BIM and Lean-Business Process Reengineering for Energy Management Optimization of Existing Building Stock

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Abstract

Global warming and energy shortage has drastically increased the necessity to reduce energy use in buildings. Improving the energy efficiency of buildings is a key step-in achieving the energy and CO_2 emission targets globally. In this effort, in the presented paper, advanced modeling methods like BIM and energy simulations are conjoined with lean waste elimination concepts into a building process-centric model. Integrating building systems, processes and energy data supports decision making for retrofitting and process reengineering actions within budget constraints. The proposed approach combines existing BIM-based energy performance tools with the development of a Business Process Reengineering architecture to develop an energy efficiency optimization model. In the first direction, BIM-based energy analysis is performed to automatically assess energy performance under varying building conditions. The Lean Business Process Reengineering (LBPR) architecture describes the fundamental layers needed to achieve more energy efficient organizational environments. These layers refer to “Definition”, “Data Information”, “Analysis” and “Therapy”. As Process Performance Indicators are also augmented to the process model, the impacts of modifications through generating different process views can be compared. An optimization model employing genetic algorithms is developed in which, considering the potential budget shortage for building asset interventions, preselected lean business process scenarios feed the optimization model to investigate the optimum solutions. A pilot case that shows the practicability of the proposed methodology is presented.

Keywords

BIM • Lean • Process • Energy • Optimization

85.1 Introduction

Energy Efficiency is a key component of the European energy policy underlying the fundamental objectives of the European Union’s (EU) 2020 strategy. Buildings are a major constituent of the urban ecosystem accounting for almost 40% of the overall energy demand in Europe [1]. Several studies on energy efficiency in buildings indicate that appropriate design improvements, supported by building energy performance simulation software, could reduce energy use in both existing and in new building envelopes [2, 3]. Building energy performance can be more accurately analyzed by taking into account both descriptive data of the building (structural characteristics, equipment) and information related to building user operation. Focusing on both, design and retrofitting phase, this paper presents a framework that captures the organizational processes

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underlying the building operations, attempting to deliver a holistic building performance simulation framework. The proposed framework can be considered as a further extension of BIM utilization in the domain of commercial premises, towards incorporating business process modeling (BPM) elements regarding organizational structure and respective business processes performed by its occupants. Alternative energy efficient building designs are extracted based on optimization and balancing of typically conflicting building performance aspects, namely energy efficiency and business performance taking into account the information from the real building usage by the occupants.

85.2 Related Work

Significant research efforts focus on BIM-based assessment of building energy performance at earlier stages of building projects but only a few papers report on research using BIM for energy efficient building operation. Costa et al. [4] consider BIM as a structure for visualizing measurements and building performance datasets. In Wong and Zhou [5], the authors review a number of studies addressing “environmental sustainability over building life cycles through green BIM” and identify that BIM used in operation and maintenance (OM) should provide efficiency, improve the quality of service to customers, reduce emergencies in OM, improve safety, and reduce resource waste. Gokce et al. [6] develop a continuous assessment process by combining the data from different sources and phases in a single data repository centered on building BIM spaces. However, Reeves et al. [7] highlight a limitation in using BIM (associated with the building energy model (BEM)) for monitoring the building performance in operation which is its “inability to simulate building performance under realistic conditions”.

Recently, there is an increasing emphasis on delivering simulation tools and methods that improve the prediction of the building energy use by analyzing also the performance in connection with the building space utilization by its occupants [8]. A comprehensive occupancy model was proposed by Zimmerman [9] for the aim of improving the building control system (lighting, heating and cooling system), which investigated the modeling of user activities over time considering user groups, their roles in functional units and the tasks that they may perform. In another study, Tabak [10] categorized activities in three different ways depending on (i) the nature of the activity (social, physiological or business related); (ii) the number of occupants involved resulting in solo or group activities, and (iii) the type of the activity, such as planned or unplanned.

