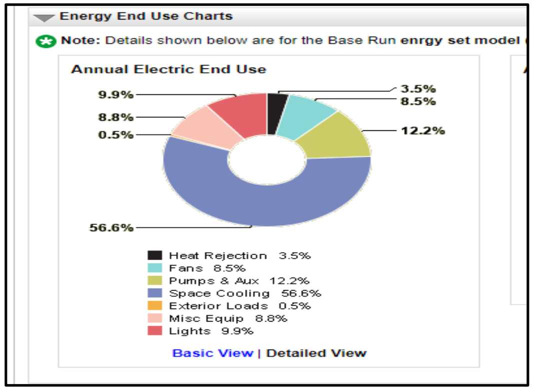
Figure 36: Monthly Cost Data for Case 02

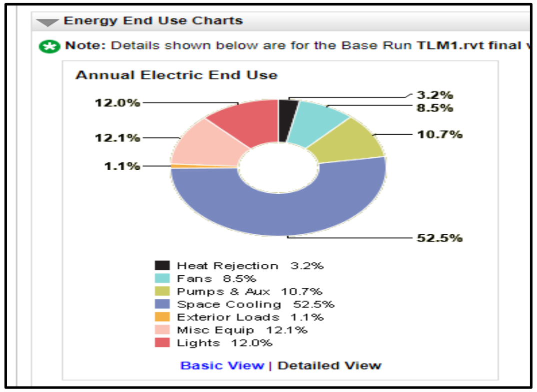
Since, a free trial was used for the simulation, there were issues in specifying actual values as mentioned previously, especially for the values of utility information. Thus, the results of energy simulations cannot be directly interpreted with the actual performance of buildings in terms of costs. Further, I was unable to change the criterion and values of hot water systems, thus the results indicated energy consumption for hot water systems. Since there were no hot water systems in buildings, results for hot water energy was irrelevant for the study. Furthermore, following energy simulation results were achieved from GBS simulation.

Table 10: Energy Simulation Results

<table>
<tr><th></th><th>Case 01</th><th>Case 02</th></tr>
<tr><td>Annual Electric End Use (basic view)</td><td>


</td><td>


</td></tr>
<tr><td>Annual Electric End Use (detailed view)</td><td>


</td><td>


</td></tr>
</table>

Annual Energy Cost	Rs. 92,638.00	Rs. 42, 562.00
Lifecycle Cost	Rs. 1,261,726.00	Rs. 579,694.00
Annual Net CO_2 Emissions	136.5 Mg	62.2 Mg
Annual Energy Use Intensity	2,281 MJ/m^2/year	1,851 MJ/m^2/year
Annual Electric Usage	920,636 kwh	417,818 kwh
Annual Peak Demand	250.2 kw	114.6 kw
Water Consumption L/Yr	8,576,224	5,013,938
Water Consumption Rs/Yr	Rs. 12,785.00	Rs. 7192.00
Annual Energy Savings through Photovoltaic Potential • Total Installed Panel Cost • Nominal Rated Power • Total Panel Area • Maximum Payback Period	168, 028 kwh Rs. 859,492.00 107kw 778m^2 37 years (@ Rs. 0.09 kwh)	75,219 kwh Rs. 325,538 41kw 295 m^2 33 years (@ Rs. 0.09 kwh)

Wind Energy Potential	729 kwh	729kwh
Natural Ventilation Potential • Total Hours Mechanical Cooling Required • Possible Natural Ventilation Hours • Possible Annual Electric Energy Savings • Net Hours Mechanical Cooling Required	4885 hours 4 hours 563 kwh 4881 hours	4885 hours 4 hours 236 kwh 4881 hours

As mentioned above, the simulation results mentioned in above table which resulted from GBS for energy simulation cannot be related to the actual performance of buildings since the actual energy data were not used for the simulation. Hence, only an overall perception can be taken for the energy performance of buildings. The default project values used for U values and R values are indicated in figure 40 for case 01 and case 02 respectively. These values are transmitted from the Revit software, which were applied for building elements during the designing of BIM models.

Roofs	R13 Wood Frame Wall, Wood Shingle U-Value: 0.46 R20 over Roof Deck - Cool Roof U-Value: 0.25
Exterior Walls	R13 Wood Frame Wall, Wood Shingle U-Value: 0.46 R13 Metal Frame Wall U-Value: 0.88
Interior Walls	Uninsulated Interior Wall U-Value: 2.35
Interior Floors	Uninsulated Interior Wall U-Value: 2.35 R0 Wood Frame Carpeted Floor U-Value: 1.16
Raised Floors	R13 Wood Frame Wall, Wood Shingle U-Value: 0.46 R20 over Roof Deck - Cool Roof U-Value: 0.25
Slabs On Grade	R13 Wood Frame Wall, Wood Shingle U-Value: 0.46
Air Openings	North Facing Windows: Single Tint Green U-SI 6.17, U-IP 1.09, SHGC 0.61, VLT 0.75 (5 doors) U-Value: 6.17 W / (m²-K), SHGC: 0.61 , Vlt: 0.75 Non-North Facing Windows: Single Tint Green U-SI 6.17, U-IP 1.09, SHGC 0.61, VLT 0.75 (40 doors) U-Value: 6.17 W / (m²-K), SHGC: 0.61 , Vlt: 0.75
Operable Windows	North Facing Windows: Double Clear U-SI 3.16, U-IP 0.56, SHGC 0.69, VLT 0.78 (45 windows) U-Value: 3.16 W / (m²-K), SHGC: 0.69 , Vlt: 0.78 Non-North Facing Windows: Double Clear U-SI 3.16, U-IP 0.56, SHGC 0.69, VLT 0.78 (52 windows) U-Value: 3.16 W / (m²-K), SHGC: 0.69 , Vlt: 0.78

Roofs	R15 over Roof Deck - Cool Roof U-Value: 0.36
Ceilings	Interior Drop Ceiling Tile U-Value: 2.60
Exterior Walls	R13 Metal Frame Wall U-Value: 0.88
Interior Walls	Uninsulated Interior Wall U-Value: 2.35
Interior Floors	Interior 4in Slab Floor U-Value: 4.18
Raised Floors	U 0.322 Mass Floor U-Value: 1.38
Air Walls	Air Surface U-Value: 15.32
Air Openings	North Facing Windows: Unglazed opening (14 doors) U-Value: 0.00 W / (m²-K), SHGC: 1.00 , Vlt: 1.00 Non-North Facing Windows: Unglazed opening (16 doors) U-Value: 0.00 W / (m²-K), SHGC: 1.00 , Vlt: 1.00
Fixed Windows	North Facing Windows: Single Clear-L Tint (8 windows) U-Value: 4.99 W / (m²-K), SHGC: 0.25 , Vlt: 0.13 Non-North Facing Windows: Single Clear-L Tint (25 windows) U-Value: 4.99 W / (m²-K), SHGC: 0.25 , Vlt: 0.13
Operable Windows	Non-North Facing Windows: Single Clear-L Tint (5 windows) U-Value: 4.99 W / (m²-K), SHGC: 0.25 , Vlt: 0.13

Figure 37: Project Defaults for U values and R values

However, though actual performance indicators were not obtained, when analysing the energy consumption patterns resulted from GBS simulation, highest energy consumption can be identified for space cooling. Similarly, energy consumption patterns can be analysed for lighting, pumps, operations of fans and miscellaneous equipment. Hence, by incorporating actual values using original version of GBS, these simulation results can be utilized to optimize energy consumption of buildings.

