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A FACILITY MANAGEMENT APPROACH TO REDUCING ENERGY AND CARBON FOOTPRINT OF BUILT FACILITIES

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ABSTRACT

Purpose: The main purpose of this paper is to emphasize the importance of a life cycle approach and the role of facilities management practices in reducing the environmental footprint of built facilities. An approach to holistic life cycle energy and carbon reduction is also proposed.

State of the Art: Built facilities consume over 40% of global energy annually resulting in over 33% of world's total carbon emission. According to literature, for a significant reduction in energy use and resulting carbon emissions, it is critical that both the embodied and operating energy use of a facility is optimized.

Approach: A literature-based discovery approach was applied to collect, analyze, and synthesize the results of published case studies from around the globe. The energy use results of 158 published case studies were analyzed to derive conclusions.

Results: A comparison of energy efficient and conventional facilities revealed that decreasing operating energy may increase the embodied energy components. Additionally, the analysis of 95 commercial facilities indicated that nearly 10% of the total U.S. carbon emissions was influenced by facilities management practices.

Practical Implications: The proposed approach to holistic environmental footprint reduction can guide facility management research and practice to make meaningful contributions to our efforts for creating a sustainable built environment.

Research Limitations: The results were derived from case studies that belonged to various locations across the globe and included facilities constructed with a variety of materials.

Originality/Value: This paper quantifies the extent to which a facilities management professional can contribute to the global efforts of reducing carbon emission.

Keywords: Facility Management, Embodied energy, Recurring energy, Carbon emission

1 INTRODUCTION

Looking at the current environmental conditions and the amount of resource use, we may not be able to completely avert the global warming, no matter in what amount we now try to reduce the carbon emission (Hacker et al., 2008). The major cause of Earth's warming is anthropogenic greenhouse gas emission, particularly the emission of carbon dioxide, methane, and nitrous oxide (Hacker et al., 2008; USEPA, 2011). Nearly 95% of the total global carbon emissions can be attributed to fossil fuel combustion as a result of electricity production, transportation, residential and commercial operations, and the manufacturing industry (USEPA, 2011). A majority of carbon dioxide emission is the result of consuming energy sources such as electricity, petroleum, natural gas, and coal, but according to the U.S. Greenhouse Gas Emission Report (USEPA, 2011), the electricity generation alone was responsible for nearly 42% of the total U.S. carbon dioxide emissions in 2009.

The building sector consumes over 40% of global energy annually in the construction, use, maintenance, and the demolition of buildings (Dixit et al., 2012a). Both the primary (e.g., coal, petroleum) and delivered energy (e.g., electricity, gasoline, and natural gas) are used directly or indirectly (Marszal et al., 2010; Dixit et al., 2013). The total life cycle energy (LCE) consumed by a facility is made of two components: life cycle embodied energy (LCEE) and operating energy (OE). The relative proportion of embodied and operating energy in a facility's life cycle has been debated in the literature (Dixit et al., 2012a). However, the literature agrees on the fact that, for a significant reduction in energy use and resulting carbon emissions, the consumption of both the embodied and operating energy needs to be reduced (Brown and Pit, 2001; Elmualim et al., 2010). Facilities management practices can significantly impact the energy and environmental footprint of a facility (Jensen and Neilsen, 2008; Elmualim et al., 2010; Dixit et al., 2014). For instance, decisions regarding facility maintenance, replacement, renovation, capital renewal, retrofit, and demolition can affect the total LCEE and OE (Dixit et al., 2014; Elmualim et al., 2010). Issues of human comfort, user satisfaction, and operating costs relate to the life cycle operating energy, which is one of the major domains of facilities management (Jensen and Neilsen, 2008; Elmualim et al., 2010).

The main purpose of this paper is to highlight the importance of adopting a life cycle perspective for evaluating an energy-efficient and carbon neutral building. In addition, the impact of facility management practices in reducing the life cycle carbon footprint of built facilities is emphasized. We also examine the case studies of energy efficient facilities to investigate the savings of LCEE and OE over facilities' life cycle.