In this paper, two main contributions are provided: ((i) a BIM-oriented methodology is presented for supporting building energy optimization, based on which directions with regards to lean business process reengineering and to the aim of minimizing process energy wastage are identified, and (ii) an application use case to demonstrate the feasibility of the proposed framework is provided.

85.3 Methodology

The proposed approach combines existing BIM-based energy performance tools with the development of a Lean Business Process Reengineering architecture to develop an energy management optimization model.

85.3.1 BIM Energy Analysis

In the first direction, BIM-based energy performance analysis of buildings is performed employing advanced and interoperable (gbXML files) simulation techniques. Energy simulation involves cloud-based tools to automatically assess energy requirements and performance under varying building conditions. Building element characteristics are then altered to obtain instant feedback on performance impacts. This task is aimed at defining asset retrofitting actions that can potentially be executed to improve the global performance of the buildings. Retrofit actions may refer to construction or mechanical systems, building heating or cooling equipment, appliance replacement, and lighting fixtures.

85.3.2 Lean Business Process Reengineering for Energy Efficiency

The Lean Business Process Reengineering (LBPR) architecture describes the fundamental layers needed to achieve energy efficient organizational environments. These layers include the "Definition", "Data Information", "Analysis" and "Therapy" ones.

Definition Layer: The first layer "Definition" is used to identify and define appropriate KEIs (Key Energy Indicators) [11] which reflect measurable attributes that characterize the building energy performance with respect to its demand for power and electricity consumed (heating, cooling and lighting) and PPI (Process Performance Indicators) describing Business Performance aspects, e.g. total execution time of a business process, total activity time per room, etc.

Data Information layer: In this layer, the measurement of KEIs is performed and linked to the corresponding activities and processes. For the calculation of energy consumption referring to the whole business process, we need to collect the necessary data of each process activity. This layer is responsible for collecting energy use data from WSN devices. This data stream is captured automatically, appropriately processed and analyzed, addressing specific types of loads/sensors including:

(a) ubiquitous loads, like HVAC and lighting, triggered by business processes,
(b) office equipment loads directly linked and supporting the execution of everyday business activities, and
(c) environmental sensors, which capture context conditions (luminance, temperature & humidity) within premises.

Analysis layer: For the "Analysis" layer, 'process views' [12] that enable a proper visualization of the process model are developed with the use of BPMN 2.0 software. By means of augmenting the process model with energy information from the previous layer, virtual views of a process are built and the KEIs of the complete process or specific activities of interest are identified and visualized. This enables analyzing the current energy impact of a process model by identifying the main cause of KEI deviations. Based on the 'process views', Lean metrics are combined with the energy data to determine non-adding value activities of the process in order to reduce or eliminate such activities in favor of adding value activities for minimizing energy wastage. As PPIs are also augmented to the process model, the impacts of modifications through generating different process views can be compared [13]. A first step when detecting a KEI violation is that the given process model needs to be augmented with related data (Fig. SM1 in supplementary material, left). The augmented process model now contains all relevant information about the PPIs and KEIs to proceed with the next step, in which activities with the highest amount of energy are reengineered. First, we use a visual transformation that omits all activities where the augmented energy consumption is below their dedicated threshold Xn. As a next step, we additionally omit all activities that cannot be changed and alter the color and/or the size of the process view depending on their augmented energy consumption data (Fig. SM1 in supplementary material, right).

Therapy layer: Several Business Process Reengineering techniques are feasible to improve the KEIs of the observed process. These include but are not limited to: (1) New binding of services implementing a process activity, (2) changing the underlying infrastructure which better adapts the process characteristics, (3) changing the flows of a process model, (4) rearranging activities, i.e., add, remove or modify (groups of) activities, or (5) introducing dynamic provisioning of activities. Utilizing these techniques provides a wealth of opportunities for making a business process more sustainable and can therefore be fully applied to our approach.

85.3.3 Building Information Model and Business Process Model Alignment

In BIM model, the hierarchical structure is presented, starting from the building to floor and further space level, in which the association of devices with specific spaces is presented. Following to the BIM related parameters, business processes, associated to specific devices and spaces accordingly (and further to specific users) are presented, within the context of the LBPR model. The overall model is a synthesis of energy uses, business process modeling, and building information modeling, associated with the corresponding KEIs and PPIs (Fig. 85.1).