4.6 Analysis of the Suitability of Data Used for the Application of Green BIM

Suitability of the data used for the Green BIM application was analysed during the creation of building models and the simulation. The existing data of the available drawings were not reliable and suitable in case 01, as there were numerous deficiencies and issues compared to the as built conditions of buildings. Thus, the data were actually not suitable and appropriate for the use of Green BIM. Compared to case 01, the existing data of case 02 were suitable for the study as there were only minor issues in available drawings. As suitability of data was analysed during the application of the technology, findings of the suitability analysis are also discussed in section 4.7 with the challenges identified during the study.

4.7 Challenges Identified During the Application of Green BIM

All the challenges identified during the study are discussed under this section.

4.7.1 To get missing information of the building plan

Getting missing information of drawings was a considerable challenge due to the issues of visibility and clearance of available dimensions. Most of values were shaded and difficult to read due to the size of fonts. Further, dimensions for external wall thickness, internal wall thickness and height and length of walls were not included in drawings. Since, the hard copy of the drawing was only available, it was a challenge to get the correct dimensions of the building.

4.7.2 To ensure the accuracy of data

Moreover, the dimensions were incompatible with the scale given in drawings where the accuracy was become a challenge. For example, there were different values for the same length of external walls showing obvious errors. To ensure the values as per the scale, such details were taken by the rulers and multiplied according to the scale. However, the level of accuracy is less and could not be confirmed as reliable values.

4.7.3 Difficulties in obtaining permission to acquire drawings from the contractor of the building projects

Due to the issues of available data, I contacted the contractor organization of the building project to obtain the drawings. It was required to grant the permission from the client (university) first, however the process was delayed several times. Hence, due to the managerial and organizational restrictions and lack of authorization to issue drawings without the permission of client, the contractor organization was reluctant to grant permission to release the drawings. As it was delayed, I continued the study with the available data only.

4.7.4 Complexity of understanding details due to the incompatibility of available data with the actual building

Due to the aforementioned challenges, verification of available dimensions in drawings was become important for the study through a manual inspection of the building. Though an effort was taken to realise the drawing details while inspecting the building, it was an onerous task as there were different modifications have been done later, for the initial building plan. It was needed to update the drawings for all three levels of the building as per the modifications. However, it was a challenge to redesign the drawing and verify the spaces in the drawing and the actual as built conditions of the building since as built conditions were considerably different compared to the available drawings.

4.7.5 Need of access for more resources

Manual inspection by a single person was a difficult task and thus it was required to facilitate it with more resources. Human resources, instruments and equipment for on-site measurements were needed to conduct the inspection properly with the permission and under the authorization of the university. As I was not able to ascertain the required resources at the very first instance without the permission, it was a challenge that had to be faced for the manual inspection.

4.7.6 Excessive time consumption

Excessive time consumption was another significant challenge, which experienced in re-measuring the building dimensions. As it was required to make periodical inspections for the building to re-measure the dimensions, it was an unavoidable challenge. Furthermore, time consumption was experienced during the creation of BIM model, as the building was complicated to design.

4.7.7 To determine the accurate thickness of walls and slabs

To design wall elements of the building in BIM design software, it is required to include the wall thickness for the wall structure. However, as the selected building was already constructed, it was unable to measure the wall thickness of the core structure. Even though, wall thickness was measured manually from outside, the measured value includes the thickness of the plastering layer of the wall. It was not possible to measure the thickness of that plastering layer to determine the thickness of brick wall. Further, it was not possible to measure the floor to floor height as it was required to know the thickness of the slab. Thus, such values were unable to determine to model the building accurately in BIM.

4.7.8 To measure the accurate dimensions of columns and beams

Since the columns and beams details are not available, it was required to check the placements of columns and beams during the manual inspection of the building. However, I was not able to find all the locations of columns and beams throughout the building as the building's structure was complicated to understand in as built conditions. The interconnections of columns and beams inside the building were also difficult to understand. The edges of beams and columns have been extended outside the walls and thus I was confused in identifying the actual locations of columns and beams. The exact length of columns which connect all three levels as shown in figure 41, was difficult to measure due to the practical issues and inability to measure the thickness of slabs.

Figure 38: Issue of Measuring Columns

4.7.9 To measure the accurate dimensions of the roof terrace

A roof terrace has been designed for the mechanical engineering building. A part of the roof terrace has been extruded outside the normal structure. The all possible dimensions of the roof terrace which could be measured manually were drafted including length, width and height. However, it was difficult to take the exact measurements due to the difficulty in accessing the extruded part of the roof terrace which is shown in figure 42.

Figure 39: Issue of Roof Terrace

4.7.10 Creation of families

Creation of families was also a difficult and tedious task as the building was an old one and thus all building objects were not included in Revit software libraries. Hence, most of families had to be created separately which consumed considerable time.

4.7.11 Difficulty to measure the dimensions of building facades and shading elements

Dimensions of building facades and shading elements were disregarded during the manual inspection, due to the practical issues in reaching such elements. There was not any proper way to measure such elements and thus only the assumed values had to be taken.

Figure 40: Issue of Measuring Shading Elements

4.7.12 Difficulty to create different architectural features of the building

The architectural design of the building was comprised of different features to create its aesthetic appearance. However, much effort was needed to create such design features during the modelling due to the inability to measure the accurate dimensions. Similarly, the placements of some wall openings were impractical to reach and, thus when creating such elements in BIM software, numerous errors were occurred. A different design has also been used for the windows by embossing windows inside the walls where the actual dimensions cannot be measured.

4.7.13 Clashes and errors between elements during the modeling

It was a complicated task to complete each and every section of the building due to the occurrence of number of clashes, mismatches and deformations during the modelling. Even though actual dimensions were taken in most occasions during the manual inspection, such values were mismatched in the BIM model and clashes and errors occurred between building elements.

4.7.14 Identification of types of building materials

To create the BIM model of the building, it was necessary to specify the materials of each designing elements. However, as the building was in its old condition and some of building materials are deteriorated with the time, to verify the correct materials that were used for each building element was difficult. Thus, only the verified building materials were included to the model while others were assumed with common building materials. However, as the model development was selected based on LOD 200 scale it was not a significant challenge.

4.7.15 Lack of support from building occupants

As the manual inspection had to be taken during the occupied time of the building, it was difficult to get the information due to lack of support from building occupants. Because of the inconvenience occurred for the working environment, many restrictions had to be faced during the observations. Thus, measurements had to be taken quickly without the support of occupants which was a challenge.

