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BUILDING INFORMATION MODELLING (BIM):

AN EVALUATION OF BIM APPLICATION ON ACHIEVING SUSTAINABLE DESIGN

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ABSTRACT

In recent years, building information modelling (BIM) is paid much attention and still getting widespread concern in construction field and the majority of the projects that using BIM technology obtained good consequences to effectively balance between economic and sustainability. The most important decisions in respect with building sustainable features are made during the design and pre-construction phases. The application of BIM has the possibility to enhance the quality of provided information for making critical decisions for design concerning an environmental impact of the building. The fundamental aspects of integrative design, multiple stakeholder collaboration, common goal-setting, the quick efficient presentation of complex concepts to enable fast and effective decision-making, and an emphasis on dialogue between stakeholders are as fundamental to sustainable design processes as they are to BIM enabled construction. The long term aim of this study is to examine the suitability of BIM on sustainable design and sustainability analysis by two case studies. It will show the green decisions by using BIM to achieve sustainability, the assessment methods like BREEAM and an integrated team with BIM

Keywords: Building information modelling (BIM), Sustainability, BREEAM, BIM application.

1. INTRODUCTION

Nowadays, there is a high demand to have sustainable buildings with minimal environmental impact. The most important decisions in respect with building sustainable features are made during the design and pre-construction phases [1] as more than 90% of carbon emissions and consumption of energy for the commercial buildings happens in operational phase. The Brundtland Commission offered the best definition to the United Nations in the 1987 report that "sustainable development meets the needs of the present without compromising the ability

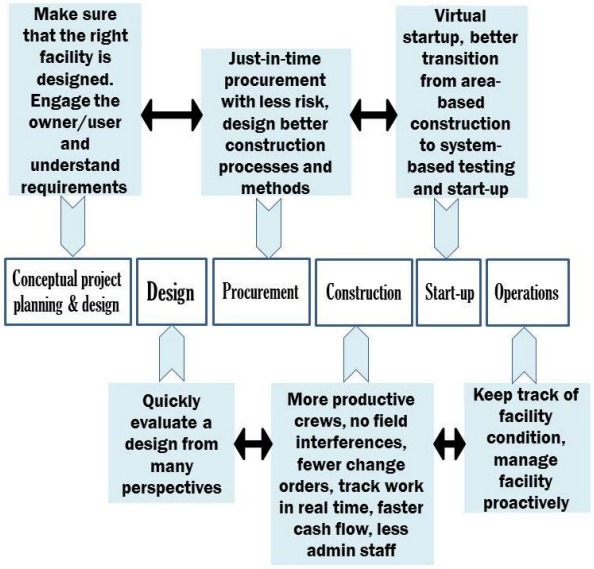

Figure 1 BIM applications in the different phases of an AEC project [11]

of future generations to meet their own needs" [16]. The integration's lack during the design process, such as, the analysis of performance and energy before or after the architectural design and construction documents, results to inactive process of retroactively alteration for the design to fulfil a set of performance criteria [23]. Thus, to achieve the building performance assessment in the early stages in realistic way, it is required to access to a comprehensive knowledge's set that relating to building's form, context, materials and technical systems. So that, the opportunity for sustainability measures and performance analysis to be performed during the process of design is created by BIM which can allow multidisciplinary information to be composed in one model, as shown in figure (1)[23] [4].

Building information modelling (BIM) regards as one of the most promised developments in the architecture, engineering and construction (AEC) industries which based on a number of software solutions. Since 1970, BIM concept has been introduced by Professor Charles M. Eastman [12]. After that, in 2000, BIM had started to be implemented by AEC industries in construction projects [6]. By BIM technology, the precise virtual models are constructed in a digital way. When the computer generated models has been completed, they have accurate geometry and data to support the construction, fabrication and procurement activities of the building [12]. During the use of BIM, it facilitates the process of exchanging building information to manage construction projects. In addition to that, the BIM process makes the best utilisation of resources are available to the buildings' developers, consequently the buildings can develop at a lower cost.