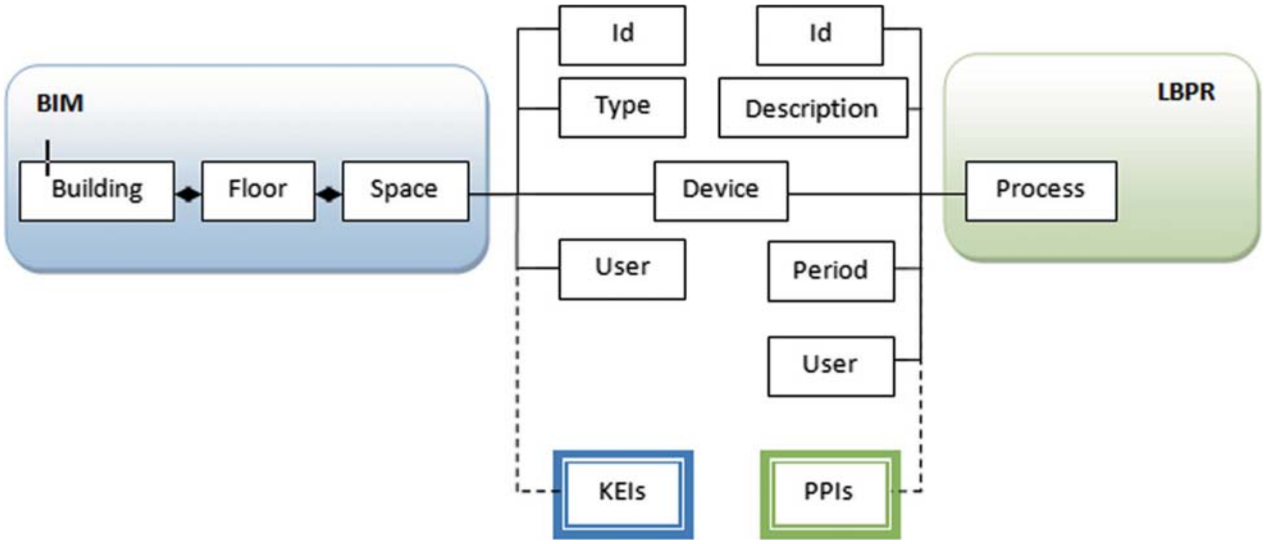

Fig. 85.1 BIM to BPM representation

85.4 Case Study

To illustrate our proposed methodology, we use a motivating example in which a part of the Transportation Lab in Civil Engineering Department, University of Patras, has been selected as the pilot site. More specifically, the place includes the Director office, Researcher office I, Researcher office II, and Meeting room, as shown in the plan view (Fig. SM2 in supplementary material). Six staff persons regularly work in these rooms. A list of pilot specific requirements has been defined to set constraints on the proposed framework.

85.4.1 Building Requirements

The pilot site limitations, either topology limitations or organization limitations, which set the list of requirements for the case study development, are described in Table 85.1. Based on observation of the activities taking place in the building units, there is a potential in managing the plug-in loads in premises but the highest potential is in reengineering activities towards reducing the heat and cooling consumption of ACs. In general, the observation has come up with the following conclusions:

C.1 Continuous usage of lighting devices, is observed leading to high consumption during the day.
C.2 Typical office activities are performed in office premises (typical usage of PCs, printers) with a potential of promptly managing loads during idle mode.
C.3 A/Cs are managed independently by the users.
C.4 Considering thermal and visual preferences, there are no significant complaints from occupants.
C.5 High potential for eliminating vampire loads.
C.6 Highest potential for managing heating/cooling devices in a more efficient way.

85.5 Framework Application

BIM Energy Analysis: The specific building characteristics have been used to develop the BIM model using the Autodesk Revit platform. Based on this model, the Insight software has been used to run energy simulation and calculate current building energy performance (Fig. SM3 in supplementary material).