4.7.16 Validation of the developed BIM model

Since the BIM model was created with numerous challenges of data, the accuracy and validation of the developed model was a challenge. However, validation was important as the correct dimensions of the building are essential to get the correct simulation results.

Compared to case 01, there were few challenges identified during the modelling of case 02 building. These challenges were identified during the modelling only, as the architectural drawings were available.

4.7.17 Creation of families

As case 02 was a building constructed recently, different architectural features were identified in the building where various family creations had to be done.

4.7.18 Errors and missing information of drawings

There were several errors in drawings for walls and windows. However, by comparing all the drawings it was possible to clarify such errors. Further, it was unable to find out the dimensions of some building objects as that information were not available in drawings.

4.7.19 Complex details of drawings and excessive time consumption

Time consumption was a considerable issue as the details of drawings were complicated to understand during the modelling. Further, time was considerably spent to create the families.

4.7.20 Challenges Faced During the Simulations

4.7.20.1 Unavailability of detailed simulation features in Revit

Though Revit BIM software has been integrated with daylighting features of Ecotect, detailed daylighting features were not available in the software even with the direct plug-ins to Ecotect. Only the sun shading analysis was available in Revit and thus, it was required to find the other direct plug-ins of lighting simulation software for detailed lighting simulation. Though Autodesk Insight plug-ins to Revit were available on web, detailed lighting simulations were not possible to conduct as there were number of network errors and technical errors. Besides, same errors were occurred for the energy simulation in Revit. Due to these errors, which cannot be overcome, only the solar analysis was done combining the Revit and Insight solar analysis features. Further, energy simulation had to be conducted using a separate software which was freely available on web. However, it was unable to perform detailed lighting simulations using separate Green BIM software due to financial constraints.

4.7.20.2 Inability to input actual data for the simulation

As the energy simulation was done using a free trial of GBS software through web, it was not allowed to change some of the input data into actual values. For example, default values had to be used for utility information. To change all default values as required, the original software should be purchased. However, due to the financial constraints, conducting actual simulations through freely available software with lack of control, was a challenge.

4.7.20.3 Unavailability of required simulation data

Unavailability of values for simulation data including sensible heat gain, latent heat gains and design temperature was a challenge since such data were not available at the FM department. Standard values were used for the data including lighting power density, equipment power density and area per person. However, it is important to input the all required simulation values since incorrect simulations can be resulted.

4.7.20.4 Classification of Challenges

After the identification of challenges during the study, the identified challenges were categorized under several criteria as informational challenges, organizational challenges, functional challenges and technical challenges as shown in figure 44.

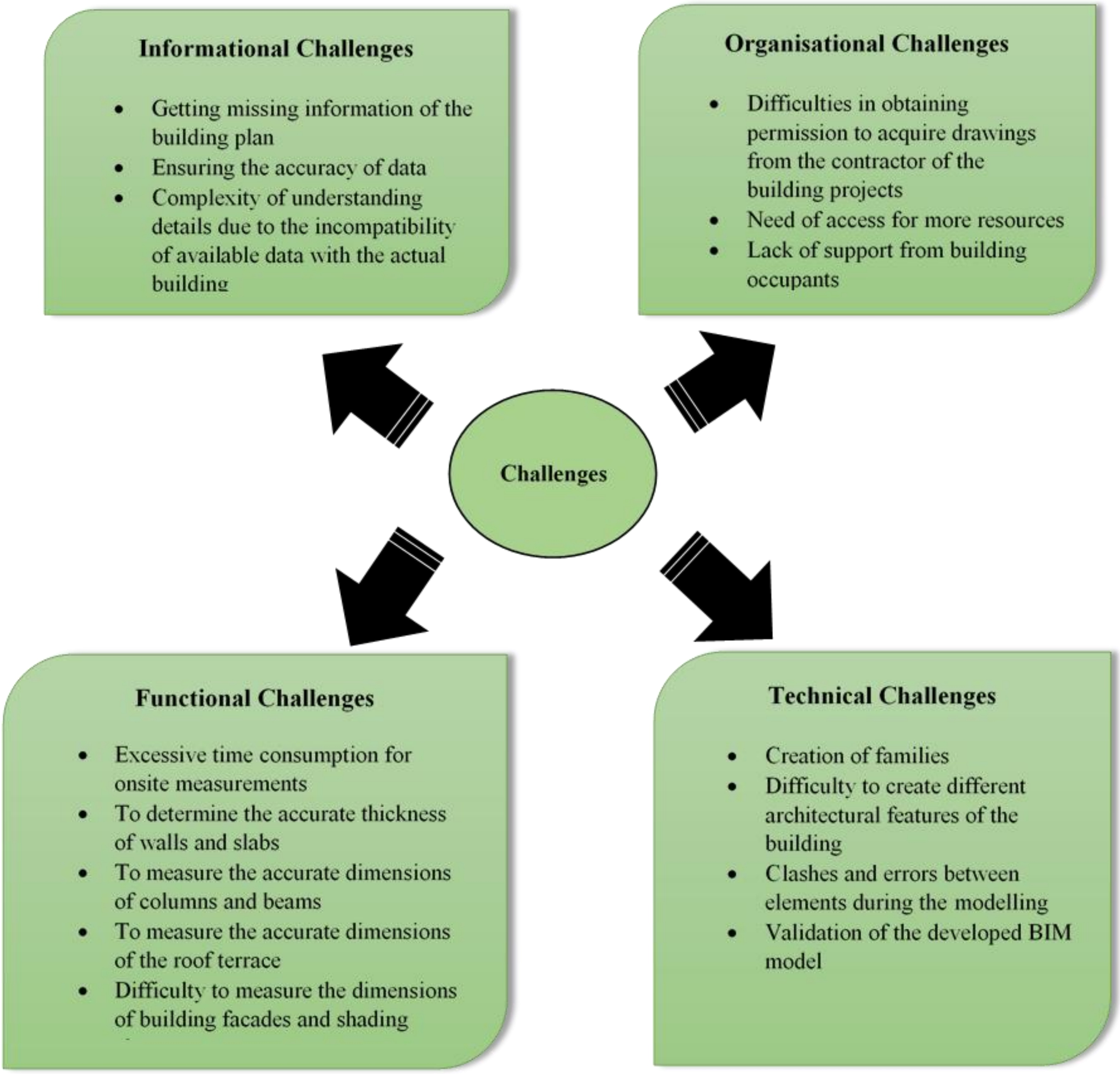


Figure 41: Classsification of challenges

4.8 Development of the Framework

After the identification of challenges during the application of Green BIM for selected two cases, the study intended to develop a framework providing the solutions to overcome the identified challenges. The identified challenges and solutions were included as the key elements of the framework. The developed framework is presented in figure 45. This section has been mainly included with and discusses the solutions used during the study to overcome the challenges faced. The solutions provided in the framework and recommended solutions are entirely based on the experiences gained during the study.

