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BIM Application on Sustainable Design

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Abstract—**Sustainable design is a must in today construction industry. However, it needs effective tools to facilitate design decisions from the beginning to the end to save time and avoid any mistakes that might be fatal to green strategies. Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward. BIM not only brings technical benefits to the development process, but delivers an innovative and integrated working platform to improve productivity and sustainability throughout the project life cycle [Elmualim et al. 2014]. This paper investigates the potentials and possibilities that BIM can add to the sustainable design process through all phases from schematic phase to construction and management phases. The objective of the study is to demonstrate examples and how BIM can make green design decisions easier. The paper also investigates in the integrated process of BIM and its benefits to sustainable design. Finally, it detects the future of the construction industry needs in terms of BIM and what is expected.**

Index Terms: **Building information modelling BIM, sustainable design, digital architecture, integrated design.**

I. INTRODUCTION

Building Information Modeling (BIM) is a method to manage and create construction information for a certain project throughout the whole life cycle of the project. This method includes digital developed description for all the building aspects. It happens using an appropriate technology that usually develop a group of 3D models that are rich in information and data. Today building industry is looking for methods to select building information that are earned in a sustainable concept of the design process. Sustainable BIM is the process of creating BIM objects with environmental and sustainable properties to help designers in making sustainable decisions using these properties. Building information Modeling (BIM) is considered a great tool to integrate between team members with different backgrounds. In addition, BIM is proven to be most effective as it enables sustainable construction management [Green 2008]. As architects, we found BIM to be smooth and helpful in the design process. We can get very early feedback on design decisions, both aesthetic and sustainable ones. BIM is useful in pre-design, schematic design, and in choosing systems and materials. Moreover, BIM is useful in modeling the building for design decisions and green strategies. These decisions begin from massing, selecting the site, and building orientation. BIM use continues with day lighting design and ends with applying materials and systems like water runoff management, rainwater harvesting, and renewable energy usage. Moreover, BIM focuses on the lifespan of the building and allow more information to be added during the building's performance [Florkowski 2008]. BIM helps with green design decisions by offering building simulations and modeling related to day lighting issues, applying building envelope materials, and estimating the cost of green strategies. In addition, it provides great communication to create an integrated team. The integration, connectivity and interdependence positively affect the final green solution.
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II. GREEN DECISIONS USING BIM

From the very early scheme of the design, BIM could help with massing decision. It can be used to compare different massing, like comparing a C-shape mass with a tall and narrow one. The comparison might be according to the day lighting, HVAC system, energy efficiency, or envelope systems. The first simple sketches can be drawn as BIM models and translated to energy simulations using energy-analysis software such as Energyplus to get a basic energy use per square meter for each form. Furthermore, the comparison between forms can be according to the day lighting and sun shading possibilities for each of them. Moreover, we can assume the proper building envelope of each form and the primary cost for each selection. "Figure. 1," shows energy and cost stimulation for a Revit model using BIM technology. The design was for an office building designed and simulated by the author. The graph compares the energy consumption before and after applying the green strategies using BIM. The numbers show the rise in initial construction cost in both cases and life-cycle cost.

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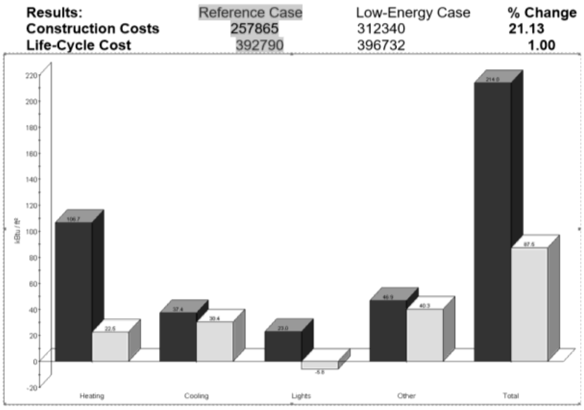

Figure 1. Energy and cost stimulation before and after applying green strategies in an office building design using Energy-10 program.

In addition to choosing the proper form, we can use the basic model to choose the site orientation concerning energy and day lighting issues. Selecting the location in BIM application is easy by knowing the latitude and longitude of where the project will be built. After that, we can view different solar studies of different orientations and rotations of the model in the site. This helps in site selection, orienting the building on site, and design suggestions. Additionally, the BIM model can show us the relation between our building, the site components and surroundings. The decision here is influenced not only by aesthetic relation with the neighborhood but also by the shading and day lighting issues.