Table 85.1 Building technical requirements and limitations

Building units	Occupants	Size (m^2)	Facilities	Working hours	Heating/cooling (power cons.)	Lamp power cons. (w/h)	Computers power cons. (w/h)
Director's office	2	18	1 Heating/Cooling AC (12000 btu) 2 windows 6 fluorescent lamps 2 computers 1 Heating/Cooling AC (9000 btu)	Director Tue–Thur: 9:00–12:00 & 15:00–18:00 Finance Manager Mon–Fri:9:00–18:00	A/C 12000 BTUs: 1.333 w/h	58	280
Researcher 1 office	2	12	1 window 2 fluorescent lamps 2 computers 1 Heating/Cooling AC (9000 btu)	Mon–Fri: 9:00–18:00	A/C 9000 BTUs: 900 w/h	58	280
Researcher 2 office	2	18	1 window 3 fluorescent lamps 2 comp ut ers 1 Heating/Cooling AC (24000 btu)	Mon–Fri: 9:00–18:00	A/C 9000 BTUs: 900 w/h	58	280
Meeting room	6	25	2 windows 8 fluorescent lamps	Wedn: 9:00–15:00	A/C 24000 BTUs: 2.800 w/h	58	Laptop–60

Definition Layer: Easily quantified and measured PPIs are selected to give an indication of the building business process performance with respect to energy consumption [14]. The following types of PPIs are taken in consideration in the case study:

Energy Consumption per m2 (EC_A)—this measures building energy consumption (for a specific reporting period, e.g. annual, hourly) related to the total floor space.

Energy Consumption per Business Process (EC_BP)—by addressing also the BPM elements as part of the BIM model, a detailed alignment of energy consumption with main business processes is revealed. Therefore, this indicator defines the cost of energy per business process in premises (measured in kWh).

Business Process Cycle Time (BPCT)—is related to the time period needed to perform a specific process. This indicator is not directly aligned to energy measurement data, but it is linked to the typical time period needed for a process and therefore affects the usage of specific devices within this timeframe (measured in hours).

Data Information Layer: Within this task, a small number of representative low-cost sensors will be deployed in the lab environment and will have connection to a single master, namely gateway, which is the end connection to the proposed system. Information about the activation and use of loads will be captured for remote observation of the on-going activities and under certain conditions.

As this is a step forward to the research, for the purposes of the example, energy capacity metrics of resources used in a business process and affecting the energy consumption will be used.

Analysis layer: The information previously collected provides the basis for analyzing and managing the existing organizational processes by facilitating the identification and localization of vital KEI violations. In order to localize and finally visualize the cause of a KEI violation, we use the concept of process view to reengineer two common energy consuming processes.

Business Process Reengineering 1: 'Weekly Progress Meeting', as it is identified as one of the most energy consuming process of the department. At the initial process condition, this is conducted in the meeting room every Wednesday for a fixed 6 h period time. The lab director and finance manager provide feedback to the researchers for several subjects in a parallel way. This is changed to a sequential communication process, based on themes, where the involved researchers participate and the maximum time period for each one is set to be 0, 5 h/theme (usually between 4 and 6 different themes discussed). Aris Business Process Modeling platform is used to visualize the initial and transformed process (Fig. 85.2a and b respectively).