4.8.1 Actions Taken During the Study and Proposed Solutions to Overcome the Challenges

4.8.1.1 Manual Inspections

Manual inspections were conducted periodically as the first solution, to overcome the challenges which faced at the beginning of the study (to get the missing information, to ensure the accuracy of data and inability to get the permission from the consultant to acquire relevant drawings). Dimensions including lengths and widths of walls, floor areas, ceiling areas and some of columns and beams were able to be measured during the manual inspection.

4.8.1.2 Getting assistance from experts in the field of architecture

Though manual inspection was conducted with the purpose of correcting the challenges of available data, I was also confronted with substantial challenges. For example, complexity of understanding available data in drawings due to the incompatibility with the actual as built conditions, was a challenge faced during the manual inspection. To overcome this challenge, it was important to get the assistance from experts in the field of architecture, to clarify the conflictions occurred with building plans.

4.8.1.3 Use of standard values for dimensions

Even though manual inspection was done to identify the missing dimensions, all values were unable to be measured, for example values for thicknesses. Hence, this action was taken to determine the correct dimensions of walls and slab thicknesses as it was strenuous to identify correct values by measuring externally. Assuming the internal and external concrete walls as load bearing walls, 150mm was taken for the thickness of walls. However, to verify it, wall thickness was measured externally and reduced the standard value of 150mm and assumed the thickness of plastering layer as 25mm. As the thickness of plastering layer was reasonable, 150mm was taken as the thickness of walls. Similarly, following standard dimensions were assumed when the existing data were not available for the modelling.

- Thickness of columns and beams - 200mm
- Thickness of internal partitions - 100mm
- Thickness of slabs - 225mm

4.8.1.4 Use of assumed values for the dimensions where standard measurements are not available

As discussed in the above section, there were practical issues in measuring and determining the accurate dimensions for roof terrace, shading elements and wall openings of buildings. Thus, values for such elements had to be based on assumptions, to design the building model.

4.8.1.5 Correction of errors during the modeling and before the simulation

As there were errors during the modelling, different clashes and mismatches between elements were prevalent, Revit software shows the incorrect modelling action with error messages indicating how such error is occurred. Thus, this is important to rectify the errors by following the messages given by the software until the errors are corrected. Even though, correct dimension was unknown, it could automatically be corrected while eliminating the incompatibilities shown in Revit. Moreover, once the model is completed for simulations, there was an opportunity to identify any errors attached to the model before the simulation. The software does not allow the model to be simulated, with the presence of hidden errors when it is exported to the simulation software. Hence, the errors which were not recognized during the modelling are again listed and shown by the software before allowing the simulation. Thus, it was also an important way to validate the created model before the simulations. As shown in the figure there were no any errors in the model and if there were any, error symbol is shown indicating the error with details.

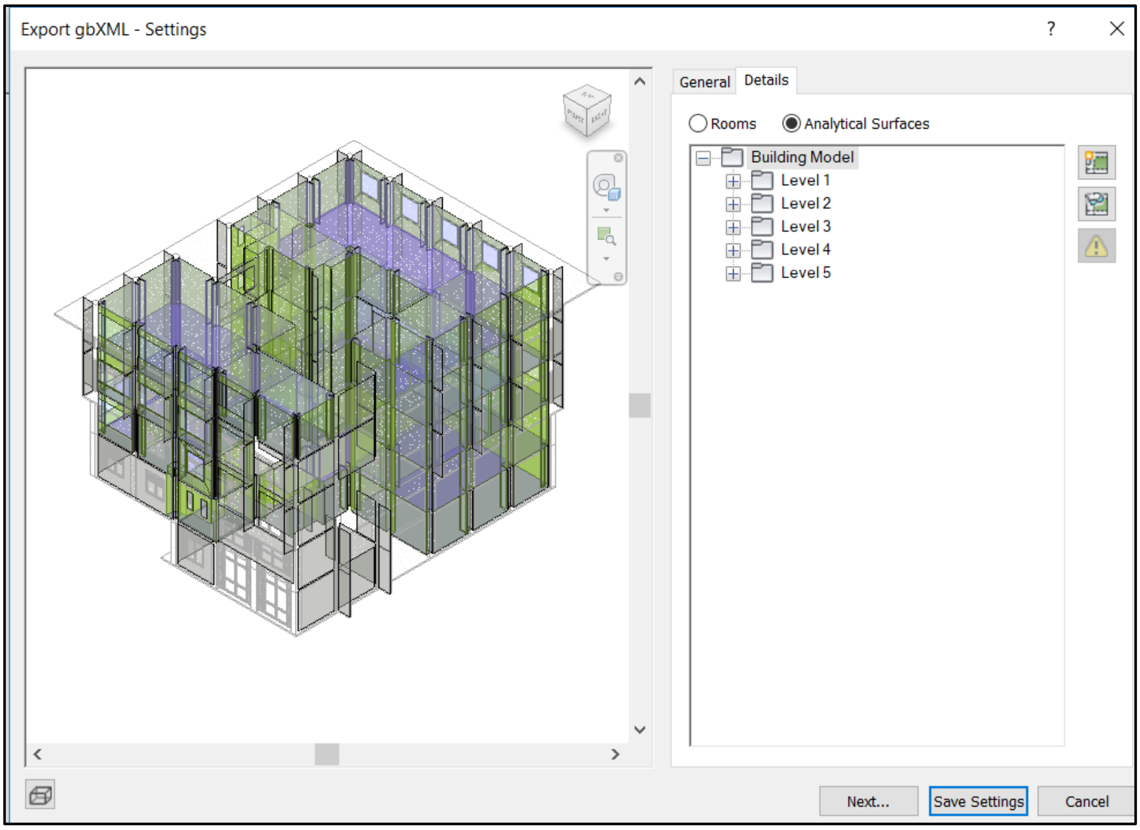


Figure 42: Exported gbxml Model

4.8.1.6 Interaction with the design team members of the building project

Communication and personal contacts made during the study was also important to overcome the challenges of the study. Considering the challenges aroused at the beginning, I wanted to find the contractor of the building project to determine whether there was any possibility to obtain the drawings.

Accordingly, by personally contacting the officials who were the colleagues in the field of quantity surveying, I was able to contact the contractor and also the architect of the project. Accordingly, I was informed about the necessary drawings and however the permission from the university was a compulsory requirement to obtain the drawings. Nevertheless, since the process to permission was delayed, I obtained the drawings directly from the architect and in this situation involvement of FM was also become important to influence the contractor for this purpose. Therefore, it was a significant opportunity to overcome the challenges connected with the validation of BIM models through the correction of developed models.

In this situation, the background as an FM student was considerably advantageous. Thus, for an FM student, the ability to interact with differently specialized people including architects, quantity surveyors and facilities managers is a significant advantage to overcome these challenges.

Moreover, based on the experiences gained during the study, following solutions can be recommended.

