

**STUDY OF POSSIBLE APPLICATIONS OF CURRENTLY AVAILABLE
BUILDING INFORMATION MODELING TOOLS
FOR THE ANALYSIS OF INITIAL COSTS AND ENERGY COSTS
FOR PERFORMING LIFE CYCLE COST ANALYSIS**

A Thesis

by

PAYAL TAPANDEV MUKHERJI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2010

Major Subject: Construction Management

Study of Possible Applications of Currently Available Building Information Modeling Tools for
the Analysis of Initial Costs and Energy Costs for Performing Life Cycle Cost Analysis

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Approved by:

Co-Chairs of Committee,	Sarel Lavy
	Zofia K. Rybkowski
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ABSTRACT

Study of Possible Applications of Currently Available Building Information Modeling Tools for the Analysis of Initial Costs and Energy Costs for Performing Life Cycle Cost Analysis.

(December 2010)

Payal Tapandev Mukherji, B.E., University of Pune

Co-Chairs of the Advisory Committee: Dr. Sarel Lavy
Dr. Zofia K. Rybkowski

The cost of design, construction and maintenance of facilities is on continual rise. The demand is to construct facilities which have been designed by apply life cycle costing principles. These principles have already given strong decision making power to the manufacturing industry. The need to satisfy the environmental sustainability requirements, improve operational effectiveness of buildings and apply value engineering principles has increased the dependency on life cycle costing analysis. The objective is to obtain economically viable solutions by analyzing the alternatives during the design of a building. Though the LCCA process is able to give the desired results, it does have some problems which have stood as hindrances to the more widespread use of the LCCA concept and method. The literature study has highlighted that the problem areas are the lack of frameworks or mechanisms for collecting and storing data and the complexity of LCCA exercise, which involves the analysis of a thousand of building elements and a number of construction-type options and maintenance activities for each building element at detailed design stages.

Building Information Modeling has been able to repeatedly answer the questions raised by the AEC industry. The aim of this study is to identify the areas where BIM can be effectively applied to the LCCA process and become a part of the workflow. In this study, initially four LCCA case studies are read and evaluated from the point of view of understanding the method in which the life cycle costing principles have been applied. The purpose, the type alternatives examined, the process of analysis, the type of software used and the results are understood. An attempt has been carried out to understand the workflow of the LCCA process.

There is a confidence that Building Information Modeling is capable of handling changes during the design, construction and maintenance phases of the project. Since applying changes to any kind of information of the building during LCC analysis forms the core, it has become necessary to use computer building models for examining these changes. The building modeling softwares are enumerated. The case studies have highlighted that the evaluation of the alternatives are primarily to achieve energy efficient solutions for the buildings. Applying these solutions involves high initial costs. The return on investment is the means by which these solutions become viable to the owners of the facilities. This is where the LCCA has been applied. Two of the important cost elements of the LCC analysis are initial costs and the operating costs of the building.

The collaboration of these modeling tools with other estimating software where the initial costs of the building can be generated is studied. The functions of the quantity take-off tools and estimating tools along with the interoperability between these tools are analyzed. The operating costs are generated from the software that focuses on sustainability. And the currently used tools for performing the calculations of the life cycle costing analysis are also observed.

The objective is to identify if the currently available BIM tools and software can help in obtaining LCCA results and are able to offset the hindrances of the process. Therefore, the software are studied from the point of view of ease of handling data and the type of data that can be generated. Possible BIM workflows are suggested depending on the functions of the software and the relationship between them. The study has aimed at taking a snapshot the current tools available which can aid the LCCA process. The research is of significance to the construction industry as it forms a precursor to the application of Building Information Modeling to the LCCA process as it shows that it has the capacity of overcoming the obstacles for life cycle costing. This opens a window to the possibility of applying BIM to LCCA and furthering this study.

DEDICATION

Dedicated to my mother

NUPUR MUKHERJEE

for her undying support and love

and to my father

TAPANDEV MUKHERJEE

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank Dr.Sarel Lavy, my committee co-chair for his guidance and support to my research. I would also like to thank my committee co-chair Dr. Zofia Rybkowski for continuous guidance throughout my research, her valuable inputs to every issue of my study, her constructive criticism and concern for the timely completion of my study. I also thank her for introducing me to the topic of Life Cycle Cost Analysis. I also thank her for all the productive research meetings and being a constant support through the entire process. I also thank Dr. John Walewski, my committee member, for his interest in my research and providing me with a sense of maintaining a correct approach towards my study. I also thank him for his invaluable suggestions and comments for improving my research.

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Finally, I thank my sister, Doyal Mukherjee, for her unvarying belief in me and her constant support for everything I have undertaken.

NOMENCLATURE

LCCA	Life Cycle Cost Analysis
LCC	Life Cycle Costing
BIM	Building Information Modeling
IFC	Industry Foundation Classes
ASTM	American Society for Testing and Materials
AIA	American Institute of Architects
ICT	Information and Communication Technology
BLCC	Building Life Cycle Cost
DOE	Department of Energy
BIPV	Building Integrated Photovoltaic Systems
BEES	Building for Environmental And Economic Sustainability
HVAC	Heating, Ventilation and Air-Conditioning
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
CFD	Computational Fluid Dynamics
IES-VE	Integrated Environmental Services – Virtual Environment
LCA	Lifecycle Assessment

TABLE OF CONTENTS

	Page
ABSTRACT.....	iii
DEDICATION.....	v
ACKNOWLEDGEMENTS.....	vi
NOMENCLATURE.....	vii
TABLE OF CONTENTS.....	viii
LIST OF FIGURES.....	x
LIST OF TABLES.....	xi
1. INTRODUCTION.....	1
1.1 Problem Statement.....	2
2. LITERATURE REVIEW.....	4
2.1 Life Cycle Cost Analysis.....	4
2.1.1 Life Cycle Cost Logic.....	6
2.1.2 Parameters Associated with LCCA.....	8
2.1.3 Historical Development of LCC.....	9
2.1.4 LCC Assistance to Recent Trends.....	12
2.2 Building Information Modeling.....	14
2.2.1 Overview of BIM.....	15
2.3 BIM and LCCA.....	17
3. RESEARCH AIM AND METHOD.....	20
3.1 Scope of Work.....	20
3.2 Assessment/Study Process.....	21
3.3 Analysis/Interpretations and Conclusion.....	22
4. FINDINGS.....	23
4.1 Evaluation of Case Studies.....	24
4.1.1 Case Study 1.....	24
4.1.2 Case Study 2.....	28
4.1.3 Case Study 3.....	30
4.1.4 Case Study 4.....	32
4.2 Findings from Case Studies.....	37
4.3 The Factors Considered while Studying the Possible BIM Tools for LCCA.....	39
4.4 List of Building Modeling Software.....	40
4.5 Initial Costs.....	41
4.6 Operating (Energy) Costs.....	42
4.7 Cost Estimating Software Currently in Use.....	43
4.8 BIM Solutions for Quantity Take-off and Cost Estimating.....	46

	Page
4.9 Energy Simulation Software Currently in Use	51
4.10 Life Cycle Cost Analysis Software Currently in Use	60
4.11 Data Access and Generation.....	63
5. ANALYSIS	84
5.1 BIM Integration with LCCA	84
5.1.1 BIM and Quantity Take-off and Estimation	84
5.1.2 BIM and Energy Simulation Software	85
5.1.3 Possible BIM Workflows	86
5.1.4 Features of BIM Software Performing Quantity Take-off and Estimation.....	93
5.1.5 Features of BIM Software Performing Energy Simulation	94
6. CONCLUSION	99
6.1 Summary of Findings.....	99
6.2 Original Contribution.....	101
7. FUTURE RESEARCH.....	102
REFERENCES.....	103
VITA	112

LIST OF FIGURES

	Page
Figure 1: LCC Cost Elements	4
Figure 2: Life Cycle Cost Process	5
Figure 3: Life Cycle Costing Logic	6
Figure 4: Cash Flow Diagram	9
Figure 5: The Information Delivery Virtuous Circle	15
Figure 6: Factors that have been Influenced by BIM	16
Figure 7: Scope of Work of this Study	20
Figure 8: Building Characteristics of Simulated Building Types.....	34
Figure 9: Innovaya BIM Solutions	46
Figure 10: TOCOMAN iLink and Express Workflows.....	49
Figure 11: Energy Analysis	54
Figure 12: 'BLCC' Features	60
Figure 13: 'BLCC Report'	61
Figure 14: Shadows and Reflection.....	67
Figure 15: Solar Analysis	68
Figure 16: Lighting Design.....	69
Figure 17: Right to Light	69
Figure 18: Acoustical Analysis	70
Figure 19: Thermal Analysis.....	71
Figure 20: Water Usage and Costs	74
Figure 21: Estimated Energy and Cost Summary	75
Figure 22: Reports Generated by BLCC.....	82

LIST OF TABLES

	Page
Table 1: Historical Development of LCCA	9
Table 2: Recent Trends and Their LCC Concerns	12
Table 3: Alternatives Studied for Case Study 1	24
Table 4: Cost Elements Considered for Case Study 1	25
Table 5: Findings from the Case Studies	37
Table 6: List of BIM Applications with TOCOMAN iLink Add-on	49
Table 7: List of Estimating Software having 'TOCOMAN Express' Integration.....	50
Table 8: Building Modeling Tools Performing Quantity Takeoff and Estimation	84
Table 9: Building Modeling Tools Performing/Facilitating Energy Simulation.....	85
Table 10: Features of BIM Software Performing Quantity Take-off and Estimation	93
Table 11: Features of BIM Software Performing Energy Simulation	95

1. INTRODUCTION

When we mean to build, we first survey the plot, then draw the model; and when we see the figure of the house, then must we rate the cost of the erection; which if we find outweighs ability, what do we then but draw anew the model in fewer offices, or at least desist to build at all?

*William Shakespeare
Henry IV, Part 2, I.iii, 1598*

The construction industry is the largest industry in the United States, employing 8 million workers and accounting for roughly 8% of the gross domestic product (U.S. Industry and Trade Outlook, 2000). Therefore, it is imperative to take sound decisions when it comes to construction of a facility which serves the purpose and is also economically successful. Moreover, today, the owners are realizing the growing economic pressure and their requirements are more focused in obtaining economically viable solutions. The inclination of the owners is to have a facility which is much more of a lucrative option (Kirk and Dell'Isola, 1995).

Today, the owners are facing problems on two fronts. Generation of capital for the initial investment which is the cost of construction and the associated fees along with the costs required for the functioning of the facility are becoming more and more difficult to achieve. Particularly, the owner needs to be prepared to pay the amount that is required annually for the operation of the equipment in the building, the working of the staff in the facility etc. These are costs that cannot be avoided. The only method to reduce the required funds is to adopt efficient solutions at the start of the operation of the facility. Such solutions will also help the owners to remain in the growing competitive environment. Therefore, the design professionals who follow the similar line of thinking are preferred by the owners (Kirk and Dell'Isola, 1995).