2 STATE OF THE ART

2.1 Carbon Emission from Built Facilities

The building sector is responsible for 33% of the total annual carbon emission of the world (Marszal et al., 2010). In the United States, building stocks alone cause 39% of the total annual carbon dioxide emission (USEPA, 2009). According to Levermore (2008), the commercial building-related carbon emission grew by 2.2% annually across the globe between 1971 and 2002. By the end of 2030, building-related carbon emission would increase by 72% from its 2002 levels, projections state.

Most of the carbon emission originates from electricity and primary energy use. The 2002 Economic Census (USCB, 2005) reported a 130% rise in electricity use and 23% in natural gas use by the U.S. construction industry between 2002 and 2007. As reported by the 2011 Annual Energy Review (USDOE, 2012a), over 40% of the total United States' energy supply was consumed by the residential and commercial sector. A majority of this energy supply (more than 80%) came from the fossil fuel-based sources. Because the electric power sector still remains the biggest contributor to the nation's total carbon dioxide emissions (33-34%), any increase in electrical demand would raise carbon emissions proportionally (USEPA, 2013). For instance, in 2006, a 2.5% increase in electricity demand resulted in a 3% increase in carbon dioxide emissions from the electric power sector (USDOE, 2008).

2.2 Energy Consumption Model for Built Facilities

Built facilities use both the primary and delivered energy in their life cycle stages of production, operation, maintenance, and demolition (Dixit et al., 2010). The total energy consumed in constructing a facility is known as initial embodied energy (IEE) (Vukotic et al., 2010; Dixit et al., 2013). This energy is embedded in products (e.g., materials, assemblies, and equipment) and processes (e.g., construction, transportation, and administration) used in the construction of the facility. When the facility is occupied and used, products and processes are consumed in the activities of maintenance, replacement, and retrofit. The energy embodied in these products and processes is known as recurrent embodied energy (REE) (Vukotic et al., 2010; Dixit et al., 2013). When the facility is demolished and its materials are sorted for recycling, reuse, or disposal, the energy consumed in such activities is called demolition energy (DE). The sum of IEE, REE, and DE is termed the life cycle embodied energy (LCEE). The fraction of life cycle energy used in operating a facility in the processes of air-conditioning, heating, lighting, and powering facility's appliances is known as operating energy (OE) (Vukotic et al., 2010). The sum of total LCEE and OE is termed the total life cycle energy (LCE). According to literature, for a significant reduction in the environmental footprint of built facilities, a life cycle energy and carbon accounting is important that takes into account both the LCEE and OE (Aste et al., 2010).

The percentage of embodied energy in a building's life cycle depends upon the building's location, climate, and fuel sources used (Nebel et al., 2011). Low-energy buildings have a relatively higher fraction of life cycle energy use as embodied energy than the conventional buildings. This is due to the fact that low energy buildings consume less operating energy and may contain building materials such as insulation that hold higher embodied energy.

2.3 Facility Management and Life Cycle Environmental Analysis

The field of facility management affects all three dimensions of sustainability: economics (life cycle cost), environment (energy and emissions), and society (user satisfaction and productivity) (Ashford, 2004). The consumption of resources, particularly during the use phase of a facility, such as building materials, energy sources, water, and labor, mainly depends on a facility manager's maintenance and replacement planning and scheduling (Brown and Pit, 2001; Elmualim et al., 2010). Building systems such as HVAC, hot water, lighting, and building appliances consume a significant amount of energy that can be decreased by effective facility management. In a study of educational facilities, Cash and Twiford (2009) found that a typical school in the United States consumed nearly 55% of its annual energy on space conditioning and 30% on lighting. This means that approximately 85% of the total annual energy use was under the control of a facility manager. Energy consumption, pollution, and resource consumption are the primary aspects of environmental efficiency that connect facility management to sustainability (Brown and Pitt, 2001). For creating a truly energy efficient built facility, both the embodied and operating energy should be optimized (Brown and Pitt, 2001; Elmualim et al., 2010).