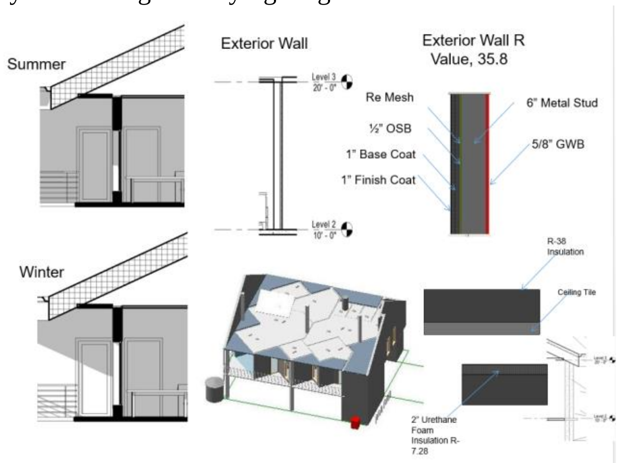

Figure 2. Day lighting, sun shading, and material selection calculation and stimulation for the same office building design using Revit BIM and Opaque 10.

Day lighting analysis does not end with site selection and orientation. It continues to more detailed modeling. We can use the Revitmodel to analyze day lighting in different seasons at our location. We can compare different glazing applications and placements. Figure. 3 shows another example of BIM models and stimulation is for a strip shopping center. The figure shows elevations with materials selection, daylighting and shadings possibilities. Here we were able to get an early feedback of daylighting issue and manage to decide where and which daylighting and shading systems are needed to optimize the design. We can also translate these lighting systems to other soft wares such as Ecotect to compare the different day lighting systems and available luminance for each space. According to this, we can edit the type of system or its design. Many projects use this technology to demonstrate LEED credits for day lighting and views. [Autodek 2005]

Continuing more in design details, BIM is also used in choosing and designing systems applied to the building. As mentioned before, a more developed BIM model can be simulated using energy analysis programs; therefore, we can optimize the energy use by comparing different building envelopes, sun shading, HVAC systems, and day lighting. We can edit in the BIM model sun shading, day lighting, or building envelope systems and translate the different models to an energy analysis program and an estimating program to get a comprehensive comparison between different solutions. Thus, the design decision would be more accurate and effective. In addition, a BIM model can easily provide room information including area, volume, and perimeter. This information is more accessible for the mechanical design. “Traditionally, users of HVAC design and simulation tools have had to manually transcribe information from other sources,” says Vladimir Bazjanac, a researcher at Lawrence Berkeley National Laboratory. “Such transcription and duplication of data often delays productive work and results in numerous errors and omissions.” [Snyder 2006]

Figure 3. Elevations with materials selection, daylighting and shadings possibilities

Furthermore, knowing the amount of energy the building consumes enables the designer to apply renewable energy sources. After calculating the amount of energy produced from different renewable energy resources—such as wind, solar energy, and geothermal energy—we can determine which source is better to apply according to the cost and payback. We can, for example, use the BIM model to determine the roof area available for us to put solar panels to produce the needed energy and the best roof slope and position to optimize solar energy production. Another example is choosing the best location of wind turbines depending on aesthetic and climatic factors.

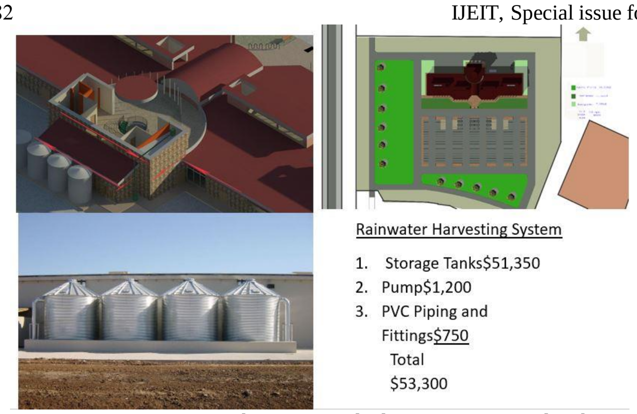

Figure 4. Rainwater harvesting calculations, system, and tanks selections. Here the cost and capacity of the rainwater harvesting system are calculated in the schematic phase.