This thesis follows the style of *Journal of Construction Engineering and Management*.

Therefore, the relationship between the initial investment for an option and its lifetime cost in the future needs to be established and presented to the owners (Schade, 2007). The designers of today are facing issues in finalizing a design idea which can satisfy the design requirements and also answer the questions related to rising problems associated with facility obsolescence, achieving environmental sustainability and improving operational effectiveness. Robust economic methods and systems are required at the design stage so that each of the design alternatives can be analyzed from the economic point of view and an optimum solution can be provided (Kirk and Dell'Isola, 1995).

Quoted by John Ruskin “It’s unwise to pay too much, but it is worse to pay too little. When you pay too much, you lose a little money – that is all. When you pay too little you sometimes lose everything...” To avoid such a situation, using LCC methodology to analyze the total building costs is a helpful way in making decisions between the various options during design, construction and maintenance. LCC is defined as an “economic evaluation process that can assist in deciding between alternative building investments by comparing all of the significant differential costs of ownership over a given time period in equivalent dollars” (Johnson, 1990).

1.1 Problem Statement

Using LCC methodology to analyze the total building costs is a helpful way in making decisions between the various options during design, construction and maintenance. Though LCC is capable of making effective economic evaluations, it is dependent on the sufficiency and accuracy of LCC data which are fundamental cores of life cycle costing. However, such needs of LCC are usually difficult to meet. The reason for insufficiency of LCC data is mainly the lack of frameworks or mechanisms for collecting and storing data. On the other hand LCC exercise is too complex to be handled manually as it could concern thousand of building elements and a number of construction-type options and maintenance activities for each building element at different stages of design (Fu et al., 2004).

Therefore, using the advancements in technology can be possible ways to offset some of the mentioned problems of LCC. As the AEC industry becomes more oriented to Building information modeling (BIM) and to the development of Industry Foundation classes (IFC), they can be applied in overcoming the issues surrounding the use of LCC. As evident from the present advantages of BIM, there is a chance that BIM may help to promote higher degree of usage of LCC methodology by the building industry. For that reason, it is initially, important to analyze the kind of technology that is available today and their possible applications to LCC. This study aims for the same. The likely improvements that BIM can bring to LCC methodology and probable incapacity of some current BIM applications to give LCC answers are studied. The required areas of improvements in BIM to assist LCC will also be suggested. This study is of significance to industry professionals and building owners to as it initiates in understanding the possible use of BIM in the area of LCC.

2. LITERATURE REVIEW

The literature review has aimed in covering three important areas related to this study.

1. Understanding ‘Life Cycle Cost Analysis’ and its purpose in the AEC industry.
2. An overview of BIM with a look at its use, applications and visible advantages.
3. Study of the work related in linking the process of LCCA with BIM.

2.1 Life Cycle Cost Analysis

“Life cycle costing for a design professional can be defined as an economic assessment of competing design alternatives, considering all significant costs of ownership over the economic life of each alternative, expressed in equivalent dollars”.

The cost elements that are involved during the LCC analysis of an option are as enlisted in **Figure 1**,

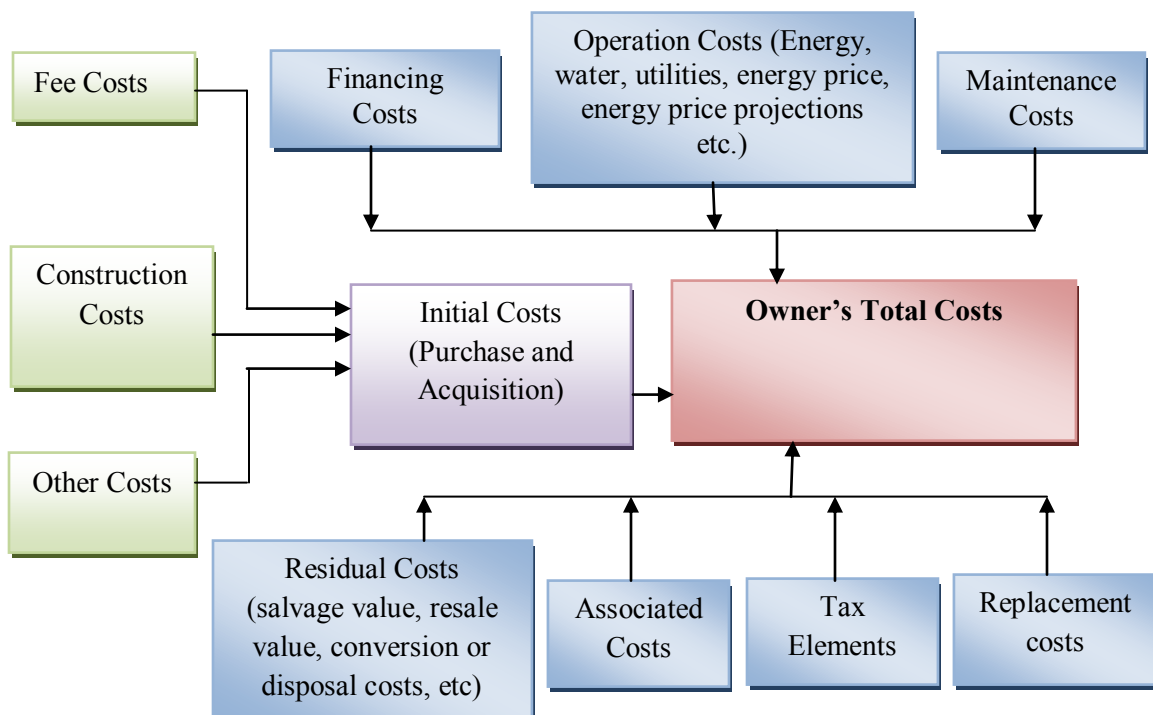


Figure 1: LCC Cost Elements (Adapted from Kirk and Dell’Isola 1995 and Sieglinde Fuller 2010)

In 1972 the U.S. Department of health, Education, and Welfare summarized life cycle analysis as the systematic consideration of “cost, time and quality”. Life cycle costing most certainly addresses these as well as the need and type of data management techniques, the methods that used for economic analysis, development of more effective methods of calculations and investigations etc (Kirk and Dell’Isola, 1995).

The fundamental process of life cycle costing is easily understandable from the **Figure 2**. It enlists the steps of the LCCA process.

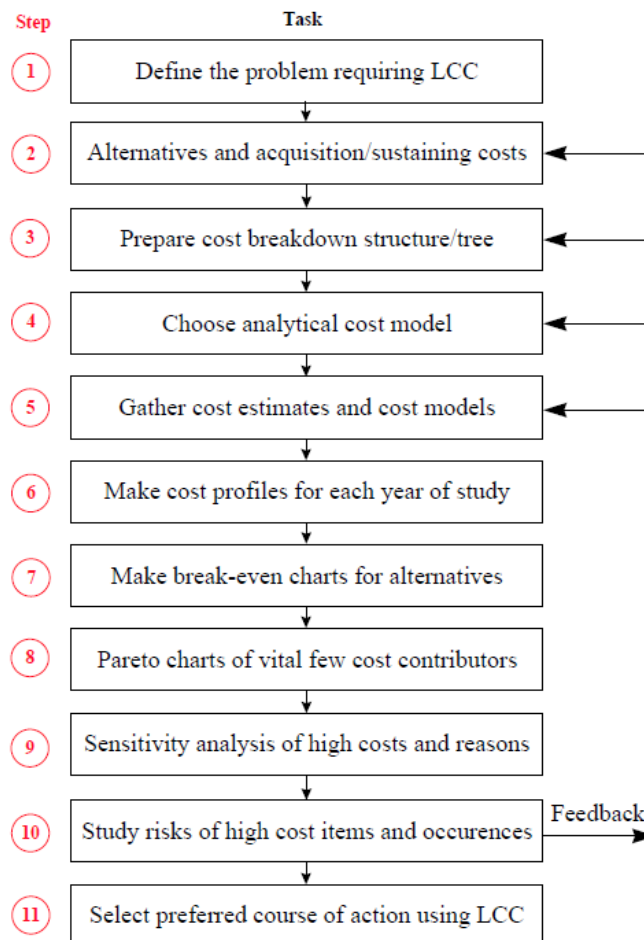


Figure 2: Life Cycle Cost Process (Reprinted from Barringer, 2003)