3 APPROACH

The main goal of this paper is to emphasize the importance of a life cycle perspective when evaluating a facility for energy efficiency and carbon emission. Due to a focus on a facility's life cycle, the paper also highlights the importance of facility management practices in reducing the life cycle energy and carbon impacts of constructing, operating, maintaining, and demolishing facilities. This goal can be achieved by the following objectives:

- Investigate the OE and LCEE savings of energy efficient facilities
- Quantify relative share of LCEE and OE in the total LCE of commercial facilities
- Determine the extent to which facility management practices influence the LCEE and OE

A "Literature Based Discovery (LBD)" method was applied that derives conclusions from the review of published data. Although LBD was originally established to be used for bio-medical science research, it has been successfully applied to other disciplines also (Weeber et al., 2001; Dixit et al., 2010). A rigorous survey of literature was performed to select only studies which calculated the LCE including the three major components, IEE, REE, and OE. A total of 158 residential and commercial case studies were referred from across the globe (see Table1).

Table 1: List of the referred case studies

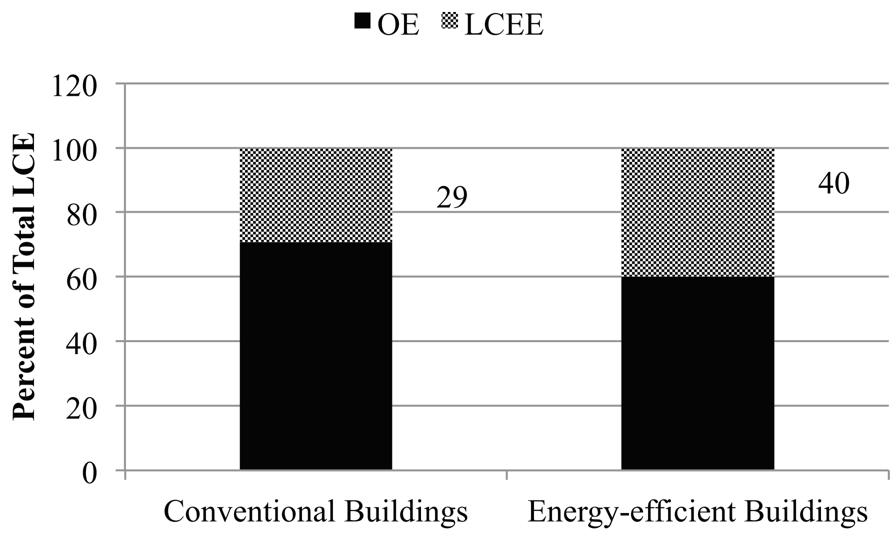
Study	Location	Study	Location
Treloar, 1993	Australia	Thormark, 2002	Sweden
Barnes and Rankin, 1995	United Kingdom	Citherlet and Hand, 2002	Switzerland
Cole and Kernan, 1996	Canada	Scheuer, 2003	United States
Kernan, 1996	Canada	Lippke et al., 2004	United States
Jaques, 1996	New Zealand	Winistorfer et al., 2005	United States
Adalberth, 1997	Sweden	Randolph et al., 2006	Australia
Kohler et al., 1997	Switzerland	Thormark, 2006	Sweden
Blanchard and Reppe, 1998	United States	Junnila et al., 2006	Finland
Fay and Treloar, 1998	Australia	Page, 2006	New Zealand
Eaton et al., 1998	United Kingdom	Thormark, 2007	Sweden
Suzuki and Oka, 1998	Japan	Citherlet and Defaux, 2007	Switzerland
Newton et al., 2000	Australia	Ding, 2007	Australia
Fay et al., 2000a	Australia	Langston and Langston, 2007	Australia
Fay et al., 2000b	Australia	Fernandez, 2008	New Zealand
Pullen, 2000	Australia	John et al., 2009	New Zealand
Johnstone et al., 2001	New Zealand	Shen, 2010	China
Treloar et al., 2001	Australia	Leckner and Zmeureanu, 2011	Canada