One of the fundamental tools using in the BIM process is Revite Parametric building modeller (RPBM) that makes the developers to recognise the inherited problems in building and modify the problems that appear to sustainable design professionals every day. As an architect, BIM is helpful and smooth tool in the design's process which allows in getting early feedbacks on the sustainable and aesthetic decisions of the design. The computerised virtual 3D model is used to design, understand and explain the essential functional and physical features of the building from conception to final demolition [8]. So that, it is important to use BIM in green buildings because of the effects during development process and even after the construction which take up enormous energy's resources and can obstruct the balance of the global energy situation. During the early design stages, the building model linking to energy analysis tools leads to energy use evaluation. There is no possibility to do this process by using 2D tools, which require analysis to be performed at the end of design, so reducing the opportunities for the early alterations and help to improve the energy performance of the building [7]. The certification and assessment methods are consistently extolled a significant means to achieve carbon emissions reduction and getting sustainable development with the most predominant method in the United Kingdom, the Building Research Establishment Environmental Assessment Method (BREEAM) and how this assessment is an effective process to change the practices for sustainable construction, as shown in figure (2) [10] [22].

Environmental section	Weighting
Management	12%
Health & Wellbeing	15%
Energy	19%
Transport	8%
Water	6%
Materials	12.5%
Waste	7.5%
Land Use & Ecology	10%
Pollution	10%
Total	100%
Innovation (additional)	10%

Figure 2 BREEAM Environmental section weightings [9]

The use of BIM keeps in progress with daylight design and ends with materials application and systems, such as, use of renewable energy, harvesting of rain water and management of water runoff. Moreover, BIM focuses on the building's lifecycle with adding more information during performance of the building [13] [18]. By offering simulation for the building and modelling for the daylight, visualisation, waste and inefficiency reduction, materials application for building cover, embodied energy and cost estimation of green strategies for evaluation and optimisation, BIM helps with green decisions to new buildings. In addition, the ultimate green solutions could be positively affected by interdependence, integration and connectivity [13].

The Benefits of Building Information Modelling

The essential benefit of using BIM is introducing precise geometrical representation of the entire building within an integration data environment [11]. There are other related benefits which they are:

- More efficient and faster process-the easiness of sharing information, adding value and reusing it.
- Better design – the proposals of buildings can be strictly analysed, quickly performance of simulations, offering innovative and improved solutions.
- More control for the costs and environmental data – better understanding for lifecycle's costs and the environmental performance is more expected.
- Better service for customer– better understanding for proposals through accurate visualisation.
- Lifecycle data – the information of requirements, design, construction and operation can be used in facilities management.

2. BIM and Green Decisions

BIM could work with some areas to achieve sustainable design and gathering decisions [16], such as, by comparing different masses like the comparison between a tall and narrow mass and a C- shape one. This comparison may be in regard to energy efficiency, daylight system and sun-shading possibilities, HVAC system or envelope system. By using energy analysis software like Energyplus to get primary energy that use per square feet for each form, the first sketches that had drawn as BIM models and had translated to energy simulations [5]. Furthermore, the building's envelope could be assumed of every form and the basic cost for each selection.

In addition to the appropriate form, the basic model could be used to choose the orientation of site regarding to daylight and energy issues. It is easy to select the location in BIM by knowing the latitude and longitude of the project's location where will be built. Subsequently, the various solar studies of different orientations and rotations in site could be viewed which helps in site selection, building's orientation in site and suggestions of design. The shading and daylight issues, in addition to the aesthetic relationship with the neighbourhood, have an influence on the decision of the design [24].

In terms of daylight analysis, it expands to more detailed modelling in addition to the selection of site and its orientation. By using Revit model, it could analyse the daylight at the location in different seasons [2]. After that, the lighting systems could be translated to other software like Ecotect™ [3] to make a comparison of different lighting systems and the availability of luminance for each space by editing either the system's type or its design.