2.1.1 Life Cycle Cost Logic

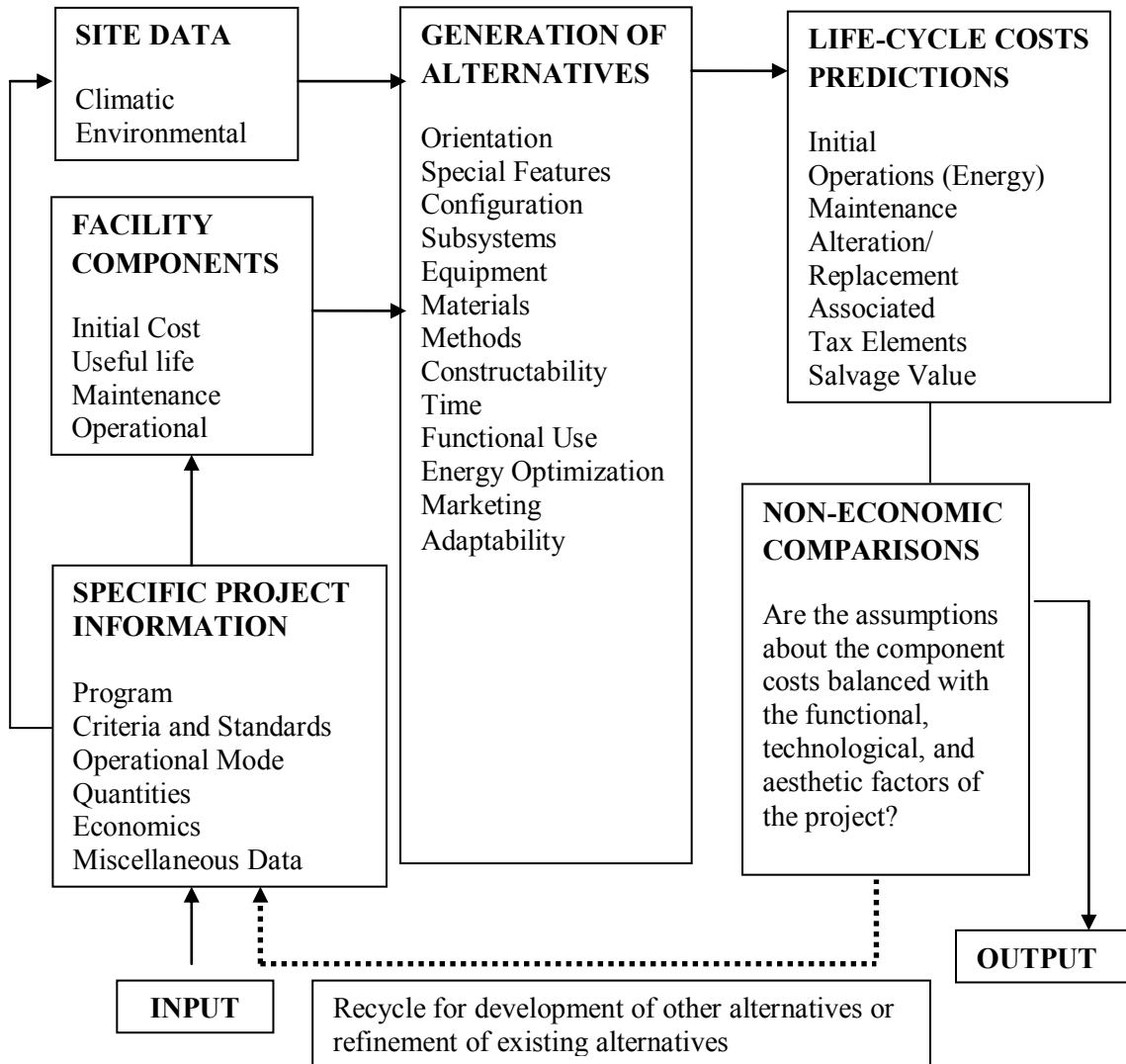


Figure 3: Life Cycle Costing Logic (Reprinted from Kirk and Dell’Isola, 1995)

Figure 3 successfully explains the logic behind the process of LCC calculations, particularly for building design and construction industry. It takes the steps from the fundamental process of LCCA and modifies it to meet the requirements of building design and construction.

The process of life cycle costing involves the following critical steps:

- 1) Acquiring the specific project information. This information should be sufficient enough which will allow us to understand the project requirements and orient towards developing the required design decision and philosophy.
- 2) Find out the relevant components of the building/project which can have a substantial effect on the cost of the solution. These components are critical in such a manner that they can impact the ease of operation, functionality of the facility, cost of building the project and cost of maintenance of the facility.
- 3) The significant step is the process in which different areas of design and construction are analyzed and the areas where alternative solutions can be created are finalized. These alternative solutions that will be finalized are critical as they can create significant changes in the final outcome and alter the behavior of the building accordingly.
- 4) Each of these alternatives will be analyzed by applying the life cycle cost parameters. The associated costs in creating an alternative and maintaining that alternative will be investigated. The time period for which the option will be applied will have to be considered too. Relevant alteration, replacement and salvage costs will also be studied.
- 5) The costs of each alternative will be discounted to arrive at the present value by applying a suitable discount factor. The lowest cost option will be preferred over the other alternatives.
- 6) If required, sensitivity analysis will be required if there is a certain degree of probability attached to more than one feasible option under study.
- 7) Finally the selected alternatives will have to be studied from the non-economic factors to finalize a most favorable solution.

In summary, the LCCA process or method primarily consists of understanding the project requirements, developing the alternatives, studying their feasibility by applying LCC parameters, deciding on the life cycle cost of each alternative, discounting them back to the present value, selecting a feasible option and finally applying non-economic factors to decide on an alternative (Kirk and Dell'Isola, 1995).

2.1.2 Parameters Associated with LCCA

- Inflation – This is defined as the “general increase in prices of goods and services over a period of time” (Kirk and Dell’Isola 1995). These inflation rates, sometimes, needs to be considered in estimating any kind of cost elements used in life cycle costing. This is usually the case with LCCA performed in current dollars where the impact of inflation has to be accounted. Popularly, constant dollars method is preferred (Sieglinde Fuller, 2010).
- Life of element – Here the life cycle cost is estimated by taking under consideration the ‘economic life’ of the element. The ‘economic life’ of an element is defined as “period of time during which an improvement has value in excess of its salvage value”. The total costs of ownership can be calculated for different economic life periods to assure that the estimated life cycle costs generated for each period do not vary drastically. (Kirk and Dell’Isola, 1995).
- Discount rate – Also, called as the ‘time value of money’ is the rate that reflects an investor's opportunity cost of money over time, meaning that an investor wants to achieve a return at least as high as that of her next best investment. Hence, usually the discount rate represents the investor's minimum acceptable rate of return (Whole Building Design Guide, 2010).

All the cost elements that are involved are brought to the same period in time to estimate the present value of the option. This is represented as a cash flow diagram or a timeline representation of the inflow and outflow of money over the lifecycle period, as shown in **Figure 4**.

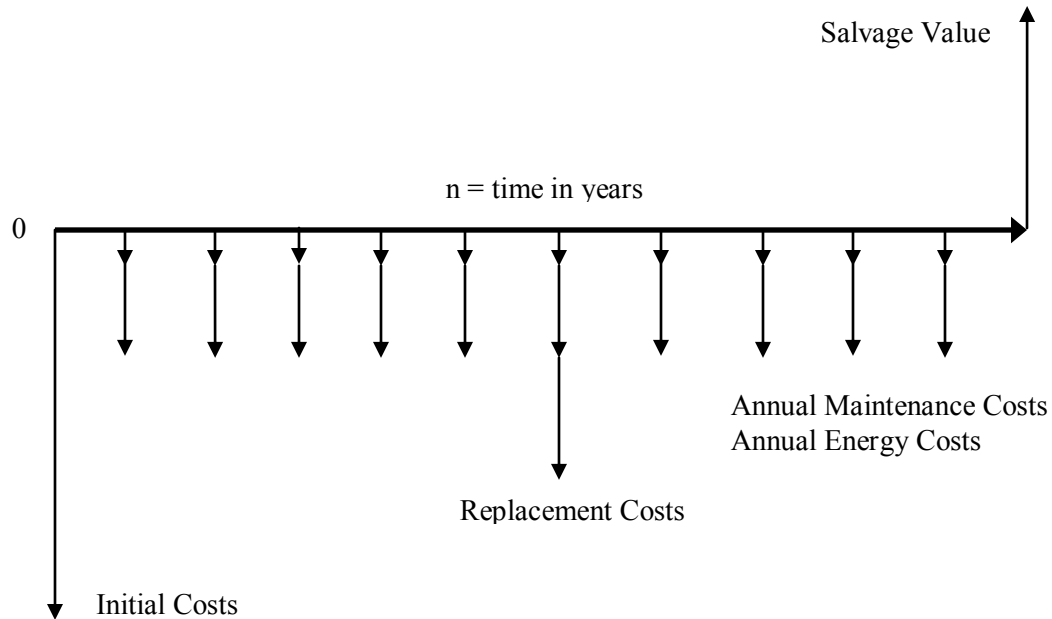


Figure 4: Cash Flow Diagram (Adapted from Kirk and Dell’Isola, 1995)

2.1.3 Historical Development of LCC

The historical development of LCC is as enumerated in **Table 1**.

Table 1: Historical Development of LCCA (Adapted from Kirk and Dell’Isola, 1995)

YEAR	DEVELOPMENT
1960	Department of Logistics Management Institute initialed that total life cycle costs were considered for Department of Defense contracts.

Table 1: Continued

YEAR	DEVELOPMENT
1961	“Methods of Building Cost Analysis” was sponsored by Building Research Institute in Washington D.C. The methods and procedures for life cycle costing for buildings and their associated performance measures in terms of lighting, air-conditioning etc. were evaluated.
1971	Department of Defense published the first in a series of three guidelines of LCC procurement. Analyses of replacement costs were mainly focused. Later a directive 5000.1 was issued which it made it compulsory to perform LCC investigations for major systems acquisitions.
1972	Comptroller General of United States issued one of the most comprehensive on life cycle costs of US hospitals facilities. The conclusion: “GAO believes that life cycle cost analysis is essential in planning and design of all hospital construction projects”.
1973	Life Cycle Costing Guide for System Acquisition was issued in 1973 and specified elementary-level life cycle cost analysis procedures. A study “Evaluation of Health Facilities Building Process” included an evaluation of existing processes for acquisition of those health facilities that are procured by federally assisted grant and loan programs. LCC was made as a permanent part of this procurement process.
1974	Two facility LCC systems have been completed by GSA. The first, Life Cycle Planning and Budgeting Model. Florida became the first state to formally adopt LCC and require consideration of initial, energy, operation, and maintenance costs as criteria for design of buildings over 5,000 square feet.
1974-75	The second GSA was completed. It introduced the bidding procedure requirements for LCC.
1975	The UNIFORMAT framework for initial costs was published by GSA. The framework was extended to LCC study prepared for the University of Alaska in 1974.

Table 1: Continued

YEAR	DEVELOPMENT
1975-1976	Series of four volumes published entitled 'Life Cycle Budgeting and Costing as an Aid in Decision Making'.
1977	The state of Illinois Capital Development Board had made it a requirement to include LCC as support for implementing value engineering principles. The AIA issued a formal set of guidelines for architects and engineering consultants electing to offer LCC as an additional service.
1978	Public Law 95-619 established the National Energy Conservation Policy Act. All the federal buildings came under the purview of LCC analysis.
1979	Department of Energy proposed the use of life cycle costing for analysis of energy efficient solutions for federal buildings.
1980	The Department of Energy made it mandatory to establish a methodology and procedures to conduct life cycle cost analysis.
1985	Recognizing the need for LCC data, the ASTM assisted in the preparation of a computerized database on building maintenance, repair, and replacement.

2.1.4 LCC Assistance to Recent Trends

To highlight a few areas where LCCA are contributing which are currently recognized as highly important and are indicative of future needs, include: total quality management (TQM), facility obsolescence, environmental sustainability, operational staff effectiveness (re-engineering), and value engineering (VE). LCC permits the economic assessment of alternatives being considered in response to these issues as shown in **Table 2** (Kirk and Dell'Isola, 1995).