As some of the studies included apartments and houses, only commercial facilities (95 case studies) were included for investigating the significance of facilities management in reducing the environmental footprint. The case studies were categorized as energy-efficient and conventional buildings on the basis of definitions given by the referred studies. Because the amount of the total REE and OE depends on the service life of a facility, the embodied energy results are presented in annual mega joules per unit area (MJ/m^2-year). To calculate the amount of carbon emission resulting from fossil fuel consumption, an average value of carbon dioxide emission coefficient was calculated using the values provided by the Energy Information Administration website (USEIA, 2013). It was assumed that the energy values are reported in primary energy units.

4 RESULTS

An analysis of the results of referred energy efficient and conventional buildings revealed that optimizing a facility's life cycle OE could mean an increase in its LCEE. Figure 1 shows the fraction of OE and LCEE in the average value of the total LCE of energy efficient and conventional buildings. As seen in Figure1, the fraction of LCEE increased in the case of energy efficient buildings due to a decrease in OE; however, even though the OE was reduced, this was at the cost of LCEE. Table 2 lists the values of OE and LCE of some of the case studies for base case (cells marked with grey shades) and energy efficient case. The fact that reducing OE could significantly increase a facility's LCEE highlight the significance of a whole life cycle energy accounting in designing and evaluating energy efficient facilities.

Figure 1: LCEE and OE fraction in the total LCE of referred case studies



Based on the results reported by the referred case studies of commercial facilities, the average value of the total annual LCE is calculated as 1222.26 MJ/m^2-year. The reported values of LCE range from 200-2841.71 MJ/m^2-year. The fraction of the total LCEE and OE in the total LCE is found as 76.6% (285.60 MJ/m^2-year) and 23.4% (936.66 MJ/m^2-year), respectively. Figure 2 illustrates the various life cycle energy components as reported by the referred case studies. As seen in Figure 2, the embodied energy components such as IEE, REE, and DE account for up to 11.45%, 11.86%, and 0.06% of the total LCE, respectively.

Table 2: Increase in LCEE due to energy efficient measures

Study	OE (GJ/m^2)	LCEE (GJ/m^2)	LCE (GJ/m^2)	% LCEE Increase Over Base Case
Feist, 1996	9.5	4.37	13.87	0.00%
Feist, 1996	4.32	5.01	9.33	14.65%
Feist, 1996	0	9.91	9.91	126.77%
Winther and Hestnes, 1999	23.7	2	25.7	0.00%
Winther and Hestnes, 1999	11.4	4.5	15.9	125.00%
Karlsson and Moshfegh, 2007	25.56	5.08	30.64	0.00%
Karlsson and Moshfegh, 2007	11.25	7.03	18.28	38.39%