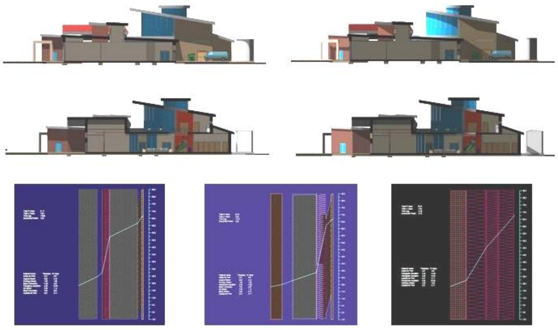

Figure 5. Day lighting, sun shading, and wall and roof materials selection calculation and stimulation for the shopping center using Revit BIM and Opaque 10.

Energy cost			
$/Therm	0.400	0.400	
$/kWh	0.054	0.054	
$/kW	2.470	2.470	
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
Energy use, kBtu	3576404	2327904	-34.91
Energy cost, $	63346	41681	-34.20
Saved by daylighting, kWh	-	45456	
Total Electric, kWh	1048092	682210	-34.91
Internal Lights, kWh	201719	105844	-47.53
External Lights, kWh	45867	34401	-25.00
Heating, kWh	96229	1497	-98.44
Cooling, kWh	277103	178772	-35.49
Fan, kWh	95613	30136	-68.48
Elec. Res. kWh	96229	1497	
Heat Pump, kWh	0	0	
Hot water, kWh	43278	43278	0.00
unregulated/process loads	288281	288281	0.00
Peak Electric, kW	228.3	167.5	-26.61
Fuel			
hw kBtu	0	0	
heat, kBtu	0	0	
total, kBtu	0	0	
Annual Emissions			
CO2, lbs	1408635	916890	-34.91
SO2, lbs	8280	5389	-34.91
NOx, lbs	4297	2797	-34.91
Construction Costs	5513430	5666286	2.77
Life-Cycle Cost	7796866	7155838	-8.22

Figure 6. Energy and cost stimulation before and after applying green strategies for the second model (shopping center) using Energy-10 program. The numbers show the saving in electricity by kwh due to daylighting strategies and the reduction in the total life-cycle cost.

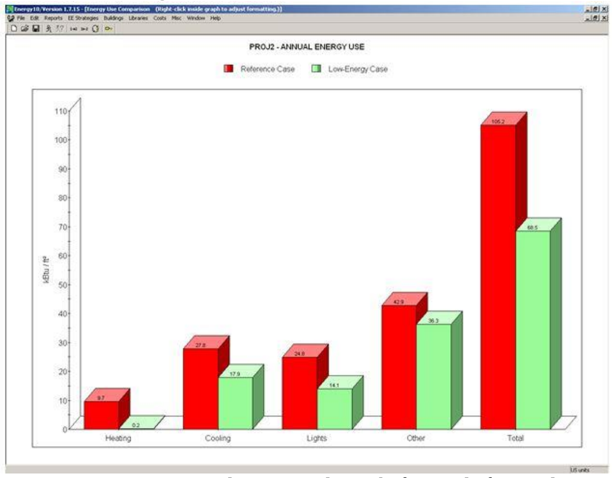

Figure 7. Energy and cost stimulation before and after applying green strategies for the second model (shopping center) using Energy-10 program.

Green systems include also rainwater harvesting and graywater reuse. The BIM model provides us with the area of each roof so that we can calculate how much rain we can get from each roof. We can eliminate the roofs which are not easy to collect rainwater from such as canopies, greenroofs, or terraces. Besides, with BIM it is easier to calculate water use and wastewater. After putting the plumbing fixtures, we can create a simple plumbing schedule with the water flow rate for each. The schedule supplies us with information regarding the amount of water consumed and the amount of wastewater emitted. In addition, it is easier to calculate graywater collected from different fixtures. For instance, we can collect graywater from drinking fountains and lavatories only and reuse it for flushing the toilets. The water collected from other fixtures such as toilets and kitchen sinks could need filtration or could be used for irrigation. Decisions are made according to the amount of water needed, the cost of filtration, and the purity of wastewater collected. Through this, we can save money in filtration and reduce potable water. The number of each fixture provides us the amount of water reduced by using high-efficiency fixtures. By knowing the amount of water needed, amount of graywater reused, and available rainwater harvested, we can calculate the capacity of the collecting tank considering the dry months in month-by-month database.