To proceed more in the details of the design, BIM can be used in systems choice and design which are applied to the building. By achieving a developed BIM model which can be simulated by using energy analysis programmes, the used energy can be optimised by comparing various building envelops, day-lighting, sun-shading and HVAC systems. As well as, getting overall comparison between many different solutions through translating the models to an energy analysis and estimating programmes. Subsequently, the decision for the design would be more precise and efficient. The information of room's area, perimeter and volume can be easily provided throughout BIM and they are more accessible for the mechanical design. As stated by Bazjanac V., a researcher at Lawrence Berkeley National Laboratory, that the transcription and repetition of information from other resources by the HVAC design and simulation tools users have an impact to delay the resulted work in many omissions and errors [21] [23].

Moreover, the designer can apply the renewable energy resources through knowing the energy's consumption of the building and the amount of energy which produced from each type of renewable energy resources [16], for example, solar energy, geothermal energy and wind. There are many use of BIM model in this field, for instance, to set the availability of the roof's area to

put the solar panels to produce the needed energy and the best slop for the roof to optimise the production of solar energy, other example is the best location choice of the wind turbines depending upon aesthetic and climatic factors [21].

Green systems include rainwater harvest and reuse of grey water as well. It could be provided each roof area through BIM model and calculate the amount of rain that would be got from each roof. Some roofs, such as, green roofs, canopies and terraces can be eliminated because of the difficulty to collect rainwater. Furthermore, with BIM it is easy to calculate use and waste of water. After putting the plumbing fixtures, the simple schedule can be created with containing the water-flow rate for each fixture. In addition to that, it is easy to calculate the collected grey water from different fixtures. For example, reuse the grey water from drinking fountains and lavatories for flushing the toilets. Whereas the water that collected from other fixtures such as toilets and kitchen sinks need filtration or could be used in irrigation processes. Through this, money will be saved in filtration and reduce drinkable water. By having idea of the amount of needed water, amount of reused grey water, and availability of harvested rainwater, the capacity of the collecting tank can be calculated by taking into consideration the dry months in month-by-month database [18].

Lastly and not the least, material selection is very essential in the sustainable design. As long as BIM model is having all the materials information, the designer will know how much these materials can work for the design and can modify them during different design phases. Using the quantities of needed materials, the designer can take decisions relating to recycled, salvaged, and regional materials that could be used. However, the decisions for select material are made according to the contents, sources, embodied energy, and quantities that used for each material. Besides that, the cost of material is an effective factor which highlights the selection procedure.

3. Team Integration with BIM

By looking at the history of AEC industry, it will be found that in the past the architect and the builder were the same person. But today's building has more issues that make a large design team, such as, landscape, structure, accessibility, security, controls, lighting, electricity, acoustics, heating, cooling and plumbing. The contractor, owner and users should be involved in the sustainable design process early alongside with the architect, engineers, and specialty consultants. Krygiel E. and Nies B. discuss the green BIM and the importance of team in Green BIM book [16] that there is difference in the way of designing and team interaction with other team members. That happens because of an increase in the amount of information and increase in the efficiency of technology to use and share this information. For instance, the data has been inputted into the BIM file by the architects which locates the building geographically and digs up information that helps in understanding by the design team the related issues to place, surrounding systems, climate and resources [14]. So that, to achieve the integration of sustainable modelling strategy into a BIM process, firstly, it is needed more integration between the design team and contracting team. But prior to start any of new processes, the contractors need to become more educated about green building standards and practises and begin to learn about eco-friendly construction. This can be done through studying the information and measures of a building's environmental performance compiled by the BREEAM [14].