Table 2: Recent Trends and Their LCC Concerns (Adapted from Kirk and Dell'Isola 1995)

Recent Trends/LCC Concerns	Total Quality Management (TQM)	Obsolescence	Environmental Sustainability	Operational Effectiveness	Value Engineering
Initial Project Cost					✓
Energy/Fuel Costs			✓		✓
Maintenance & Repair		✓			✓
Alterations & Replacement		✓	✓		✓
Administrative Costs	✓			✓	✓
Staffing Costs	✓			✓	✓
Safety/Security Systems		✓		✓	✓
Real Estate Taxes					✓

✓ – Related Costs for the study of the recent trend

Table 2: Continued

Recent Trends/LCC Concerns	Total Quality Management (TQM)	Obsolescence	Environmental Sustainability	Operational Effectiveness	Value Engineering
Water & Sewer Costs			✓		✓
Flexible Furniture Costs	✓		✓	✓	✓
Air/Water Quality		✓	✓		
Healthful Environment		✓	✓		
Sustainable Materials			✓		
New Business Technology	✓	✓		✓	✓
Communication Systems	✓	✓		✓	✓
Automation Equipment	✓	✓		✓	✓
Site Environment			✓		
Occupant Comfort/Control	✓	✓	✓	✓	
Business Profitability	✓	✓	✓	✓	✓
Bay Size/Floor Height		✓		✓	✓

✓ – Related Costs for the study of the recent trend

2.2 Building Information Modeling

“BIM is a revolutionary technology and process that has transformed the way buildings are designed, analyzed, constructed, and managed”. The way that BIM can contribute to the AEC industry is still unexplored. In our hands, lies the capacity to investigate the vast possibilities that BIM can create and ultimately become an integral part of the process of building and construction. It is our collective responsibility to investigate and sense new potential ways in which a new technology as BIM can be applied to the best of advantage (Hardin, 2009).

Charles Eastman puts it in *Building Product Models: Computer Environments Supporting Design and Construction* (CRC Press, 1999), “BIM is a digital representation of the building process to facilitate exchange and interoperability of information in digital format.”

“BIM is a process of using intelligent graphic and data modeling software to create optimized and integrated building design solutions”, as defined by the 2007 ASHRAE Handbook – HVAC Applications.

BIM is not a stand-alone technology which associates itself with buildings, but has the capacity of revolutionizing the age-old practice of approaching design and construction of buildings. It has the ability to allow decision makers and stakeholders of the project to make assessments early on which has the final impact on the operation and the commissioning of the facilities. This allows for a radical change in the process of finalizing results for buildings. In fact, many of the government agencies and research organizations are concentrating on widening the scope and outreach of BIM through continuous developments of software tools and techniques (Holness, 2008).

2.2.1 Overview of BIM

BIM can be looked at as a single source of data related to all areas of building construction and design. It consists of building elements visible in a (3D) graphical format, each of this building element will consist of an intelligent, real-time piece of information related to any specific field. The primary goal is to incorporate data into the computerized models, where the building model will act as a single point of contact for information output. The players of the AEC industry will have opportunity of accessing the desired information at single location. This gives them chance of interacting and collaborating with each other and produce a solutions in an efficient manner. The **Figure 5**, give us an idea about the scope of BIM. (Holness, 2008)

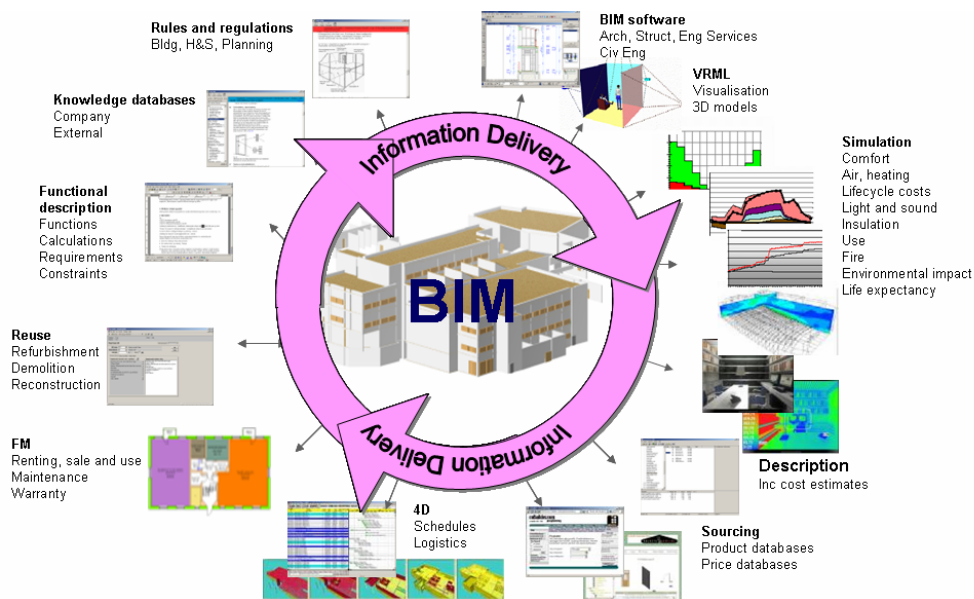


Figure 5: The Information Delivery Virtuous Circle (Reprinted from Jeffrey Wix, and Thomas Liebich, Ole-Jørgen Karud and Håvard Bell, Tarja Häkkinen, and Pekka Huovila).

An example on how integration can be achieved through BIM is using the data from one of the design calculation tools to create graphical building components in modeling software. These components will be linked to data that gives usable information. This data can be in from of specifications of the components, load calculations, estimating information, quantities etc. The subcontractor and supplier data can also be attached to the building component (Holness, 2008). It is also clear from the **Figure 6** that BIM has had far-reaching effects in the AEC industry. They have positively impacted the building process at important stages. It is evident from the table that BIM has been effectively been to influence the time and cost areas, with a significant reduction in each. It is also visible that the implantation of BIM many areas remain to be explored (Hardin, 2009).

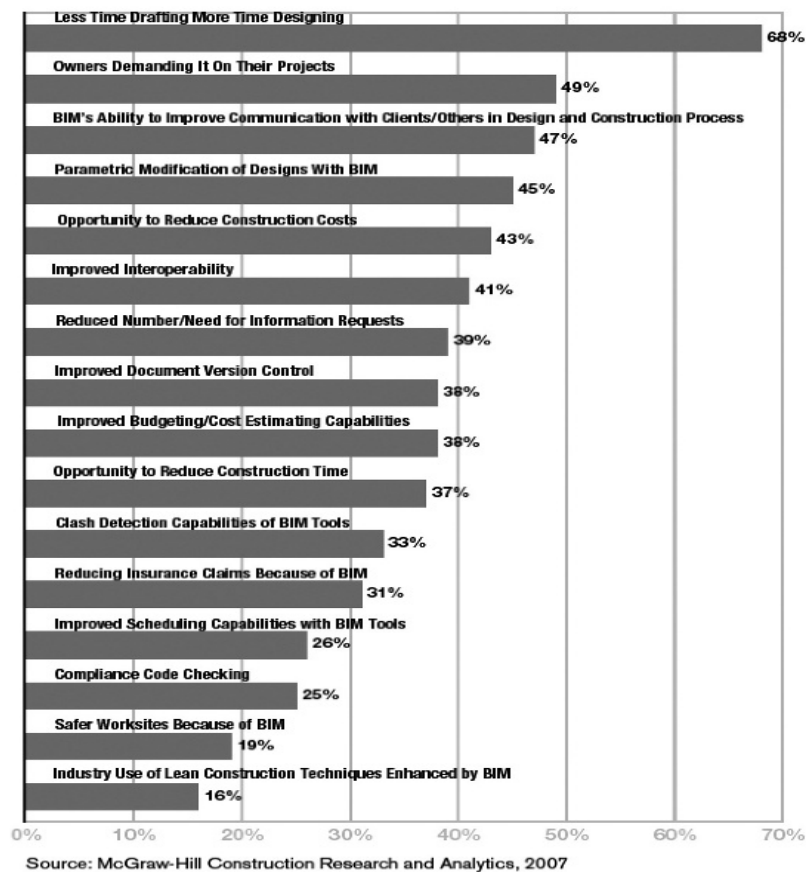


Figure 6: Factors that have been Influenced by BIM (Adapted from Hardin, 2009)

2.3 BIM and LCCA

Van Nederveen and Gielingh had timely reflections on construction industry in the current global economic scenario and stated that the aftereffects of the global meltdown will be visible for a considerable period in the future which demands to understand that what can be the future advantageous applications of building information modeling and construction ICT. They argue the need for a life-cycle modeling approach where the individual building elements are will equipped with relevant data and are able to provide the necessary information as and when required. It is argued that to “study the performance of the building as a whole which gives a higher level of value as a facility to its consumers also gives rise to the prospects of reuse, remanufacturing and recycling” (Rezgui et al., 2009).

As mentioned, a few obstacles have been noticed for LCC to become a widespread practice. The process of carrying out in-depth analysis to reach life cycle costing results for different alternatives is lengthy and time consuming. A dedicated period of time is required to investigate the several options from the LCC standpoint and therefore, can create a possible lag in making decisions on various aspects of the project. LCC analysis also heavily dependent on accurate data to perform calculations and obtain the present value for each of the option considered. Acquiring the required data is from the numerous sources as of the many options are related to each other and can have effect on the performance of other parameters of the building. So a comprehensive analysis again is time dependent (Fu et al., 2004).

Since, LCC study takes up precious time, and owners and contractors expect that the study can help achieve results which can significantly contribute in savings during the life cycle of the building as compared to a conventional design process. It is for this reason that the management requires to have a level of assurance to orient their decisions to be more LCC specific. Therefore, the process of a LCC analysis should be streamlined to overcome these limitations to attain desired results (Kirk and Dell’Isola, 1995).

It has been proved that, computerized techniques have been useful in the processes that are time dependent and have been successful in substantially reducing the same and revolutionizing the workflow.

The weaknesses of data collection, analysis of alternative options, consultations with the decision maker and re-analysis of the options which are associated with LCC can be overcome by using computerized models with data coupled to them. Since sufficiency and accuracy of the data collected and thereby their precise use is the crux of LCC operation, use of computerized methods and models will help in achieving these criticalities (Griffin, 1993).

Study of research papers and articles of various authors have indicated that LCC methodology is in fact a necessary tool for choosing alternatives. BIM can act as a very helpful tool for achieving LCC results by offsetting some of its weakness. The adoption of building information modeling methods and techniques can obtain the integrated and interoperable information of the designs (Fu et al., 2004) and can address the above mentioned concerns of adopting LCC.

Saad Dawood, Richard Lord and Nashwan Dawood in their paper ‘Development of Whole Life Cycle Assessment Framework for Built Environment’ present a framework, methodologies and technologies that will facilitate the integration of Environmental Impact Assessment (EPA), Whole Life Cycle Cost Assessment (WLCCA) and Life Cycle Assessment (LCA) using Building Information Model (BIM) technologies. They state that “Building Information models and 3D technology will be used to visualize the result and allow better or more accurate decision making for project stakeholders”.

BIM model will act as a storehouse of integrated data where any user can access relevant information for its use and also can again link back the new results developed into the BIM model. It is a continuous process of development and improvement by sharing data between the stakeholders of building design and construction. This can be started early on in the conceptual design phase so that all the changes occurring in the due course of time will be incorporated in the final solution (Fu, 2005).