Material selection is very important in the sustainable design. There are 14 out of 110 points for materials and resources in LEED-NC credits. "Design is not making beauty; beauty emerges from selection, affinities, integration, and love." Because a BIM model is carrying all the material information, the designer can know how much these materials work for his/her design and edit them through different design phases. S/he can know the amount of material needed for the building. Using these quantities, the designer can take decisions concerning recycled, salvaged, and regional materials that could be used. Material selection decisions are made according to the contents, sources, embodied energy, and quantities used for each of them. In addition, the cost is an effective factor that highlights the selection process. As in the methodology of energy use-based comparison, we can compare materials and save both money and time in decision-making process.

Y	N	?			
8	#			**Sustainable Sites**	Possible Points: 26
Y			Prereq 1	Construction Activity Pollution Prevention	
1			Credit 1	Site Selection	1
	5		Credit 2	Development Density and Community Connectivity	5
	1		Credit 3	Brownfield Redevelopment	1
	6		Credit 4.1	Alternative Transportation—Public Transportation Access	6
1			Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Roor	1
1			Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehi	3
2			Credit 4.4	Alternative Transportation—Parking Capacity	2
1			Credit 5.1	Site Development—Protect or Restore Habitat	1
1			Credit 5.2	Site Development—Maximize Open Space	1
	1		Credit 6.1	Stormwater Design—Quantity Control	1
	1		Credit 6.2	Stormwater Design—Quality Control	1
	1		Credit 7.1	Heat Island Effect—Non-roof	1
1			Credit 7.2	Heat Island Effect—Roof	1
	1		Credit 8	Light Pollution Reduction	1
4	6			**Water Efficiency**	Possible Points: 10
Y			Prereq 1	Water Use Reduction—20% Reduction	
2	2		Credit 1	Water Efficient Landscaping	2 to 4
2			Credit 2	Innovative Wastewater Technologies	2
	4		Credit 3	Water Use Reduction	2 to 4
#	#			**Energy and Atmosphere**	Possible Points: 35
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
8	11		Credit 1	Optimize Energy Performance	1 to 19
7			Credit 2	On-Site Renewable Energy	1 to 7
2			Credit 3	Enhanced Commissioning	2
	2		Credit 4	Enhanced Refrigerant Management	2
3			Credit 5	Measurement and Verification	3
2			Credit 6	Green Power	2
7	9			**Materials and Resources**	Possible Points: 14
Y			Prereq 1	Storage and Collection of Recyclables	
	3		Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
	3		Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Element	1
2			Credit 2	Construction Waste Management	1 to 2
	2		Credit 3	Materials Reuse	1 to 2
				Materials and Resources, Continued	
2			Credit 4	Recycled Content	1 to 2
2			Credit 5	Regional Materials	1 to 2
	1		Credit 6	Rapidly Renewable Materials	1
1			Credit 7	Certified Wood	1
8	7			**Indoor Environmental Quality**	Possible Points: 15
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
1			Credit 1	Outdoor Air Delivery Monitoring	1
	1		Credit 2	Increased Ventilation	1
1			Credit 3.1	Construction IAQ Management Plan—During Construction	1
1			Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
1			Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
1			Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
	1		Credit 4.3	Low-Emitting Materials—Flooring Systems	1
1			Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Produc	1
	1		Credit 5	Indoor Chemical and Pollutant Source Control	1
	1		Credit 6.1	Controllability of Systems—Lighting	1
	1		Credit 6.2	Controllability of Systems—Thermal Comfort	1
	1		Credit 7.1	Thermal Comfort—Design	1
	1		Credit 7.2	Thermal Comfort—Verification	1
1			Credit 8.1	Daylight and Views—Daylight	1
1			Credit 8.2	Daylight and Views—Views	1
3	3			**Innovation and Design Process**	Possible Points: 6
1			Credit 1.1	Innovation in Design: Specific Title	1
1			Credit 1.2	Innovation in Design: Specific Title	1
1			Credit 1.3	Innovation in Design: Specific Title	1
	1		Credit 1.4	Innovation in Design: Specific Title	1
	1		Credit 1.5	Innovation in Design: Specific Title	1
	1		Credit 2	LEED Accredited Professional	1
3	1			**Regional Priority Credits**	Possible Points: 4
1			Credit 1.1	Regional Priority: Specific Credit	1
1			Credit 1.2	Regional Priority: Specific Credit	1
1			Credit 1.3	Regional Priority: Specific Credit	1
	1		Credit 1.4	Regional Priority: Specific Credit	1
55	55			**Total**	Possible Points: 110

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

Figure 8. LEED checklist credits for the shopping center by the help of BIM model.