4.8.1.7 Comprehensive manual inspection with the collaboration of specialized people and redesigning the building plan

As experienced during the study, it can be suggested, to get the assistance of more specialized people in the construction industry to get onsite measurements of existing buildings accurately. As I experienced, perhaps the employees in maintenance staff, especially the technicians, are not in a specialized level of knowledge to predict the structure of the building and dimensions of building elements. For example, dimensions of columns and beams had to be roughly predicted which were difficult to identify from inside the building. In such situations, knowledge and experience in structural aspects of buildings is very important. As I am not in a positionality with the knowledge of deciding such values, I understood the necessity of getting support from such specialized people in the industry, during the manual inspection. Besides, involvement of material engineers was also identified as a need to identify the materials used in the building, as sometimes I was unable to realise the building materials. This is also important in reducing the time consumed for the manual inspection, as it will be a rapid process, when it is a collaborative activity of specialized personnel in the construction industry. Hence, the involvement of such experts in construction industry including structural engineers, material engineers, quantity surveyors and architects are important during the manual inspection for accurate observations. For an FM it is important to enhance the knowledge and experience as well.

4.8.1.8 Use of AutoCAD software to facilitate the creation of BIM model while reducing the excessive time

This solution is important to reduce the excessive time of creating the entire building model in BIM designing software. Especially for persons with lack of modelling practice, this option will be helpful to reduce the modelling time. If the building plan is recreated correctly after conducting a manual inspection, the drawing can be designed in 2D AutoCAD software where BIM allows to export that design into Revit or any other BIM designing software. Once the CAD drawing is exported, 3D model elements can be generated over the dimensions of CAD drawing and thus avoid the need to specifying each dimension in 3D interface. Considering the Sri Lankan context, as CAD drawing is popular, and experts of CAD designing are readily available, for a person who spends more time to do the modelling in Revit, can create the CAD drawing by an external party and import it into Revit. This will help to avoid the potential errors of designing the drawing in Revit when such studies are conducted with lack of experience and practice. On the other hand, this is important to validate the redesigned drawing as well.

4.8.1.9 Use of BIM compatible non – BIM software to easily create the BIM models

The application of Green BIM process is a challenge as it requires to model the building first, in BIM designing software. This is an actual challenge when applying BIM technologies specially in countries like Sri Lanka where BIM is still not matured. As the level of BIM practice is less and modelling of buildings using BIM software is also less, a person who is conducting BIM related studies will be exposed to number of challenges during the creation of models. However, though BIM is not being used, other 3D modelling software are currently used in Sri Lanka such as sketch up and 3D max. This software widely used just to demonstrate the appearance of buildings as they do not support advanced opportunities as BIM. Since the requirement of BIM for the Sri Lankan construction industry is still hidden, people who are having lack of knowledge and practice of BIM software, can get the support from experts who are using non-BIM software, to easily model the buildings as such software are BIM compatible. For example, the basic model can be created in sketch up or 3D max and can be imported into Revit. This helps to reduce the excessive time of modelling, if the user is new to handling BIM designing software. However, additional costs need to be allocated to get the model created from external parties.

4.8.1.10 Raising awareness of the people who are indirectly involved in the process

A research is successful when the support of interacting parties is high. As experienced during the manual inspection, the occupants of the building were not supportive due to their lack of awareness for the study. However, when applying Green BIM for existing buildings, it is necessary to inspect the building though appropriate drawings were available as required, to verify the as built conditions of the building. Hence, this solution will be helpful to overcome such challenges.

4.8.1.11 Enhance the knowledge and practice

However, it is important to enhance the knowledge and practice on BIM software before conducting BIM related studies. Continuous practice is essential to increase the experience in handling BIM software. Further, it will support to facilitate the creation of models without any financial constraints as 3D modelling is highly expensive in Sri Lanka.

4.8.1.12 Use of point cloud laser scanning for the creation and validation of models

Point could laser scanning is a widely used technology which helps to extract as built dimensions of existing buildings. The scope of this study focused to identify the actual challenges of Green BIM implementation for existing buildings, assuming any other technologies are not currently available. Researches have not been done using this technology in relation to BIM and existing buildings of the Sri Lankan context. Nevertheless, this technology can be mentioned as a further suggestion to develop 3D models of existing buildings to apply Green BIM.

4.9 Cross Case Analysis of the Cases Used in the Study

After the case study, a cross case analysis was conducted comparing the level of data availability and challenges faced in each case. Table 13 shows the comparative findings of both cases in this study.

Table 11:Cross case analysis

	Case 01	Case 02
Period of construction	2005	2016
Current condition	During the operation and maintenance phase	During the operation and maintenance phase
Applicable LOD scale	LOD 200	LOD 200
Data availability		
Building geometry data	Only the floor plan details are available	Only the specification details are not available
Building Simulation Data	Similar data availability	Similar data availability
Challenges		
During the model development	Getting missing information Ensure the accuracy Complexity of understanding details due to the incompatibility of available data with the actual building Need of access for more resources	Creation of families Errors and missing information of drawings Complex details of drawings Excessive time consumption Validation of the developed BIM model

	Case 01	Case 02
	Excessive time consumption To determine the accurate thickness of walls and slabs To measure the accurate dimensions of columns and beams To measure the accurate dimensions of the roof terrace Creation of families Difficulty to measure the dimensions of building facades and shading elements Difficulty to create different architectural features of the building Clashes and errors between elements during the modelling Identification of types of building materials Lack of support from building occupants Validation of the developed BIM model	
During the simulations	Similar challenges	Similar challenges

According to the analysis, similar data availability can be identified in both cases for the availability of simulation data. However, floor plan details were only available for case 01, while specification details were not available for case 02. In terms of challenges, case 02 presents less challenges comparatively than case 01. However, challenges of case 02 that identified during model development were similarly identified for case 01 as well. Further, similar challenges have been determined in both cases during the simulations.

After the cross-case analysis, re-developed framework is presented including the solutions discussed under section 4.8.1 that used during the study with proposed solutions. Figure 45 presents the revised framework.