Figure 2: Average values of embodied and operating energy components

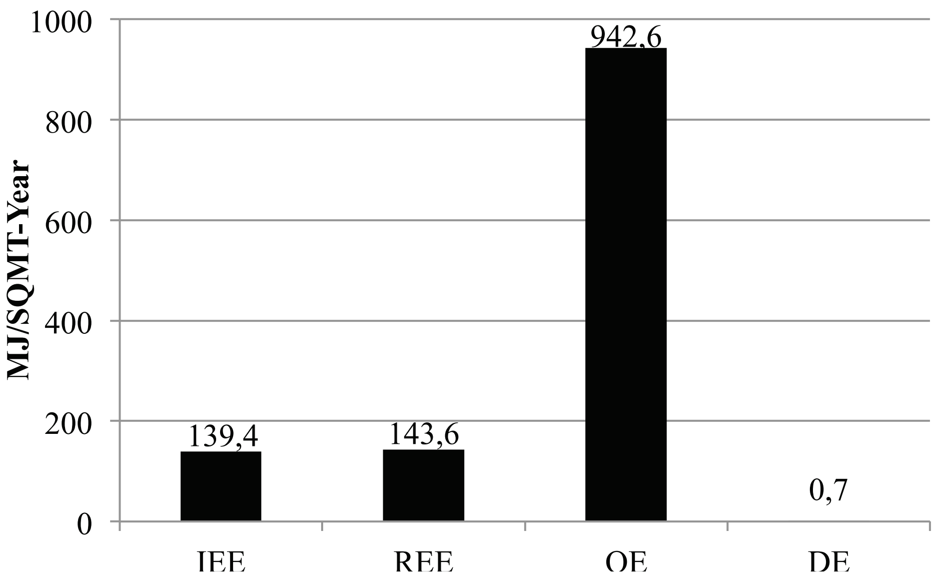
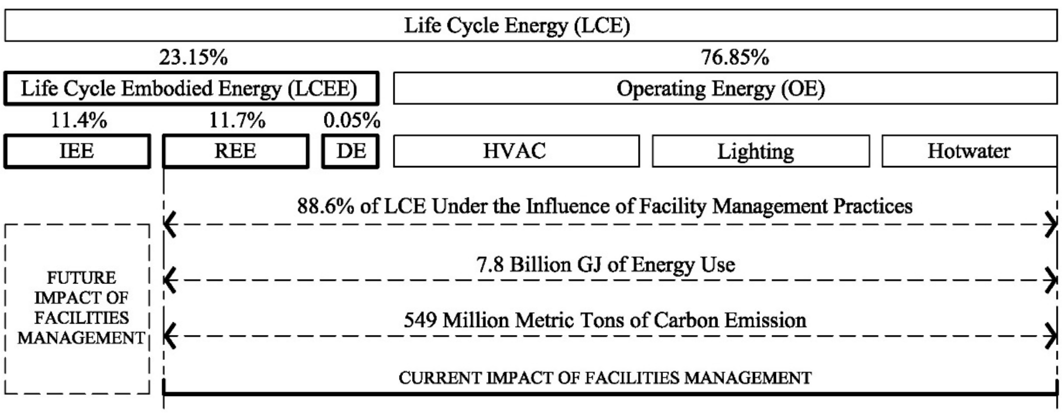


Figure 3 illustrates the impact of facilities management on the life cycle energy components.

Figure 3: Influence of facilities management over the environmental footprint of facilities



As shown in Figure 3, the facilities management practices related to a facility's operation and maintenance could impact at least 88.6% (sum of OE, REE, and DE) of the total LCE. If facility managers are involved in the pre-design, design, and construction phases, their decisions about material and product selection may impact more than 90% of the LCE. Since the values of various LCE components are calculated per unit area, the total commercial floor space can be used to quantify the total energy and environmental impacts at a national level. The Building Energy Data Book (USDOE, 2012b) reported a total commercial floor area of 81.1 billion ft^2 in the United States for year 2010. Furthermore, it was projected to reach 103 billion ft^2 by the end of 2035. Considering the total commercial floor space in 2010, 88.6% of the total LCE would represent approximately 8.2 billion gigajoules (7.8 quadrillion Btu) of primary energy. This energy use would be nearly 10% of the total national fossil fuel consumption in 2010. Using the average carbon dioxide emission coefficient (70.7 kg per million Btu) from the USDOE website, this energy use could result in approximately 549 million metric tons of carbon dioxide released to the atmosphere. According to the Building Energy Data Book (USDOE, 2012b), by the end of 2035, this energy use and resulting carbon dioxide emission would reach approximately 10.4 billion gigajoules and 698 million metric tons, respectively.