BIM can really offer an integrated team during all design phases: preconstruction, schematic design, and final documentation. Each member in team can participate in the same document and get all others' contribution to move forward to the next phase with immutability and appropriateness. During the schematic design, an architect is provided by BIM the ability to analyse the mass of the building and form to have an optimisation for the envelope and balance

glazing ratios. An engineer use BIM files to decrease the demands of energy through energy modelling that utilises the 3D model to calculate the reflectance of light and its permeation. After that, the contractor can analyse protected habits and wetlands and use the site model to organise better to eliminate probable cases. Moreover, according to existing model of a facility, the contractor can easily qualify the kinds of materials in this building that will come out to simplify the recycling and reuse efforts. By BIM technology, subcontractors can reduce carbon footprints through combining shipments. In another words, an array of resources and information that needed early can be provided by BIM file to apprise the project's team members about the sustainable issues that are connecting to the project [16].

The significance of an integrated team summarises in saving time and money that could be lost in a probable misunderstanding among the team members. Small deceptive details could be fatal to one of the green strategies that put by the designer as a main aim. BIM introduces an integrated world to the AEC industry which allows all stakeholders are involved from the start of the design process [15].

4. CASE STUDIES

4.1 BIM and Sustainable Construction: Masdar Headquarters Design

Even this project is still early in the design process which located in Abu Dhabi, United Arab Emirates and designed by Adrian Smith and Gordon Gill, but the advantages for using BIM are already produced. BIM file they use has already advanced numerous aspects to achieve the sustainability of the project [15]. Initially, they used BIM in internal design competition and after that is fully implemented when they began the concept design phase, figure (3).

Process

There are many goals for Masdar city to achieve the integrated design approach, which were the following:

- Zero waste
- Zero emissions of carbon.
- Renewable energy to produce 100% power.
- Efficiency and saving of energy.
- Zero claims by providing efficient project management systems and communication.
- Zero accidents through effective protocols of health and safety.

The project has faced many challenges and one of them is how to create a comfortable city in a hot climate. For example, there are requirements of the streets to be taken in consideration and require elements for electricity, storm water, cooling and gas which available on specific

Figure 3 **Masdar city** [25]

side of the streets and therefore need a strategy for shading through using trees, buildings and shade elements for pedestrians' comfort and designed to be pedestrian friendly . This city regards one of the liveable mixed-use communities by achieving the demands for reusing water and resources, shading and conserving energy [17].

Design Process Integration

Utilising BIM assists in the team and process integration. BIM provide team work and make the team's work together on the development of model and process because each consultant has ownership of elements in the BIM file. In the beginning of the process, the integrated design processes introduce true value of sustainable opportunities. And an integration process ensures the team is thinking about same concepts integration from the beginning and they did not wait the system' performance reviewing and confirming [12] [17].

Sustainable Construction

To increase the sustainability of the building, it can be gained by looking at the process of construction and reviewing ways to decrease the project's carbon footprint during construction and reviewing strategies to boost efficiencies of construction. The designers rethought the construction process and in order to produce the clean electricity throughout construction, it is proposed to build first the roof/trellis with PV panels of the building and the supporting cones. So the energy that cannot be used directly on site is sent back to the grid, as a result producing a net zero energy construction site and producing carbon credits to offset the carbon emissions construction activities [12].

In regards with allowing a project's 4D view and an evaluation of two construction methods' viability, the BIM file was linked to the construction schedule. One of these methods was to construct the roof and PVs firstly as a more sustainable process, and after that the second was a more traditional construction succession [25] [17].

BIM has allowed to take the architectural documents to other dimensions, such as, 2D and 3D as essential dimensions to clarify the architectural spaces to owners, and in addition to that:

Table 1 BIM dimentions of Masdar city [25]

4D	Construction information for the schedule
5D	cost components
6D	facilities management components
7D	components of sustainability

Using BIM has allowed setting carbon targets for certain project's elements as Masdar city has focused on the importance of sustainability and efficient energy and, according to that, making a validation of the design decisions or making a test for various options and comparison. Furthermore, BIM gives a real time update on the status of the recycled content [17].

However, one of the concerns did not take in consideration is the dust, as the environment of UAE is characterise with a number of dust storms during the year, thus the resulting dust that would pile up on the PV panels and obstruct the productivity. For instance, the amount of dust in the air, August 2009, was more than 1,500 parts per million which is 10 times higher than

normal, as a result, the solar plant was working at 40% below its capacity. Within nearly a week, the PV panels returned back to normal productivity after cleaning process, but the concern remains, as panels would need to be more cleaned because of the frequent dust storms and subsequently increase the costs of operating and maintenance [19].