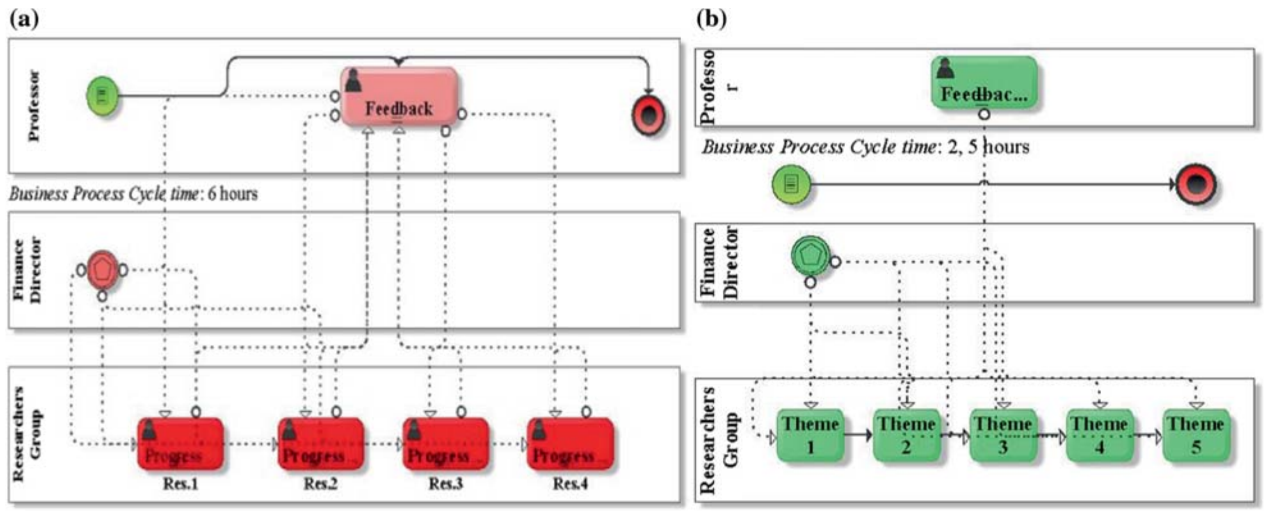

Fig. 85.2 **a** Initial process **b** Transformed process

According to this transformation,

$$\begin{aligned} \text{ECBP1i} &= \text{Energy Consumption} * \text{BP1 CTi} \\ &= (\text{HVAC cons.} + \text{Lighting cons.} + \text{Computer cons.}) * \text{BP1 CTi} \end{aligned}$$

From Table 85.1, the cost savings (from energy savings) for process 1 is:

$$\text{CS1} = 7{,}856\text{kw/h} * (\text{BP1 CTi} - \text{BP1 CTr})\ \text{h} * 0{,}1437\ \text{USD/kwh} \tag{85.1}$$

$$\text{with constraints, BP1 CTi} = 6 \text{ hours } 2\text{hours} < \text{BP1 CTr} < 3\text{hours} \tag{85.2}$$

Business Process Reengineering 2: Every researcher has to give course instructions to undergraduate students. This process currently is conducted in the meeting room by spending every day about 1 h, depending on the number of students asking for instructions. This process is reengineered and the researchers are available to give the instructions every Friday morning through skype from 2 to 3 h.

Accordingly,

$$\text{CS2} = 7{,}856\text{kw/h} * (\text{BP2 CTi - BP2 CTr})\ \text{h} * 0{,}1437\ \text{USD/kwh} \tag{85.3}$$

$$\text{BP2 CTi} = 20 \text{ hours } 8\,\text{hours} < \text{BP2 CTr} < 12\text{hours} \tag{85.4}$$

Therapy layer: At this point, in order to find building renovation scenarios, an evolutionary optimization algorithm is developed. Genetic algorithms, via Palisade Evolver software is implemented for the optimization process due to their robustness in providing efficient and feasible solutions in reasonable computational time. The objective function which evaluates the quality of chromosomes—potential solutions refers to energy cost savings and additional constraints have been set for non-overlapping (choosing between alternative activities) and non- exceeding the available budget. Based on the BIM model, Insight Energy simulation software is used for the development of a set of 25 scenarios that include interventions regarding:

- window glasses (single, double and triple glass) for each window of the different building orientation,
- shading interventions (4 different interventions with different shade sizes),
- lighting (2 scenarios with lamps of lower energy consumption).