Decisions such as physical repair and selection of products for a facility's maintenance and replacement activities significantly affect its REE and OE. In terms of the environmental impacts, such decisions could influence up to 550 million metric tons of carbon emissions. According to the 2011 Annual Energy Review, the total amount of carbon dioxide emitted as a result of energy-related use in 2010 was approximately 5.6 billion metric ton; therefore, nearly 10% of the total national carbon dioxide emission could be influenced by facilities management practices of commercial buildings. If residential buildings were included, this percentage could increase significantly.

5 PRACTICAL IMPLICATIONS

The results of this study indicate the importance of facilities management professionals in creating an energy efficient and carbon neutral built environment. For a comprehensive reduction in the environmental footprint of buildings, both the embodied and operating energy needs to be reduced. The practical implications of this study are manifold.

First, the research findings could encourage facility management professionals to adopt a whole life cycle-based approach while selecting a low energy building material or equipment. Because the amount of REE significantly influences a facility's total LCEE, selecting durable and recyclable materials with low embodied energy, long service life, and low maintenance requirements can significantly reduce its environmental footprint. Similarly, since the embodied energy is greatly impacted by transportation modes and distances, using locally available resources, a facility manager can help reduce the overall LCEE. According to Thormark (2006), approximately 17% of the total LCEE can be optimized by making such environmental choices of building materials. As seen in Table 3, significant amount of REE can be saved if number of replacements over a facility's service life is reduced.

Table 3: REE of each replacement (Based on Pullen, 2000; Junnila et al., 2006; Jaques, 1996)

Replacement Item	REE (GJ/Replacement)	Replacement Item	REE (GJ/Replacement)
Painting	787-5320	Carpet	1564-4573
Roof Cladding	5050	Retile PVC Floor/Vinyl	740-2362
Doors and fitments	2920	Services (50%)	14115

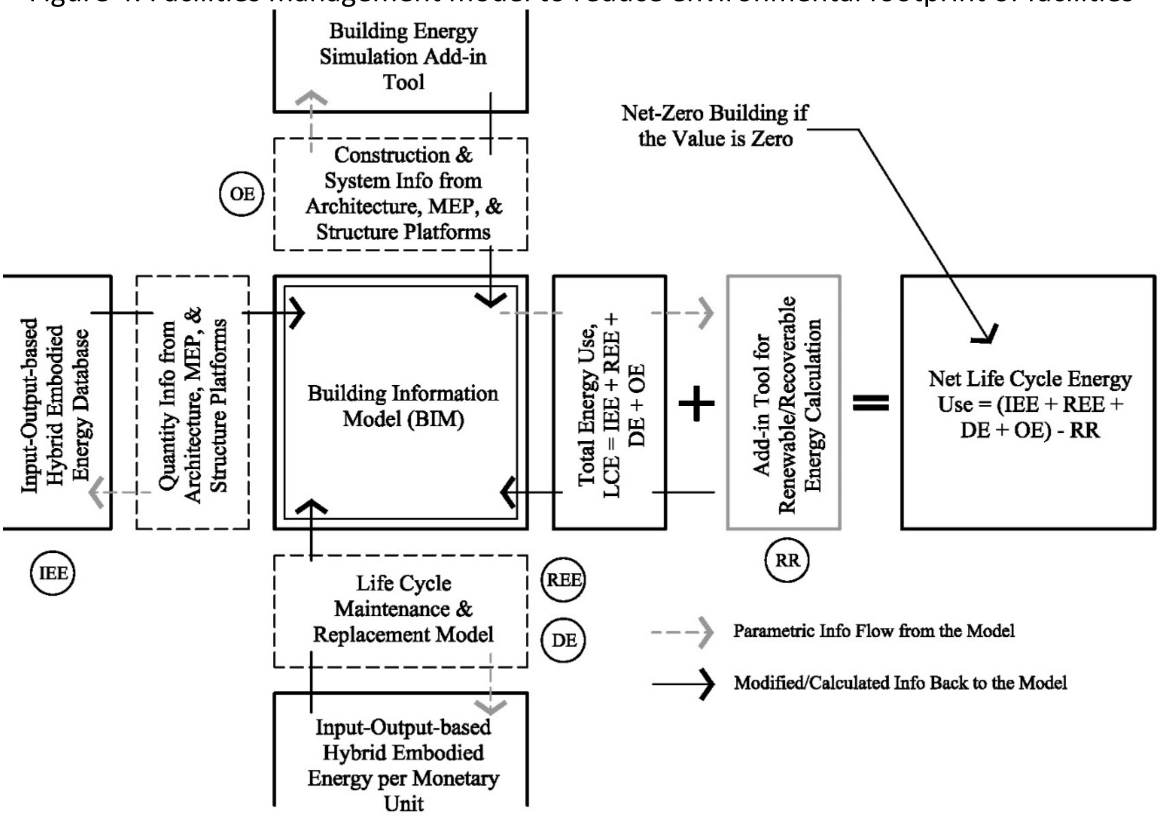
Second, since facility managers are responsible for building system operation and maintenance, a significant reduction in OE use can be achieved using strategies such as daylighting, retro-commissioning, and continuous commissioning. For instance, according to Claridge et al. (2009), by using the process of continuous commissioning, approximately 24% of the energy cost of a facility's HVAC system can be saved. By upgrading technologies and operators' skills, facility managers can reduce facility energy use (Jensen and Nielsen, 2008).