4.2 Advanced Environmental Assessment and Sustainable Design: Helsinki Music Centre

This project aimed to give the capital city of Finland a prominent and acoustically exceptional concert hall in addition to other facilities enhancing the experiences of music for all ages, figure (4) [12]. BIM applications and tools used in this project include, see figure (5):

Figure 4. Helsinki Music Centre [12]

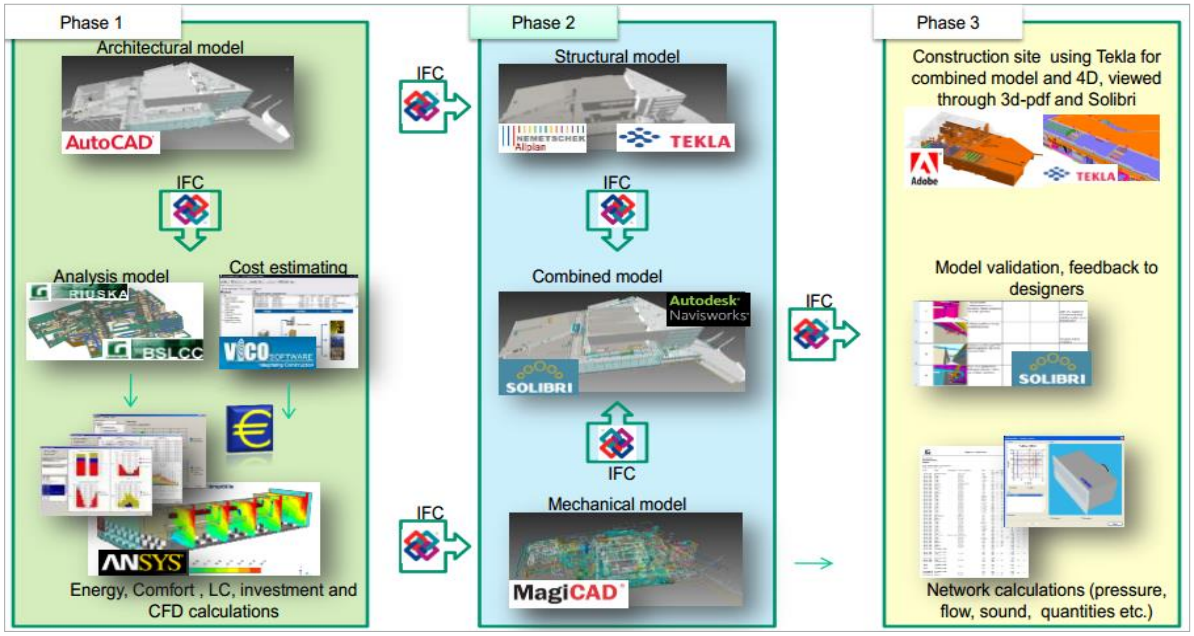

Figure 5. Applications and their models which used in the project [12]

Ruiska has showed how energy analysis can support design. It conveys the geometry data from architectural software to model of thermal simulation geometry, providing uniformity between both models. Its utilisation was shown in the simulation used for energy performance evaluation of two glazing type in the curtain wall system.