III. AN INTERGRATED TEAM WITH BIM

The evolution in building information has been rapid in the last few years. That led to a more complicated design process. It is impossible today for designers to work without consultants. If we look at the history of building, we find that in the past the architect and the builder were the same person. Today's building has more issues such as: structure, accessibility, controls, electricity, lighting, acoustics, heating, cooling, plumbing, landscape, and security. This makes a large design team. Moreover, the sustainable design team today expands to the owner and the contractor as well. The owner, contractor, and users should be involved in the sustainable design process early along with the architect, engineers, and specialty consultants.

The importance of an integrated design team resides in saving time and money lost in a possible misunderstanding between the team members. Small misleading details could be fatal to one of the green strategies put by the designer as a main aim. For example, the mechanical engineer might design a HVAC system without taking in consideration the building envelope and orientation. That costs extra money and influences the efficiency of the cooling and heating system. As mentioned above, today's design team is larger and more diverse. It is hard to collaborate and exchange information without BIM. A force driving change, BIM introduces an integrated world to the A/E/C profession in which all players are involved from the beginning of the design process. BIM facilitates synergy among a project team as well as the ability to drastically reduce change orders, budget creep, and construction waste [Pezzillo 2009]. What BIM can really offer is an integrated team through all design phases: predesign, schematic design, and final documentation. Each team member can contribute in the same document and get all others' contribution to move toward the next phase with stability and convenience.

IV. FUTURE OF SUSTAINABLE DESIGN WITH BIM

The change from CAD to BIM is what today world needs are. The modern BIM model goes with further information. The 2D/3D CAD is vague and undefined. It does not have any materials specifications. Using BIM with every object has a defined size, specification, and location, thus eliminating many errors that could occur with the undefined CAD model. "The big software trend that we foresee is the shift to BIM where one uses the drawing as a database for the entire life cycle of the building project," says John Jones, vice president, SoftPlan Systems. "BIM will greatly reduce the loss of information that can occur when a project shifts hands from say the designer to the contractor. This will in turn produce greater cost savings for all members of the project and reduction in time to complete the construction project." [All business 2009].

"The best way to predict the future is to create it." BIM can create the future of the building. Without sustainability, there is no future. Sustainability is one of the top priorities of the world building sector. Hence, 35% of architects, engineers, contracts, and owners used BIM on greater than 65% of their projects according to the BIM report authored by McGraw Hill Construction in 2008. This was expected to rise 45% in 2009. According to the McGraw Hill survey, 73% of those users used BIM in green projects [McGraw-Hill Construction, 2010]. BIM allows a quick design tool to analyze energy and water as mentioned before. The future of BIM is somehow related to the future of sustainable design and vice versa. The world today is looking forward to a greener future and more sustainable lifestyle. Some of the fields that most affect sustainability is the building industry, the embodied energy of the materials used in our buildings, the energy we use through the building operation, and the waste our buildings emit through their lifecycle and after being demolished. Many projects encourage green buildings such as Architecture 2030 program. Because BIM contributes much in the green design, it is spreading fast with the sustainable movement.

Under the framework of the BIM-SPEED EU funded project, an EU-wide survey on BIM adoption and use by European SMEs was conducted between October and December 2020. The survey was filled in by 269 respondents from 24 European countries. A summary of the key takeaways is:

- BIM usage has been increasing steadily, with higher adoption rates observed after 2016
- 40% of the responders were involved in BIM renovation projects
- Competitiveness and sustainability are the main external motivations for using BIM
- Lack of skills and awareness are the main barriers for BIM adoption by SMEs
- Personal networks and conferences are key drivers for innovation adoption
- Only 3,8% of the respondents claim that they are on track to use the full potential of BIM [Pridmore 2020].