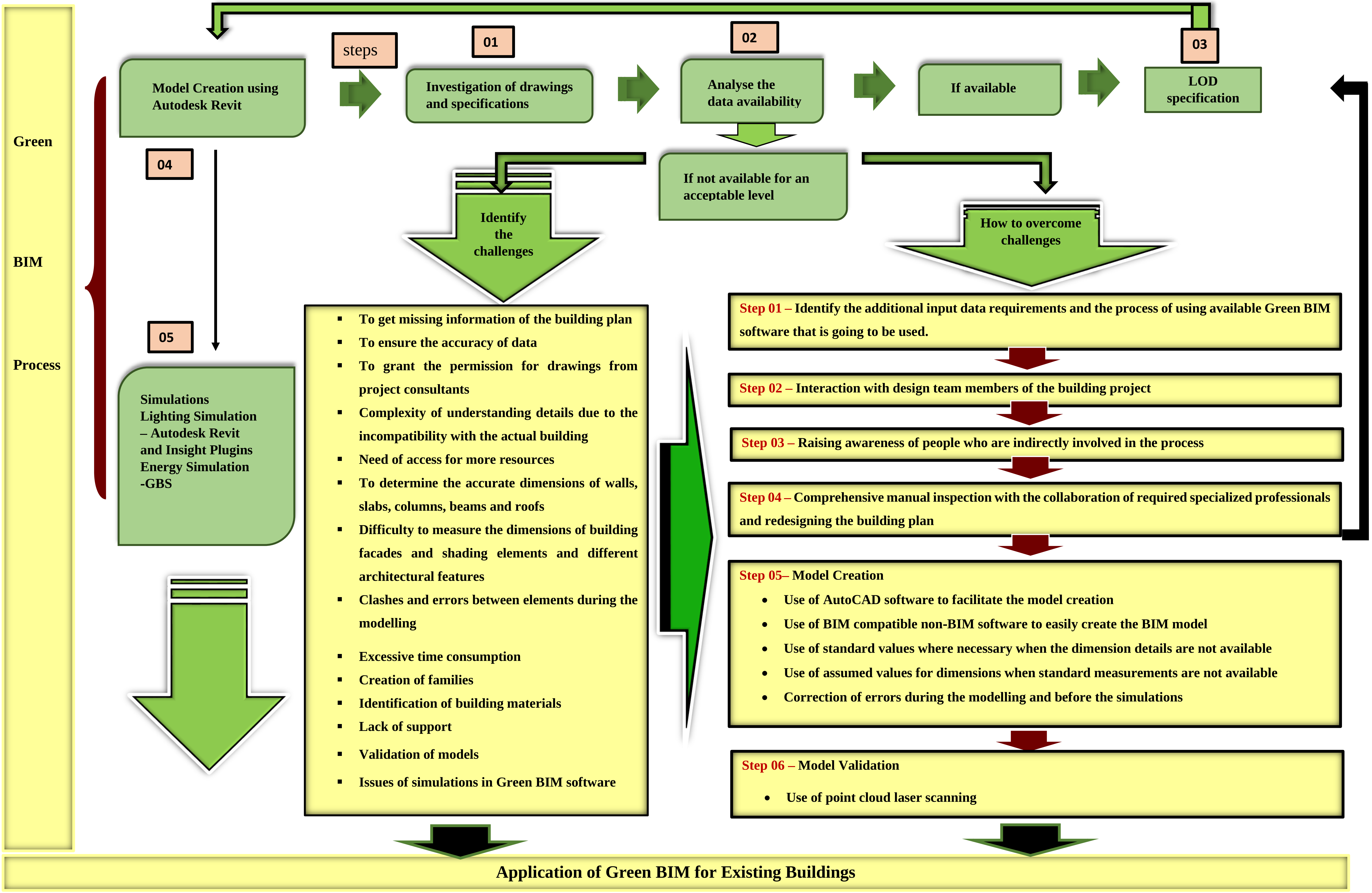


Figure 43: Developed Framework for the Study

The framework was developed by revising and improving the theoretical framework developed first for the case study. Accordingly, Green BIM process is involved with two basic steps as creation of building model and simulation. To create the BIM model first, it is required to investigate the drawings and specifications of the selected existing building. As the second step, data availability should be analysed and if the data are available up to an acceptable level, the process can be continued by creating the model and conducting simulations. According to the framework, if the data are not available, aforementioned challenges can be evaluated prior to the Green BIM implementation and the suggestions can be used to overcome the challenges. Challenges may differ depending to the researcher's background. However, proposed solutions can be important to overcome even a different challenge within the process. The solutions provided in the framework would be important to continue the process, identifying possible LOD scale to create BIM models and simulations.

4.10 Benefits of Adopting Green BIM for Existing Buildings

As experienced during the study, adopting Green BIM for existing buildings is significantly useful to optimize the energy consumption of buildings. Though it is possible to identify the areas of buildings which are exposed to solar radiation manually, by occupying the building, it is practically difficult to identify the specific areas where the solar intensity is relatively high. Hence, identification of such areas through cumulative insolation is important to recognize most applicable energy retrofits for the building to reduce the energy demand, as different energy saving retrofits may be applicable for different facades of the building based on the level of solar intensity. Furthermore, energy simulation is similarly important to optimize the energy, as it provides detailed simulation results for the energy consumption of buildings which are impossible to be made manually. As existing buildings accounts for significant portion of energy consumption compared to modern and new buildings, such analysis are important to establish possible energy saving strategies to reduce the energy demand.

It is also important to get the cost indicators, especially for the installation of solar panels as an energy saving technique, since Green BIM involves much more considerations to calculate and analyse such results including cumulative insolation of solar energy, potential energy production, weather details than manual calculations. The convenience and time saving are the other significant benefits of conducting such simulations using Green BIM. Further, accuracy, ability to create detailed simulations and potential of achieving LEED points can also be considered as significant benefits of Green BIM.

4.11 Discussion

The findings of this research were further confirmed and verified with the findings of literature review. The main challenge of this research was unavailability of data and identification of required Green BIM data from existing building information, as the buildings selected for the study were already constructed years ago. This was verified by Giuda, Villa, Paolo and Piantanida (2015), saying that the history of an existing building with detailed information of its construction is compulsory to be known for the application of BIM technologies to existing buildings. Godager (2011) mentioned that, as design and construction phases are finished for a long period ago, availability of required information is a significant issue. Similarly, McArthura (2015) has mentioned that proper identification of building information is necessary to obtain improved building performances through the application of BIM for building operations. Besides, it was also a challenge to extract the relevant data from available information since Green BIM requires comprehensive data for its application to existing buildings. This was also confirmed by Oti and Tizani (2015), indicating that existing data are not comprehensive enough for the assessment of building sustainability. In this study, finding the data which were not currently available in selected existing buildings was also a challenge due to the scarcity of required data for Green BIM. This was also confirmed by Daim, Oliver and Kim (2013), saying that implementation of Green BIM technology for existing constructions could be complicated due to the scarcity of necessary input data for building performance analyses. Moreover, Mousa, Luo and McCabe (2016) stated that lack of input data and documentation of existing buildings is attributed to lack of implementation of BIM for existing buildings. Hence, that challenge identified during this study was confirmed by above literature findings.

Due to the lack of availability of data a comprehensive manual inspection was needed to be conducted for this study. It was verified by McArthura (2015) highlighting that there is a risk in collecting and using existing building data and the uncertainty of such data could not be avoided without a comprehensive inspection of buildings. This manual inspection was also challengeable due to the excessive time consumption. This was mentioned by Wang and Cho (2015) stating that as-built data of existing buildings are not always available and will require manual collection of data with a risk of errors and high time consumption. Due to these barriers, recreating drawings for buildings was needed to create BIM models which was again become as a challenge. Bryde et al., (2013) verified this stating that creating basic BIM model is a challenge through restructuring drawings and specifications.