Lifecycle analysis (LCA) was used for comparing the environmental impact of design alternatives. It is a significant type of analysis which will play progressively a salient role in

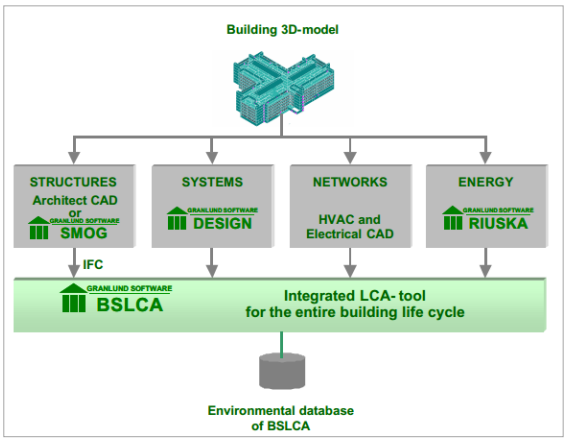

Figure 6 Structure of the BSLCA (which is an assessment tool for performed lifecycle cost) integrated with LCA tool [12]

design decision-making. So that, the materials and energy used have been provided by BIM, extracted from the building model, and was decisive for LCA analysis, see figure (6).

Computational fluid dynamic (CFD) simulation requires experts to be involved because it is known as a time-consuming, complex and costly process. The amount of work was cut by BIM to a large extent and makes the accessibility of CFD simulation to general designers. By doing a simulation through CFD, over 20% of the loads for HVAC system of the foyer have been reduced. Through using BIM, the consequences from energy simulation, Lifecycle cost analysis (LCC) and CFD could be used in the mechanical, electrical, and plumbing (MEP) system design. Whereas, with MagiCAD, the HVAC engineer and electrical engineer worked with it to cross-check the collision between the piping, ventilation and electrical installations any time [20].

According to the acoustic solutions for the concert hall, the analyses were performed based on the computer simulations although the capacities of computer simulation were limited and the data about spreading of sound waves were not obtained. So that, it was suggested to build a model with a scale of 1:10 to help acoustic engineers and interior design team to check the shape of ceiling and its construction; in addition; arrangement of seats did not have any adversely effect on the acoustic performance [20] [26].

At the final stage of design, lifecycle simulations are undertaken by specialised engineers in order to prove the previous decisions. While during the design phase, simulation of advanced energy performance explains the problems, such as, thermal comfort, air quality energy loss, visual environment and acoustical performance. However, such analyses to provide feedbacks are prevented to use by numerous actors and complex datasets of current practices.

Senate Properties, the owner and developer Musiikkitalo and the Finland's largest property asset manager, specified the importance of promoting BIM for many years and the project's requirements for sustainability. The goal is making the design, facility management and building processes more efficient through processes' and workflows' integration across all

phases and partners of the project. As well as, BIM is a way to decrease the consumption of energy and environmental impact [12] [20].

CONCLUSIONS AND RECOMMENDATIONS

This research presents a study conducted to assess the capability of BIM application to evaluate the sustainability of building through making the green decision-making process more effective and time more efficient. The study demonstrated that the benefits of BIM are: more efficient and faster process, better design, more control for the costs of whole-life and environment, better service for customer and lifecycle data. There are many ways regarding adopting BIM and green decisions, such as, comparing different masses like the comparison between a tall and narrow mass and a C- shape one, choosing the orientation of site regarding to daylight and energy issues, lighting systems, renewable energy, rainwater harvest and reuse of grey water and the recycled, salvaged, and regional materials that could be used. BIM process begins from the predesign with building massing decision, site selection, and orientation and continues with the day-lighting and sun-shading analyses. Then, the BIM model can be easily translated to an energy model and provides handy information used in calculating rainwater harvesting, wastewater strategies, renewable energy sources, and selecting materials. While at the project's end, the designer, the engineers and the contractors will collaborate various inputs to produce the model. This research presents two case studies that illustrate the significance of an integrated team in saving time and money that could be lost in a probable misunderstanding between the team members. In addition, sustainable and integrated design can be achieved by BIM, such as, zero waste, zero emissions of carbon, renewable energy, etc. and how BIM helps in making the design, facility management and building processes more efficient through the integration of processes and workflows across all phases and partners of the project. However, many issues appeared and didn't take in consideration when using BIM either in the analysis phase or post construction, such as dust issue and acoustic solutions for the concert hall. Renovated expectations and various scopes that created by adopting BIM should automatically produce improved sustainable design.

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