The scenario parameters and Eqs. (85.1), (85.2), (85.3) and (85.4) are set as inputs to the optimization model, for the extraction of several retrofitting cases with optimum cost savings. Case examples are described below

Table 85.2 Case 4 results

Asset Interventions	Energy Cost Savings (USD)	Processes	Energy Cost Savings (USD)
Window Glass		Business Pr.Reeng. 1	1174,06
Scenario 1-(G)S-Trp.	653,73	Business Pr.Reeng. 2	3522,19
Scenario 4-(G) E-Trp.	526,85	**Cost Saving**	**4696,25**
Shading		Budget=2000USD	
Scenario 15-(Sh) E-1/3H	294,7	Time Period=5 years	
Scenario 20-(Sh) S-1/6H	500,29	BP1 CTr=2 hours	
Lighting		BP2 CTr=8 hours	
Scenario 25-Lighting 2	1332,69		
Cost Saving	**3308,28/2000**	**Total Cost Savings**	8004,54

Case 1. With an insufficient budget, no asset intervention is qualified and only savings from process reengineering are gained. For maximum BPCT decrease for 3 year period time, the total cost saving is estimated at 2818 USD.

Case 2. With a budget of 1000 USD and the maximum BPCT decrease for 3 years, an average shading and the maximum lighting performance change are qualified, with a total cost saving of 3918 USD.

Case 3. With 2000 USD budget and the maximum BPCT decrease for 3 years, two high window glass changes, a high and a medium shading and a high lighting performance change are qualified, with a total cost saving of 4803 USD.

Case 4. With 2000 USD budget and the maximum BPCT decrease for 5 years, two high window glass changes, a high and a medium shading and a high lighting performance change are qualified, with a total cost saving of 8005 USD (Table 85.2).

Case 5. With unlimited budget in a 5 year period time, without process reengineering, all asset high performance changes are qualified with a total cost saving of 4247 USD.

85.6 Setting Up Future Research

The agenda is organized based on the technical needs of BIM in energy retrofitting projects. The technical needs in the pre-energy analysis phase depend on the availability of a BIM model. If a model is available, it can be used for energy simulations after the necessary updates. If there is no available BIM for the existing building, BIM modelers and architects can build one from scratch which requires a significant data collection effort. Research is already directed to automate the process of capturing as-built information, integrating it into BIM databases, with the use of laser scanners and photogrammetry technologies.

In the energy analysis phase, the interface between BIM platforms and energy simulation software is still complex because of incompatibility in information exchange protocols. Future research may focus on ensuring a smooth information flow from BIM to the selected energy simulation software by creating algorithms to automate rules for the exchange protocols.

The technical needs extend to the retrofitting options phase, where modelers face challenges in choosing the optimal retrofitting scenario, because of uncertainty or volatility in the data. Integrating, for example, energy price variation in the proposed method, it provides a more solid decision making platform for an energy-driven retrofit project. The retrofitting option will be based on these factors as they affect energy costs.

85.7 Conclusions

In this paper, an approach is presented for supporting the energy-aware adaptation and energy waste elimination of business processes in office buildings with energy management being driven by a retrofitting optimization process that takes into account both infrastructure and process activity parameters. The research proposes a four phase conceptual framework (‘Analyze’, ‘Design’, ‘Implement’ and ‘Monitor & Control’) based on Business Process Management and supported by BIM based-energy analysis. It involves several tools (such as Revit, Insight energy simulation, Aris Business Process Modeling platform, Evolver optimization software) adapted to the building energy efficiency analysis and working together as a holistic solution. The paper has also presented a case study to exemplify the use of the conceptual framework, developing a model for office energy consumption of a real building case. The case study results constitute a proof of the proposed framework practicability.

This approach is currently based on the assumption that sensoring and monitored data are available and that the necessary pieces of information regarding the essential metric values are all included in this knowledge base. Taking the research a step further, the sensing and monitoring layer will be developed in the case study area. The model will be enriched with additional Process Performance Indicators while extra infrastructural intervention scenarios will be included in the optimization model. Finally, as thermal comfort of building occupants is a major criterion in evaluating their operation performance and optimizing their energy usage, the research aims to extend its scope towards studying the feasibility of using wearable devices to collect data including location, air temperature, relative humidity, skin temperature, heart rate, and perspiration rate, integrating these metrics into the proposed framework.

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