Volk et al. (2013), have further mentioned the challenges of BIM implementation in existing buildings as high modeling/conversion effort from captured building data into semantic BIM objects, updating of information in BIM and handling of uncertain data, objects and relations in BIM for existing buildings. For model creation, accuracy of data was also a challenge that is recognized during this study. Also, Hungu (2013), has proved that existing 2D as-built drawings are inefficient and inaccurate at the operation phase of buildings. As mentioned by, Azhar et al. (2012), taking a responsibility for updating such information to ensure its accuracy involves a great deal of risk. Further to Arayici (2008), majority of existing buildings prevails incomplete, obsolete or fragmented building information. Moreover, it was mentioned by Ham and Golparvar-Fard (2014), stating that, the information is generally obtained from drawings, specifications, photos or any other available materials and the accuracy of such information is one of the most important factors need to be considered. Hence, the challenge of data accuracy was also confirmed. Significantly, issues in collecting data during the manual inspection was another challenge which was resulted in various substantial challenges. This was confirmed by Khaddaj and Srour (2016) indicating that, developing a BIM model for existing buildings requires a significant effort of data collection.

Apart from model creation, this study also experienced the challenges during the simulations due to lack of reliable information that are needed to enter for simulation software. Kamaruzzaman et al. (2016), stated that, in order to perform various sustainability analysis for existing buildings, consistent and reliable information should be entered for simulation software. Thus, that challenge was also verified in the study. Due to the unavailability and inaccurate data, simulations were also inaccurately resulted which was one of the challenges faced during the study. However, it was also verified by literature as it was mentioned by Motawa and Carter (2012), as the use of BIM for sustainability analysis of existing constructions results in unreliable and overestimated measures. Hence, these challenges identified in this study during the implementation of Green BIM, were verified with literature findings.

However, even though the aforementioned literature confirmed such challenges, this study specifically identified the practical challenges for each step of Green BIM implementation for existing buildings. For example, though literature has just mentioned that manual inspection of existing buildings is challengeable, this study separately identified the challenges of manual inspection including difficulties in obtaining permission to acquire drawings from the contractor of the building projects, incompatibility issues of actual building, need of access and getting access for more resources, to determine the accurate dimensions and thickness details of walls, slabs, columns and beam details. Further, in this study, even though literature mentioned time consumption as a challenge of manual inspection for existing buildings, this study identified the instances of where time consumption is challenged. As examples, identifying specific details that are complex to understand in available drawings and measuring specific building elements such as facades and shading elements, roof elements, different architectural features and different types of building materials can be mentioned.

Further, literature include that creating BIM models for existing buildings is a challenge. However, in this study, it was revealed that creating BIM families is a challenge instead of creating entire BIM models. Moreover, different clashes and errors during the modelling were explained in this study apart from just stating that model creation is a challenge. Also this study identified the social barriers including issues of collaborating with project stakeholders (in obtaining permission to acquire drawings from the contractor of the building projects), lack of support from parties who are indirectly involved and issues of getting assistance from people. Further, technical challenges were additionally identified including model validation, deficiencies of detailed simulation feature in Green BIM software, error simulations and issues of generating simulation data for Green BIM analysis.

In addition to that, this study has given set of solutions that can be taken to avoid the aforementioned challenges which was not reviewed in prevailing literature. These solutions have been descriptively discussed and a framework has been provided as a guide that can be implemented to apply Green BIM for existing buildings. This framework provides step by step guidance to implement Green BIM for existing buildings when the data are not adequately available. Accordingly, this study is ended up with additional challenges that arise in practical implementation of Green BIM for existing buildings with a validated framework and solutions so that they are implementable for the industrial practice, which have not been proved by present literature findings. Besides, the findings of this study are specific to the facilities management perspective contrasting to the general challenges prevailing in the literature.

4.12 Validation

4.12.1 Expert Interviews

Expert interviews were conducted by selecting the professionals from university administration hierarchy. Accordingly, total four experts from both top management and middle level management were interviewed.

According to the experts' opinions, energy conservation is not considered during the design and construction stages of the building constructions in the university. However, the energy committee which has been recently established, currently in need of conserving energy consumption of buildings due to high amount of energy cost. Hence, the energy committee is planning to develop a policy or guideline to optimize the energy usage of buildings from inception stage to operation and maintenance stage of buildings in the university which will be constructed in future. As mentioned by all respondents, the reason for not considering energy optimization in current existing buildings is, unavailability of required data relating to building constructions and systems as buildings have been constructed long years ago.

Therefore, it is expected to launch necessary programs and modern systems to record and maintain building data so that they can be used in future building operations. However, that requirement was mentioned as which is still at the discussion level as a long term objective. Hence, the respondents were highly recommended the framework given in this study as Green BIM provides a better opportunity to conserve energy in buildings and at the same time a standard database to maintain all building data throughout the life cycle of buildings. The given recommendations in this study were confirmed by all experts as implementable solutions to ensure the availability of required data during the buildings' life cycle phases.

4.13 Chapter Summary

This chapter aimed to present the findings of the study, analysis of data and discussion of the research outcomes. Accordingly, theoretical framework developed for the case study was followed step by step in this chapter, and the findings were discussed. Two existing buildings were selected for the case study and data availability analysis was done first after investigating drawings and specifications, to verify the cases for the study. Then the possible LOD scale was identified for the creation of BIM models and challenges were further identified during the model creation as a major outcome of the research. Further, challenges were identified during the simulation and finally, a framework was developed revising the theoretical framework developed previously, providing the solutions and suggestions to overcome the challenges.

CHAPTER 05

5.0 CONCLUSION AND RECOMMENDATIONS

This chapter is aimed to establish the conclusions and recommendations for the research based on the findings. Conclusions have been provided addressing the objectives of the study under each previous chapter. Further, contributions made for the knowledge have been mentioned and subsequently, based on the findings, further research directions, recommendations and limitations of the study have been discussed.

5.1 Summary of the Study

Energy consumption of buildings has been acknowledged as a severe issue currently faced by the world. Therefore, number of modern technologies are considerably increased to mitigate the total energy demand in buildings. There were numerous sophisticated technologies adopted in construction industry recent years to design the buildings with optimized energy usage. Most of these technologies are integrated for the design and construction phases of buildings, while the existing buildings are remaining with same conditions. The most of recent studies of energy, have continuously argued that the portion of energy demanded by existing older buildings are significantly high than new buildings. Nevertheless, the issue of energy in existing buildings has remained as a question to be solved. Hence, this study focused on the adoption of Green BIM technology which could be potentially used to optimize the energy consumption of existing buildings. Though Green BIM ensures the ability of reducing energy demand in buildings, degree of Green BIM implementation for existing buildings is decelerated due to the requirement of numerous data. As evident by prevailing literature, lack of data availability is actually a barrier to implement Green BIM in existing buildings due to the missing information, when buildings become older with the time.