As "Figure. 9," shows the increase in the implementation of BIM in the last 10 years as the BIM-SPEED T.8.4 survey results states.

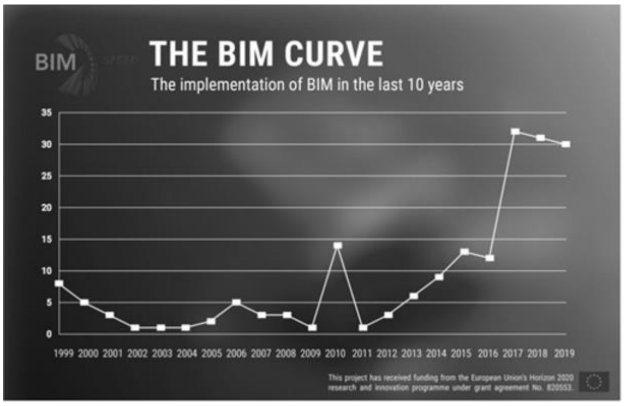

Figure 9. An EU-wide survey on BIM adoption and use by European SMEs was conducted between October and December 2020. The survey was filled in by 269 respondents from 24 European countries. Source: BIM-SPEED T.8.4 survey results, 2020

In spite of all the tools BIM offers today to sustainable design, BIM users are expecting more. For instance, a BIM model in the future might be able to calculate the amount for rainwater harvested by entering the location, roof design, and plumbing fixtures inputs.

V. CONCLUSIONAND AND RECOMMENDATIONS

BIM makes the green decision-making process more effective and time efficient. It begins from the predesign with building massing decision, site selection, and orientation. It continues with the day lighting, and sun shading analyses. The BIM model can be easily translated to an energy model. It provides us with handy information used in calculating rainwater harvesting, wastewater strategies, renewable energy sources, and selecting materials. It is easy to get an estimate and schedule early or late in the design. The BIM model can carry more than one type of information. At the end of the project, the model will be a collaboration of different inputs - the designer, the engineers, and the contractor. The BIM model is a live example of an integrated team. BIM is rapidly spreading. It is expected to spread more. Architects, engineers, owners, and contractors are expecting from the BIM model to offer them more tools to ease communicating and analysis.

In addition, there must be a shared vision and team management to implement the applications of BIM which then positively impacts the design process in which the design becomes sustainable. It is a recommended approach that the design be created with all trades involved in the project with collaboration and consultation. Companies should begin using the software on a simple or low-risk project [Abaz et al.]. Architects and contractors should collaborate with greater efficiency and interpret the project more accurately [(Brady Schimpf, 2010].

Designers can begin to offer new services that can be grouped into two broad areas:

- Concept design development:

Performance-based design using analysis applications and simulation tools to address: sustainability, energy efficiency, cost and value analysis during design, programmatic assessment using simulation of operations, such as in healthcare facilities.

- Integrating design with construction:

Improved collaboration with the project team: structural, mechanical, electrical engineers, steel, MEP, precast and curtainwall fabricators. BIM use among a project team improves design review feedback, reduces errors, lowers contingency issues, and leads to faster construction. Expedited construction, facilitating off site fabrication of assemblies, and reducing field work. Automation in acquisition, fabrication and assembly and early acquisition of long lead-time items.

Moreover, design firms can offer other services in a BIM-driven construction environment, including:

- Calculate estimated facility operating costs (energy units) for final design, or on a release-by-release basis.
- Prepare models appropriate for code reviews by authorities offering BIM enabled code review.
- Provide model management services for the contractor so that the model can be used for acquisition, scheduling and other services of the contractor's choosing.
- Coordinate fabrication level systems for spatial configuration.
- Provide geometric detail information for computer numerical control fabrication of specific subsystems.
- Prepare performance metrics for building commissioning.
- Provide detailed as-built information models for facility management and operations. [Eastman et al. 2006]

The two presented examples show that the use of BIM (Building Information Modeling) is an effective tool for the integration in architectural design, sustainable strategies, and cost estimation. Digital models of both the office and the strip shopping center gave the opportunity for energy efficiency project coordination, in accordance with the principles of green design using LEED credentials. It is essential to combine the designs and the constructions of green technology, thus making a design more reasonable and optimized, and finally achieving the accordance with green buildings

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