Third, selecting durable materials and equipment with low maintenance and replacement requirements could also generate monetary savings making the facility economically sustainable. Fourth, with a life cycle-based approach, informed decisions could be made on whether to renovate or demolish and reconstruct a particular facility. Finally, this study underscores the importance of involving facility management professionals in the early design stages, because design decisions affect most of the energy and environmental footprint of a building. If a facility management professional is involved during a facility's design and construction phases, durable and recyclable materials, assemblies, and equipment with low environmental impacts and long service life could be selected. Involving facility managers would also ensure selecting materials suitable for a particular building function.

5.1 Model to Reduce Environmental Footprint of Built Facilities

The findings of this study indicate a need to establish a system that helps evaluate a facility's environmental performance over its life cycle. We recommend developing tools and databases and integrating them to a technology such as Building Information Modeling or BIM widely accepted by facility design, construction, and management professionals. Figure 4 illustrates a model that can be applied to a BIM platform (e.g. Revit Architecture) for a life cycle energy and carbon evaluation.

Figure 4: Facilities management model to reduce environmental footprint of facilities



As seen in Figure 4, three add-in tools can be integrated into a BIM platform. The first tool extracts the material, equipment, and climate information from BIM to evaluate a facility's operating energy performance. Such efforts to integrate thermal load simulation are already underway (e.g. Yan et al., 2013). Second tool uses the life cycle embodied energy database of building materials, assemblies, products (e.g. furniture), and equipment to quantify the life cycle embodied impacts of initial construction using the material quantities from BIM. To quantify the REE, a life cycle cost model can be connected to BIM. For calculating the renewable energy generation, a separate application can be developed as explained by Dixit et al. (2012b). This model can facilitate the development of a single, user-friendly, and widely accepted tool to facility designers, constructors, and managers for calculating, analyzing, and reducing the life cycle energy and environmental impacts of a facility.

6 CONCLUSIONS

The results of referred case studies revealed that designing an energy efficient facility by only reducing its OE may not be the optimum solution to the skyrocketing carbon emissions from the building sector. An energy efficient facility should be designed based on a holistic energy accounting of the initial energy spent in its design and construction (embodied energy); the energy consumed in operating, maintaining, and renovating the facility; and the amount of renewable energy it can generate over its life cycle. Based on the net energy consumed or generated, the facility can be labeled energy efficient or energy independent. A review of commercial facilities concluded that the field of facility management could impact up to 89% of a facility's operating and embodied energy use. This is significant, for it represents up to 10% of the United States' annual carbon emission.

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