Building information modeling software that are in use today are well-equipped of performing many functions which are required in the life cycle costing of buildings. It has already been seen that these tools are being effectively applied to carry out the design analysis and optimization (architectural, structural, steel design, MEP etc.). They are also contributing in sustainable design of buildings by assessing the parameter of day-lighting, ventilation, energy analysis.

These techniques further adding to the estimating of the materials and building elements, managing specifications. Since, the processes use computerized models for achieving the results, a step ahead can be taken and the results can be used in the LCC analysis and greatly simplify the often cumbersome and difficult analyses (Dawood et al. 2009).

The paper 'IFC implementation in Life Cycle Costing' by Charlie Fu et.al presents the implementation of BIM technology in the development of life cycle estimating tool. The IFC (Industry Foundation Classes) model as an interoperable building information model has been adopted as central data repository to deliver the integrated information of building designs from CAD design systems into lifecycle costing database.

As highlighted above, BIM essentially has the capacity to handle data in a manner that generates utilizable information. One of the concern areas of LCC is lack of frameworks or mechanisms for collecting and storing data. The method of linking data with the specific building elements adds a dimension of an integrated approach to the LCC process.

It is clear from the literature review that there is surely a likelihood that BIM can become part of the LCCA practice. Both of these practices have developed in response to the problem areas faced by the AEC industry. It is the time to look if both these practices can be merged together to create effective and efficient workflow which can meet the rising demands of the owners.

3. RESEARCH AIM AND METHOD

To analyze the current Building Information Modeling applications and tools available with the objective to identify if they can serve as effective means to the Life cycle Cost Analysis process. The study is to understand the extent to which the currently available BIM software can participate in the LCCA workflow.

3.1 Scope of Work

The LCCA study involves significant costs which generally include initials costs, operational costs (energy, water etc.), fees, tax elements, maintenance costs, and replacement costs, salvage value etc. The scope of this study is limited to application of BIM tools for the analysis and generation of data in terms of initial costs and energy costs as highlighted in **Figure 7**.

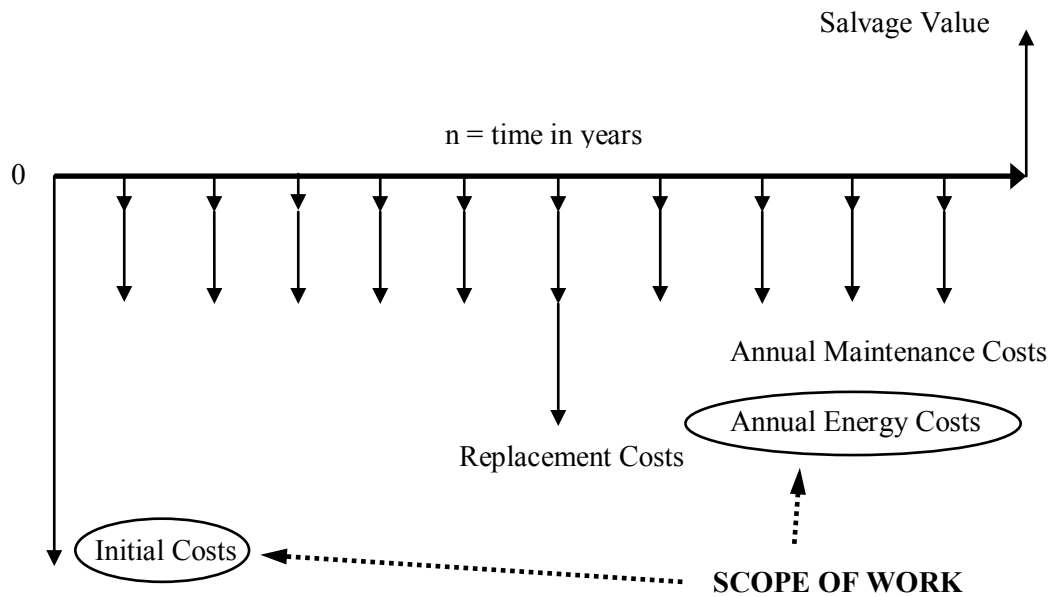


Figure 7: Scope of Work of this Study

3.2 Assessment/Study Process

TASK 1: Randomly select 4 LCCA case studies in the field of building design, construction and maintenance from literature review.

TASK 2: Study the following points from each of the case study individually

- a. The process of the LCC analysis in the case study.
- b. The suggested design alternative undergoing the LCC analysis and the reason for choosing the same.
- c. The need of carrying out a LCC analysis for the alternative.
- d. The method and the calculations done to obtain the results.
- e. The implications of the alternative on the functioning of the building.

TASK 3: Identify the existing BIM tools and attempt to respond to the following question related to possible use of current BIM tools to the LCCA case studies,

Are there any BIM tools and software's available that can be applied to analyze the alternative which is considered in the case study?

TASK 4: If such BIM tools are available, then identify the ways and extent in which they can contribute to the LCCA process. The purpose, functions and features of the BIM application's will be studied from the manuals, demo videos, white papers, tutorials provided by the manufacturer in print and electronic form.

TASK 5: Recognize if there is any non-BIM tools used in the case studies to arrive at the LCCA results. Analyze the feature of the application.

TASK 6: Provide an overview of the study by enlisting the type of BIM applications that can be used in the LCC process from the above assessment. Also specify the purpose for which they can be used.

TASK 7: Study if the features of the non-BIM applications that have been used, are present in any of the current BIM tools. If they are not, they will serve as requirements of the LCC analysis for the existing BIM products.

3.3 Analysis/Interpretation and Conclusion

The possible application of BIM to LCC will be analyzed by establishing a link between the requirements of LCC methodology and the features of the BIM software's after the study of the same. The possibility of BIM being a part of the LCCA workflow will be determined. If present, the visible constraints in the software's features will be understood. The possible behavior of the software's between each other and interoperability issues will be addressed. The aid that BIM can offer to LCC methodology will be highlighted and the possible improvements will be suggested.

4. FINDINGS

The case studies that were studied are as listed below,

Case Study 1

Life Cycle Cost Analysis for Air Conditioning Systems in a Perimeter Zone for a Variable Air Volume System in Office Buildings

Yeon Jeong Na, Eun-Ji Nam and In-Ho Yang, *Journal of Asian Architecture and Building Engineering* (Received April 8, 2009; accepted January 14, 2010)

Case Study 2

Critical Factors in Reducing the Cost of Building Integrated Photovoltaic (BPIV) Systems

Hatics Sozer and Mahjoub Elnimeiri, *Architectural Science Review*, Volume 50.2, pp 115-121

(Received April 2006; accepted 31 January 2007)

Case Study 3

Life-Cycle Cost Analysis for Selection of Energy-Efficient Building Components in Lodging Facilities, *Building Integration Solutions*, pp 1-15.

Giovanni C. Migliaccio, Sachin Goel, and James T. O'Connor

Case Study 4:

Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings.

Joshua Kneifel, *Energy and Buildings*

(Received August 3, 2009; received in revised form September 16, 2009; accepted 17 September 2009)

4.1 Evaluation of Case Studies

4.1.1 Case Study 1

Life Cycle Cost Analysis for Air Conditioning Systems in a Perimeter Zone for a Variable Air Volume System in Office Buildings

Yeon Jeong Na, Eun-Ji Nam and In-Ho Yang

(Received April 8, 2009; accepted January 14, 2010)

Alternatives Studied

Economic analysis of the following systems as listed in **Table 3**.

Table 3: Alternatives studied for case study 1

Perimeter zone of the office building	Comparison between	Interior zone of the office building
1. Convector	1) VAV + convector, VAV + FCU, VAV + FPU	Variable Air Volume system (VAV)
2. Fan Coil Unit (FCU)		
3. Fan powered Unit (FPU)		
	2) CAV + FCU and VAV + FCU	

Reason for the Analysis

The necessity of reducing energy consumption in Korea is increasing due to the rise in oil prices and dependence on the foreign oil reserves. In Korea, it has been observed that of the 30% of the energy that the building consumes, 50% of it is used primarily for the air-conditioning systems. The study aims at trying out alternatives which will help in reducing the energy consumption by the air-conditioning systems.

An efficient air-conditioning system should be able to satisfy the requirements of comfort and sustain the heating and cooling load according to the functioning and location of the building.

For achieving the same, initial costs and running costs of the system need to be analyzed. In this paper, LCC has been able to provide these answers.

Selection of LCC Cost Items

The various cost items that were considered for study are enumerated in **Table 4**.

Table 4: Cost Elements Considered for Case Study 1

Phase	Cost Items	Detailed Cost Items	Costs
Design phase	Plan cost and Design Cost	Planning Cost, Designing Cost	2.42% for the schematic design and 4.85% for the construction design.
Construction Cost	Construction cost	Material cost, Labor cost and indirect costs	Estimate and 2.26% as supervision costs
Running phase	Energy cost	Electric power cost and gas cost	Computer simulation

Planning/Designing Costs

In this paper, the schematic design cost is related to planning cost and the cost of design for construction is related to designing cost by considering the specific character of design companies. Equipment design is mainly included in the engineering field. (Jung, J.R. et al., 2003). Thus, the planning and designing costs are determined according to the rate of construction cost.

In this study, the planning and designing costs are calculated using the construction cost rating according to the Korean Engineering Costs Guideline standard. Therefore, planning

and designing costs were applied at a rate of 2.42% in the schematic design and 4.85% in the construction design.

Cost of equipment and construction cost

The amount that requires to be paid to the by the owners to the contractors are estimated using the traditional estimating methods by considering the initials costs, costs of construction etc. Control system cost is also included in the estimate and 2.26% of the construction costs for supervision costs. Due to similarity in the plant systems and the aid from government they were not considered in the LCC calculations.

Energy Costs

Electric power cost and fuel cost for the main equipment and sub-equipment were calculated by using computer simulation to obtain the total energy consumption and by finally computed by applying the domestic electricity fees and gas fees.

Due to insufficient data, on the kinds of air conditioning system and the management capacity in each building, it is difficult in determining the running costs. It is for this reason that the LCC period was kept up till 15years which does not require the repairing and replacing costs to be included.

The similar costs, such as, tax, insurance costs, government aided costs and removal costs were not applied in the LCC calculations.

Selection of Variables of the Cost Items

1. The present value method is chosen for analysis and for conversion of all costs to the same time value for calculating LCC.
2. LCC analysis period is set at 15 years which is the average life span of equipments in Korea, Japan and United States.
3. The discount rate is equal to the mean loan interest rate in the construction field which is taken as 5%.
4. The increasing rate of equipment costs is applied at 2%.

5. In case of energy costs, an increasing rate of 3% for electric power and 6% for gas is considered for calculations.

Methodology of Economic Analysis

A model office building in Seoul was chosen. Its air conditioning method was CAV + FCU. In this study, initial costs were determined by changing the values of the air conditioning methods, conditions of air conditioning schedule and design. The energy consumption and the running costs were determined by using computer simulations.