Hence, this research was aimed to identify the challenges of recreating BIM data from existing information for the use of Green BIM technology in existing buildings. To accomplish the above stated aim, four objectives were established.

A comprehensive literature review was conducted first to identify Green BIM techniques, tools and data requirements for each tool as preliminary findings of the research. Data requirements were separately reviewed from the literature for each Green BIM technique and tool. As Green BIM techniques energy and thermal analysis, lighting and shading analysis, value and cost analysis, acoustic analysis, water harvesting, system simulation and space simulation were identified. Green BIM tools were recognised mainly under two categories as BIM design tools and BIM simulation tools. As BIM designing tools Revit, Bently system, ArchiCAD, Digital Projects, Vector Works and Tekla structures were identified while BIM simulation tools were recognized including Ecotect, Green Building Studio, IES VE, Riuska, Energy Plus, Design Builder, eQuest and Eco designer. Further, available LOD scales were reviewed for the selected simulations of the study with required input data for each technique under each LOD scale. Accordingly, the first objective of the research was accomplished and the literature findings of first objective, facilitated the achievement of second, third and fourth objectives of the research.

From methodological point of view, a qualitative research approach was selected for the study with a multiple case study analysis. Two existing buildings were used for the case study analysis including an older building and a new building from a university which were educational buildings. Criteria for the selection of cases were established from the literature review before selecting the cases for the analysis. From practical point of view, a process flow diagram was developed after the selection of cases for the study, including the steps to be followed and the study involved participative observations engaged with ethnographical features. Hence, following this process, available building data were investigated first through drawings and specifications in each case. Subsequently, the availability of required data was analysed as per the literature and findings reviewed that there is a high data availability in new buildings compared to the older existing buildings. This was mainly identified for the geometry data of buildings while the availability of simulation data was similarly identified for both cases. The analysis of data availability facilitated the next step of specification of LOD scale to design the model and simulations. According to the analysis of data availability, LOD 200 was specified as the most applicable scale for the case study.

Thus, solar and shading analysis and energy analysis were conducted under LOD 200 scale.

As per the steady flow, BIM models were then created for each selected case using Autodesk Revit BIM designing software. During the modelling of buildings, number of challenges were encounted especially for case 01, achieving the third objective of the research. These challenges were basically aroused due to the incorrect and missing information of available drawings. Accordingly, getting missing information and ensuring the accuracy of data were the foremost challenges faced for case 01. Inability to obtain the required drawings from the contractor of the project was another similar challenge faced initially due to the delay of confirmation for the permission. Thus, the study continued with the available data and to overcome these issues, a manual inspection was done by periodically visiting the building. However, it was also resulted with significant challenges. These challenges were included as complexity of understanding details due to incompatibility of available data with actual condition of the building, need of resources and excessive time consumption.

Further, challenges were identified including difficulty to measure the dimensions of walls, slabs, columns, beams, sun shades and roof terrace, creation of families, creation of different architectural features of the building, clashes and errors during the modelling and lack of support from building occupants. However, regarding case 02, several challenges were identified including creation of families, errors of drawings, complexity and excessive time consumption for modelling. Hence, it can be mentioned evidently that there are comparatively less challenges in newly constructed buildings than the existing older buildings within the practical context of Green BIM implementation.

Moreover, this study has reviewed the challenges aroused during the simulations. For simulations, energy simulation and daylighting simulation were intended to be conducted using inherent Green BIM features of Revit and exporting models to separate Green BIM software. This step involved considerable challenges since there were number of technical and network errors which cannot be ignored or corrected. Besides, unavailability of required Green BIM software, inability to find Revit detailed Green BIM features with direct plug-ins were similarly identified as the challenges of simulations. Further, unavailability of simulation data which required to enter for the simulation software was another challenge as such data were not available at the FM department. At the same time, inability to change some of the project default values including utility information was another challenge faced, which had a considerable impact for final simulation results. With respect to the above stated challenges, inaccurate simulation results were resulted especially for energy analysis and thus, the interpretation of energy simulation results for the actual performance of buildings was not possible as another identified challenge. However, considering the day lighting simulation, potential energy saving strategies were suggested to reduce the energy consumption of the building.

In light of the discussed challenges in this research, it can be provably concluded that there are more challenges need to be faced for the implementation of Green BIM for existing buildings than new buildings which could impede the adoption of Green BIM. However, the study itself identified the solutions to overcome the challenges and based on the knowledge gained during the study, recommended solutions have been further provided. The challenges and solutions were discussed sequentially as identified during the study. The solutions which sequentially followed were included as manual inspections, assistance from experts in the field of architecture, use of standard values, use of assumed values, correction of errors by following the Revit guidance, involvement of FM and interaction with design team members. Finally, a framework was improved providing step by step guidance based on the findings and experiences of the study for the implementation of Green BIM technology in existing buildings.

5.2 Conclusions

The framework provided in this study may help to identify the challenges which might be aroused for studies in the same nature and especially for the researchers who are in the same contexts and positions. Importantly, this framework may further help to apply the solutions given, to overcome the identified challenges as well as potential non-identified challenges.

5.3 Recommendations

Following recommendations can be provided based on the findings of this research. These recommendations have been provided considering the future building constructions to ensure the data availability during operation and maintenance phase.

- Integration of requirement of Green BIM for the management and regulatory level of organisations and the government.
- The data of building projects after the design and construction stages should be transferred for the FM before the operation phase to ensure the required data availability for the application of Green BIM in existing buildings.
  or
- Involvement of FM can be recommended for the design and construction phases of buildings to ensure the data availability during the operation and maintenance phases.
- Use of document management systems since early stages of building projects.
- Involvement of available experts for 3D modelling during the design and construction stages of building projects.
- Ensure the availability of software before the implementation of BIM technologies.
- For existing buildings, conducting a preliminary survey can be recommended for the collection of required data for both model creation and simulation relating to the available software.

5.4 Contribution to Knowledge

This research has made contributions to knowledge by revealing the hidden challenges of Green BIM implementation for existing buildings and providing real life solutions to overcome the challenges from facilities management perspective, focusing the Sri Lankan context. These solutions may equally important to overcome the challenges which would be potentially faced by same positioned researchers. Further, this study contributes to the knowledge by providing a validated framework that could be used as a guidance to implement Green BIM for existing buildings, that is important for facilities management professionals as a new knowledge.

5.5 Limitations

This research was limited for the educational buildings considering the ability for the access for data. Further, the simulations for this study were conducted using freely available software on internet due to the financial constraints. The study also limited only for two cases due to time constraints.

5.6 Areas for Further Studies

For the explorers who are interested in the field of Green BIM, could use this research as a mother guidance which could guide them towards their research directions. The identified further research directions are mentioned below.

- Implementation of Green BIM for buildings in other different sectors.
- An in-depth analysis of challenges faced during the Green BIM implementation.
- A study to investigate the capability of implementing the solutions and recommended suggestions for the adoption of Green BIM for existing buildings in the Sri Lankan context.

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