The building energy analysis program DOE-2.1E was used to calculate the initial costs and running costs. The heating and cooling loads of the building as well as energy consumption were calculated by simulation. With these values, design of systems and plants was performed to determine the running costs.

Data fields in DOE-2.1E:

LOADS – Material related to the location, schedule of occupancy, lighting and infiltration and design condition of the air conditioning system.

SYSTEMS – On/off schedule of the air conditioning system and control condition of each zone.

PLANTS – Data of the boiler, chiller and cooling tower.

Results

The VAV+FPU unit had the least life cycle cost among all the alternatives and can reduce the cost of the convector system by 9%. The FPU system is the most effective for the reduction of energy use. Sensitivity analysis was performed for the variables related to the cost items. The parameters for sensitivity analysis were the changing discount factors, changing life cycle period etc.

4.1.2 Case Study 2

Critical Factors in Reducing the Cost of Building Integrated Photovoltaic (BPIV) Systems

Hatics Sozer and Mahjoub Elnimeiri

Received April 2006; accepted 31 January 2007

Alternatives Studied

Cost of Building Integrated Photovoltaic (BPIV) Systems compared with non-PV integrated building and different PV system application.

Reason for the Analysis

In this paper, it is shown that a major barrier that exists in analyzing renewable energy systems is “assembling and presenting the technical and financial data to persuade a client that a BIPV would make economic sense” (Wenger & Eiffert, 1996).

One of the major explanations behind the lack of use of photovoltaic systems by the AEC industry is the obvious obstacles that exist which stop its full usage. (Eiffert & Kiss, 2000). These obstacles are in the form of lack of understanding of the photovoltaic systems and the design requirements of a building in order to integrate BIPV. Also, there is a factor of unidentified performance which is further enhanced due to the lack of common ground of discussion and interaction of the concerned players. A major area of concern is the lack of economic analysis of the BPIV system.

The life-cycle cost analysis (LCCA) is recommended (Eiffert & Thompson, 2000) for the purpose of designing and sizing BIPV systems. The reason for performing this kind of analysis is to provide the owners with grounds for making investment decisions. Since, LCC presents a picture where all the significant costs are visible and the owners can make informed decisions.

Selection of LCC Cost items

A BIPV system includes PV modules and balance of system (BOS) components, which include inverters, electrical storage, or a grid-metered connection, fault protection, cabling and wiring (Randall, 2001). These costs with the cost of integration of design and installation should be

included in the BIPV cost. The result is compared with the traditional construction product to determine the added cost of a BIPV system.

Labor Costs

Initially, the advent of photovoltaic systems had higher design, manufacturing and installation costs due to low market demand. The problem is still present, but as the continuous advancements in expertise and knowledge of PV technology will eventually decrease the labor costs required of a BIPV system.

Maintenance Costs

Cleaning, repair and replacement of the PV system for the part of maintenance costs

Utility Interconnection Costs

“Costs can include large interconnection fees, net metering tariffs, metering calibration charges, engineering study fees, and standby charges. Additional requirements for liability insurance, property easement, legal indemnification, record keeping of O&M, and additional protection equipment will contribute to even greater utility interconnection costs. The relative cost of meeting these requirements is much greater for a small system than it is for a larger system” (Eiffert & Thompson, 2000).

Building Permit, Standard and Code Costs

Required prior to construction and vary according to location.

Salvage Value/Costs

One of the significant costs that is included in the LCC analysis are the disposal costs associated with PV components including the batteries required for the functioning of the system.

Methodology of Economic Analysis

An eleven-storey office project selected as a case study in Northeast USA. The LCC analysis was carried out for two kinds of system. The first was the application of BIPV system and the second being the traditional glass curtain wall system. Both these systems were integrated on the spandrel as a façade. The roof was not considered for the application of PV systems due to

functional reasons. Building Life Cycle Cost (BLCC) Analysis software was used for performing LCCA. DOE-2 software was used for calculating the energy consumption of the BIPV system and computing the resulting annual savings.

Results

The payback period for the BIPV system has come to 43 years. The analysis has clearly shown that the BIPV system entails higher costs as compared to the traditional curtain wall system. The main reason for these results is that the installation of this system requires team of experts in this area with an added cost for specialized technical supervision. The payback period also shows sensitivity to the labor cost.

4.1.3 Case Study 3

Life-Cycle Cost Analysis for Selection of Energy-Efficient Building Components in Lodging Facilities

Giovanni C. Migliaccio, Sachin Goel, and James T. O'Connor

Alternatives Studied

This paper outlines a methodology for applying life-cycle cost analysis (LCCA) for selecting building components in a typical modular and repetitive lodging facility.

An analysis of life-cycle costs for a window system in a typical two-story economy lodging facility. The effect of one design factor, site location, is investigated through a sensitivity analysis, which considers a location for each different climatic area in the United States.

Moreover, a contingency analysis is also performed to assess how changes in energy prices will affect the decision process.

Reason for the Analysis

Recently, it has become clear that cost of operation of lodging facilities are increasing, especially due to the energy costs. The rises of both energy prices and usage resulted in a 6% increase in utility costs for the lodging industry between 2003 and 2004 (PKF, 2004). Since electricity costs represents 60% of the utility costs, this has come up as a concern area which has initiated the methods in which reduction in electricity usage can be achieved.

LCC techniques were rarely adopted for evaluating the performance of building elements and the in turn generations of high electricity costs were not anticipated. The need has made the application of life cycle costing to the evaluations of components. Even though, the LCC process is cumbersome and costly, it can be adopted as they can be repeatedly be applied to lodging facilities since the building elements are modular and repetitive in nature.

Methodology of Economic Analysis

The process is based on the traditional two-phased approach of running energy simulations and using the results for performing the LCCA. The first step is running of the energy simulations and understanding the impact of the components to the performance of the building. The geometry, site orientation etc were fixed for running these simulations.

The second phase uses the results of the energy simulation to determine the energy-related operational costs. These costs together with other categories of costs over the life of the facility (i.e., investment costs, maintenance costs, other operation-related costs, etc.) are discounted to the present value to determine the expected life-cycle cost (LCC).

The LCC period is chosen as 20 years. The LCC value includes window system procurement costs, energy-related operational costs, and window system replacement costs. Finally, the energy consumption for each window system is estimated based on factors affecting the consumption for heating/cooling but not for lighting the built environment. The energy loads are evaluated.

RESFEN, a software program developed by Lawrence Berkeley, was selected as the energy simulation processor for estimating the amount of energy consumption due to the window system.

Authors initially selected the Building Life-Cycle Cost (BLCC) Program that adheres to the National Institute of Standards and Technology (NIST) LCC procedures (Fuller and Petersen, 1995). However, this software package allows limited data interoperability. Therefore, a spreadsheet version of BLCC procedures was selected (Addison, 1999). Using a spreadsheet allowed for the integration of part of the uncertainty analyses in the LCC by the use of a

Microsoft Excel add-in which was developed by researchers of the Dartmouth College for NIST (Baker et al., 2003).

Database of economic and physical characteristics for 29 window systems was built. An electric heat pump mechanical system was also assumed in the baseline model. The results from the energy simulations were factored together with the assumptions on the electric utility charge plan and energy price to provide the energy related operational costs for the LCC model.

Results

Initially, the LCC for the baseline window system is determined. An energy price of 9 cents/kWh is assumed as a base scenario for the decision because of its closeness to the average electricity price (DOE, 2005). According to the results, window system # 3 is the one that offers the lowest LCC in every location.

Two patterns are clearly represented by the results. Window system # 4 presents the lowest LCC for locations with a predominance of the cooling season (i.e., TX and AZ) under high-price scenarios thanks to its lower SHGC value. On the other hand, window system # 18 offers the best value in locations with a predominance of the heating season (i.e., NY, IL and TN) under the same high-energy price scenarios thanks to its lower U-value.

4.1.4 Case Study 4

Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings. Joshua Kneifel, Office of Applied Economics, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, MD 20899, United States.

(Received August 3, 2009; received in revised form September 16, 2009; accepted 17 September 2009)

Alternative under Study

Prototypical building is used for three design alternatives, namely, designs to the ASHRAE 90.1-2004, ASHRAE 90.1-2007 energy efficiency standards and a higher efficiency 'low energy case' (LEC) design. The components that were changed to meet ASHRAE 90.1-2004 and

ASHRAE 90.1-2007 were insulation and windows. Insulation material and/or thickness in both the walls and roof decks are changed.

The Reason to Apply LCCA

Literature review from the study showed that energy efficiency has become the key focus area in building construction. The aim is lower the energy use. Torcellini et al., (2006) has evaluated that it is possible to built higher value and better performing buildings which can also contribute in reducing the energy consumption. This is possible by applying the “whole building design approach” during the design stages. Contrary to the popular believe, this approach can reduce the energy use below 25-30% as enumerated in the standards.

ASHRAE Advanced Energy Design Guides has proposed techniques and offered solutions by which the usage of energy required for functioning of the buildings can be minimized by 30% as compared to the standards listed in ASHRAE 90.1 – 1999. Though these solutions have the capacity to achieve the said reduction but their usefulness has not been analyzed for the economic standpoint. To reach the decision of applying such solutions requires an understanding of all the significant costs involved.

The suggested energy reducing measures are applied for a building system. The study of the solution is carried out on an individual basis where the performance of the component alone is analyzed. An all inclusive study of the solution is rarely carried out which combines the study of the cost parameters, energy use, the implication on the lifecycle performance. The need is to have a combined integrated evaluation before finalizing an energy saving solution.

The paper studied, has attempted to follow the “whole-building design approach”. It has tried evaluating the energy reducing solutions from multiple perspectives. The performance of the building is analyzed by carrying out lifecycle assessment studies along with energy simulations of the design. The lifecycle cost analysis is also performed to derive the cost implications of the design solution in the future.

Methodology Adopted

Twelve building types are evaluated to consider a range of building sizes and energy intensities.

Figure 8 shows the building types evaluated in this paper represent 46% of the U.S. commercial building stock floor space.

Building type	Number of floors	Floor height m (ft)	Building size m ² (ft ²)	Occupancy type	U.S. floor space (%)
Dormitory	3	3.66 (12.0)	2 323 (25 000)	Lodging	7.1
Dormitory	6	3.66 (12.0)	7 432 (80 000)		
Hotel	15	3.05 (10.0)	41 806 (450 000)		
Apartment	3	3.05 (10.0)	2 090 (22 500)		
Apartment	6	3.15 (10.3)	5 574 (60 000)		
School, Elementary	1	4.57 (15.0)	4 181 (45 000)	Education	13.8
School, High	2	4.57 (15.0)	12 077 (130 000)		
Office	3	3.66 (12.0)	1 858 (20 000)	Office	17.0
Office	8	3.66 (12.0)	7 432 (80 000)		
Office	16	3.05 (10.0)	24 155 (260 000)		
Retail store	1	4.27 (14.0)	743 (8 000)	Mercantile ^a	6.0
Restaurant	1	3.66 (12.0)	465 (5 000)	Food service	2.3

^a Only includes non-mall floor area.

Figure 8: Building Characteristics of Simulated Building Types (Reprinted from Kneifel, 2009)

Data collected were;

Building Construction Costs

The first costs of the prototypical building and its components are estimated from the online database of RS Means CostWorks. Particularly, standard costs listed RS Means Square Foot Estimator is used to arrive at the initial costs. The changes in the costs are made in order to meet the changes that happen due to the alternative design options. The 2008 RS Means CostWorks City Indexes are used for applying the possible price discrepancies depending on the location of the building. The different sets of city indexes are used to adjust the costs of the building and also the related components. The final ‘initial cost’ is calculated by applying the fees of the contractor and the architect.

Maintenance, repair and replacement costs

The building types and building components come with costs that are required for maintenance, repair and replacement. This is necessary for carrying out the lifecycle cost analysis. The “Whitestone Research Building Maintenance and Repair Cost Reference” is used as a source for

calculating these costs. The changes that occur in costs due to implementing the design alternatives are derived from the RS Means CostWorks. Since, the window systems are the suggested alternative in the paper, they are assumed to have a repair cost which is equal to 1% of all window panes.

Energy costs

The energy costs are derived by performing a 2 step process. Energy simulations are carried out using the EnergyPlus program to achieve figures for the consumption of energy by the building. These figures are then multiplied by the rates for fuel and natural gas which are obtained from EIA (Energy Information Administration) to calculate the final annual energy costs of the building. An average retail price for electricity is also use for computing the annual electricity costs of the building and its components.

LCC Calculations

The study includes the computing the LCC of 3 cases. The ASHRAE 20.1 – 2004 is considered as the “base case” against which the comparisons with the design alternatives are studied. The two alternatives are the design solutions suggested by ASHRAE 20.1 – 2007 and the “Low Energy Case” designs. The cost evaluations are performed from two perspectives. The difference in the LCC values between the “base case” and one of the alternative. This stands as the net savings from the alternative suggested. The second viewpoint is the calculation of the adjusted internal rate of return. This is the return on the initial investments on the energy reducing measures. If the AIRR is greater than the MARR then that particular alternative is preferred.

NIST’s BEES software is used to compute the life-cycle costs for the building design alternatives in compliance with ASTM Standards of Building Economics.

Results

It was realized that the operating costs are usually overlooked. As the life cycle period increases, more building type-location combinations find it cost-effective to adopt the most energy efficient building design alternative.

The results have shown that the energy saving measures were able to reduce the carbon emissions by 32% over the 10-year lifecycle phase.

It has been observed from the study that the comprehensive all-inclusive approach helps in giving a strong foundation for making investment decisions in order to implementing energy reduction strategies. The target should be to approach the analysis of alternatives from multiple outlooks.

NIST is targeted in making upgrades to the BEES software program to better serve the analysis requirements. NIST hopes that after making the necessary improvements it will be able to provide better economic data for the analysis. The government regulations and acts have also been considered for these improvements.

4.2 Findings from the Case Studies

Some of the findings from the case studies are summarized in the **Table 5**.

Table 5: Findings from the Case Studies

No.	Findings	Case Study 1	Case Study 2	Case Study 3	Case Study 4
1.	Target of LCC study	Analyze energy saving solution	Analyze energy saving solution	Analyze energy saving solution	Analyze energy saving solution
2.	Cost Elements				
	i. Planning/Design costs	✓	✓	✓	✓
	ii. Cost of Construction	✓	✓	✓	✓
	iii. Energy Costs	✓	✓	✓	✓
	iv. Maintenance costs	✓	✓	✓	✓
	v. Utility Interconnection costs	X	✓	X	X
	vi. Salvage Value	X	✓	X	X
	vii. Replacement Costs	X		✓	✓
	viii. Fee Costs	X	✓	X	X
3.	Period of Analysis	15years	20 years	20 years	10 years, 25 years and 40 years
4.	Software used for initial costs	DOE-2.1 for system costs	DOE-2.1 for system costs	X	X
5.	Software used For energy simulation	DOE-2.1	DOE-2	RESFEN	EnergyPlus
6.	Software used for LCC calculation		BLCC	BLCC	BEES
7.	Decision from the results	Least LCC	Yearly Savings and Payback period	Least LCC	Net Savings and comparison AIRR with MARR

✓ – Considered in the analysis

X – Not considered

- The above case studies have used the process of ‘Life Cycle Cost Analysis’ and have been able to achieve the desired results for making informed decisions.
- The case studies primarily studied alternatives which targeted at achieving energy – efficient buildings. The objective was to choose between different energy saving options.
- It is realized that the energy saving options do require expensive investments due to which it is necessary to understand the return on these investments. LCCA study is an effective way of understanding the cost implications of the choice.
- The choices are made between different design options. Some of the examples are different type of materials of the building elements, changes in the conventional systems adopted, type of the equipments used for functioning of the building etc.
- LCCA also has allowed assessing the feasibility of a certain new option. And to understand if any new improvements are needed for its acceptability into the building.
- In terms of the methodology and the software tools used for the process, no software tools were mentioned for calculating initial costs in the LCCA process. It is assumed that traditional popular methods have been used for the calculations.
- In terms of data for estimating initial costs, RS Means CostWorks was one of the sources. In one of the case studies, maintenance and repair data was collected from ‘The Whitestone Building maintenance and Repair Cost Reference’.
- It is also possible, that none of options have been analyzed in the context of developing an estimate for the construction of the building as a whole. The assessments have been carried out individually for the particular option under study.
- There has been no mention of use of any ‘Building Information Modeling’ tools or workflows being used.
- Since, the alternatives studied were for achieving energy – efficient solutions, there has been usage of energy simulation software. These software, primarily are the ones that were developed by the ‘Department of Energy’ such as DOE-2. The other version of DOE-2 which were used is EnergyPlus. DOE-2 is also the source of algorithms for simplified methods like RESFEN (Residential Fenestration Performance Design Tool), COMFEN (Commercial Fenestration Performance Design Tool) etc. Such applications were also used for specific simulation purposes.

- The LCCA software which was predominately used is ‘Building Life Cycle Cost (BLCC)’ which is developed by ‘National Institute of Standards and Technology (NIST)’. There is a use of some individual spreadsheet applications developed as a part of the research methodology.
- There is also a mention of ‘Building for Environmental and Economic Sustainability (BEES) 4.0’ as an analysis framework.
- Primary objective of the LCCA analysis is to find the life cycle cost of the alternative. There is lesser dependence on finding out other forms of economic results. One case study found out the payback periods of the alternative under study.
- In some of the cases, sensitivity analysis was also carried out of the options in order to reinforce the choice of selection.

4.3 Factors Considered while Studying the Possible BIM Tools for LCCA

- As studied in the literature review, the main hindrances for the widespread adoption of LCC methodologies has been the lack of framework or a platform to store data related to the building elements and also due to the need of ease in handling a number building alternatives a multiple number of times.
- The possible software that will be required for LCCA study depending on the case studies is divided into three categories, cost estimating software for calculation of initial costs, energy simulation tools for calculating annual savings and tools for carrying out LCCA computations.
- Since, the modeling tools required are listed which will be used to model the building elements. The modeling of the building elements offers us the ease of working with them a multiple times. The changes made to building model with respect to the number of iterations carried out during an LCCA study will make the process less effort intensive.
- Initial costs need to be calculated at the starting stage of the LCCA process. The software available for performing quantity takeoff and estimation are currently available. The features of these tools are studied with a point of view making the process much quicker as opposed to the traditional methods. The collaboration between the building

modeling tools with estimating software is noted. This is imperative for achieving an efficient way for calculating initial costs of construction.

- Since, LCCA is carried out mainly for evaluation of energy efficient options it is necessary to take in to account the energy simulation software presently in use. Here again the association between the modeling tools and simulation software needs to be understood. Here, the aspect of effective data management is also studied.
- The availability of the LCC software which offer ease in performing larger number of computations in lesser time is evaluated.
- The issues of interoperability among this software are specifically studied. Also, software which is comprehensive in nature in terms of solutions that it can offer is specifically noted.
- The objective is to look at possible BIM workflows for the LCCA process which help in two main functions, namely, data handling and data generation.

4.4 List of Building Modeling Software

The popular building modeling tools that are available are listed. These are particularly equipped with functions where parametric analysis and change management can be implemented.

- Autodesk's Revit Architecture
- Autodesk's Revit MEP
- Bentley Microstation
- Bentley Microstation PowerDraft
- Tekla Structures
- Graphisoft ArchiCAD
- Graphisoft MEP Modeler

4.5 Initial Costs

“The sum of initial and future costs associated with the construction and operation of a building over a period of time is called the life cycle cost of a facility” (Mearig et.al., Life Cycle Cost Analysis Handbook, Department of Education and Early Development, State of Alaska, 1999).

Initial costs can be defined as the costs which are required to be invested to construct the building in the first place. It is starting phase in the study and calculation of life cycle cost elements. These costs usually include the fee costs for design, legal, consulting and construction costs. The construction costs are inclusive of cost of all furnishings, equipment needed to operate the building and other costs. The changes in the future costs of the facilities which are carried out while analyzing alternatives also have an impact on the initial costs. Therefore, its analysis at the start of the life cycle cost predictions is an indispensable prerequisite (Kirk and Dell’Isola, 1995).

Initial Investment Cost /one time start-up costs can also include costs related to construction management, land acquisition, site investigation, design services, construction, equipment, technology, indirect/administration, contingency (Life Cycle Cost Analysis Handbook, Department of Education and Early Development, State of Alaska, 1999).

Initial costs can be calculated by following the popular principles of cost estimating.

The stages of cost estimating are,

- Order of Magnitude
- Conceptual/Schematic Design phase
- Design Development
- Construction Documents
- Bid Phase (Whole Building Design Guide, National Institute of Building Sciences, 2010)

Cost estimation data in form of unit rates of building elements, labor hours, material prices, equipment costs are available in various estimation publications in reasonable detailed manner. Popular sources are *Building Construction Cost Data* published by Robert Snow Means

Company, Inc. and *General Construction Estimating Standards* published of Richardson Engineering Services, Inc. (Kirk and Dell’Isola, 1995).

Some major publications for cost estimation are; (Whole Building Design Guide, National Institute of Building Sciences, 2010)

- American Society of Professional Estimators
- Building News International
- From Concept to Bid...Successful Estimating Methods by John D. Bledsoe, PhD, PE. Kingston, MA: R.S. Means Company, Inc., 1992.
- GCCRG—General Construction Cost Review Guide
- GSA Project Estimating Requirements
- R.S. Means

4.6 Operating (Energy) Costs

Energy costs are described as costs that are required to be paid for the consumption of the fuel for the functioning of the building. These include the costs of electricity, oil, natural gas, coal and other fuels. These costs are continuing costs generated on a regular basis beginning from the time when the building is being used. (Kirk and Dell’Isola, 1995) The design of the building greatly affects the performance of the building which in turn also produces varying energy costs. These costs need to be known beforehand for life cycle cost analysis. Energy simulation and analysis software are capable of providing such information depending on the detail of design. Energy prices and energy price projections are necessary for estimating these costs. Energy price projections can be obtained either from the supplier or from energy price escalation rates published annually on April 1 by DOE in ‘Discount Factors for Life-Cycle Cost Analysis, Annual Supplement to NIST Handbook 135’. (Life Cycle Cost Analysis, Whole Building Design Guide, 2010)

4.7 Cost Estimating Software Currently in Use

1. Sage Timberline Office

Sage Timberline Office is one of the products offered by 'Sage Construction and Real Estate'. Timberline office is primarily an estimating tool with added capabilities which help in achieving total integration of data and offers a single point of information control. It has the capacity to bring together information for different sources at a single location (Sage Construction and Real Estate, 2009).

This software provided by Sage Construction and Real Estate provides the following solutions, accounting, estimating, procurement, production management, project management, real estate management, reporting and productivity tools and service management (Sage Construction and Real Estate, 2009).

It has the following features that facilitate the estimating process,

- Database Builder Wizard – Allows to develop multiple estimates needed during the phases of construction. Also provides with the customization option which permits to create databases according to the user's preference. Facilitates build of database for further use which can become a single source of information (Sage Construction and Real Estate, 2009).
- Key Efficiencies – Point-and-click, drag-and-drop technology of the worksheets. It is powered with RS Means estimating databases. Can be used to classify multiple estimates by various naming and numbering conventions which when used with Internet Explorer can be used to perform searches with Estimating Explorer management tool (Sage Construction and Real Estate, 2009).
- Advanced Spreadsheet Capability – Analyzes numerous estimates and compare the results from the different estimates at the same time. Allows dragging and dropping information from one estimate into another which helps in studying alternative estimates of the different components of the building. Viewing the estimate by division or item, takeoff order, assembly, bid item or other user-defined Work Breakdown Structure (WBS) code is available and saving a different views of the same estimate which highlight different levels of detail

and can be used to make precise inferences. These spreadsheets are saved on the hard-drive which eliminates the risk of losing the data (Sage Construction and Real Estate, 2009).

- Fast Takeoff – Quick takeoff's from the databases into the spreadsheet, Item Takeoff for estimating items before entering them into the spreadsheet and Smart Assemblies for all the similar building elements in one step reducing time. These assemblies are incorporated into the application and also provide the option of modifying and creating new assemblies as required. Also called as the Model takeoff (Sage Construction and Real Estate, 2009).
- Model Estimating – Estimating by using building assemblies uses Knowledgebase of Sage Timberline Office estimating software: Electrical, Commercial or Residential, to produce fast, precise estimates. Bid, concept, or estimate can be easily calculated with the available costs, quantities, crews, hours, and waste factors database. And with Model Estimating, estimates can be easily modified and monitored as changes are made to the design or project plan. The impact of these changes can be judged, before they add up to a budget (Sage Construction and Real Estate, 2009).
- Subcontractor's Quote – Provides a location where the subcontractor quotes can be analyzed and stored with all the required information. They can be included into the estimate with a click and the estimate will get instantly be updated (Sage Construction and Real Estate, 2009).
- Database Editor – Update the database easily with the changes being updated at all the places where a certain piece of information is referenced in the estimate (Sage Construction and Real Estate, 2009).
- Digitizer Extended - Generated linear, area and counted takeoff in seconds. Eliminates the use of manual calculations (Sage Construction and Real Estate, 2009).
- ePlan Takeoff – Can be connected to On Center's Onscreen Takeoff to generate takeoffs from electronic documents (Sage Construction and Real Estate, 2009).
- Estimating TRA-SER Integrator – Estimation data is always updated with the item prices from the Trade Service Corporation using TRA-SER Integrator

which serves in obtaining accurate pricing of electrical, plumbing and HVAC components (Sage Construction and Real Estate, 2009).

- Advanced Assembly Databases – Includes Composite Database, Commercial Database, Residential Database, Concrete/Masonry Database, Site Work Database, Starter Database are few of the databases available with Sage Timberline Office. RS Means database acts as an all encompassing source of information for estimating costs for building and construction, commercial facilities, green building, mechanical, electrical, repair and remodeling etc (Sage Construction and Real Estate, 2009).

2. MC²

Interactive Cost Estimating (ICE) is the estimating software offered by MC². (MC² Products) It has the following features that facilitate the estimating process,

- Knowledge Bases – These knowledge bases form the integral part of the application. The ‘Construction Systems’ requires the dimensional information and the material specifications of the building components that are being estimated. The database is updated to calculate the quantities and provide the estimate by obtaining the information of material, labor, equipment and subcontract pricing (Management Computer Controls, Inc, 2010).
- Modules included in the databases - General Contractor's Module, Construction Manager's Module, Residential Contractor's Module, Drywall Contractor's Module, Site work, Steel Fabrication, Steel Erection, Wastewater Tanks, Industrial Equipment, Plumbing, Fire Protection, HVAC, Electrical, Instrumentation and Process Pipe Module (Management Computer Controls, Inc, 2010).
- Models - A model is a prepared line of takeoff that can free you from repeatedly entering all of the dimensions and specification selections of a frequently used detail. It is possible to create models within a few seconds to handle conceptual and detailed estimates. The libraries of these models can be repeatedly used for faster estimating (Management Computer Controls, Inc, 2010).

4.8 BIM Solutions for Quantity Take-off and Cost Estimating

1. Innovaya

A range of Innovaya software solutions are available which do have the capacity of contributing to the process of calculating the first costs in the LCCA process by applying BIM principles. Innovaya products are able to collaborate with the CAD applications to create files which can be used for performing other functions like quantity takeoff, estimating and simulation. All Innovaya software solutions interact with the CAD applications and extract the 3D geometric and parametric data in form of .INV files. These files contain the cost and scheduling information which are connected to the building elements. These .INV files are created by ‘Innovaya Composer’. It also has the capability of working on multiple CAD files and creating a single source file containing all the related information of almost all the building elements. This .INV is can be used for the Innovaya visual solutions as listed in the **Figure 9** (Innovaya, LLC, 2010).

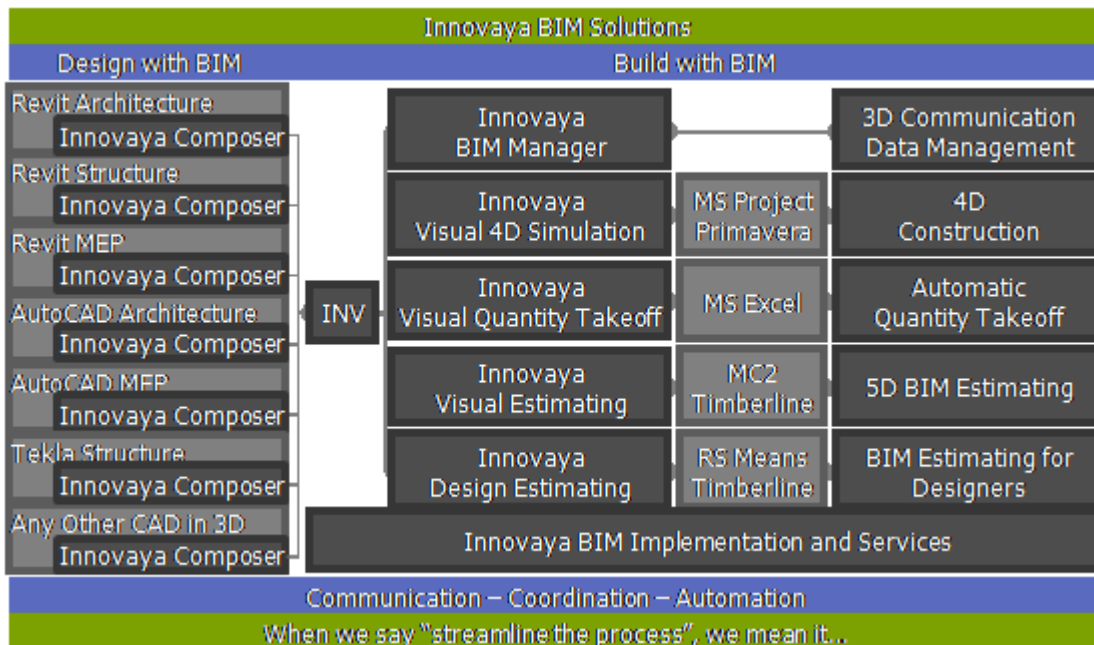


Figure 9: Innovaya BIM Solutions. (Screen Print from Innovaya, LLC 2010)

- Innovaya Visual BIM – All the models that are obtained from Revit, AutoCAD, Tekla Structures is easily visible in an interactive 3D environment. The building models can be navigated by walk through and the elements are selectable for assigning and extracting information. Also allows viewing of building components separately from the model which is usually not visible in the enclosed model (Innovaya, LLC, 2010).
- Innovaya Visual Quantity Takeoff – Can generate object quantities of the different objects within the model. The quantities are extracted based on object types and their dimensions. The quantities are classified according to the object type and the user information. It also is equipped with drag and drop feature which permits to drag any object into the quantity generation window for ease of use. The quantities can be classified according to the CSI Master Format Divisions and also color coded for easy tracking and management. It can be generated as a separate file which can be further used for the Sage Timberline Assembly and Item Takeoff. Has markup and emailing features too (Innovaya, LLC, 2010).
- Innovaya Visual Estimating - The quantities from the takeoff have direct association with MC2 ICE and Timberline Estimating construction systems and assemblies. Visual Estimating also allows the variables of the objects that were quantified to be remembered, so that as and when similar items with different variables are studied they can be quantified within seconds. The MC2 and Timberline estimates can be opened by the Innovaya Visual Estimating software. Therefore, there easy transfer of information between these software. If any changes are carried out in the model, then the changed quantities are displayed with different colors. Therefore, only those changes in the estimate will be updated (Innovaya, LLC, 2010).
- Innovaya Design Estimating – With Innovaya Design Estimating, the RS Means assemblies are made 'aware of' Revit Categories and they 'understand' how to automatically assign object dimensional values to assembly variables. Therefore, these assemblies can be automatically selected and taken-off into an estimate at run-time without wasting anytime in defining the dimensions repeatedly (Innovaya, LLC, 2010).

2. MAP Building Software Solutions

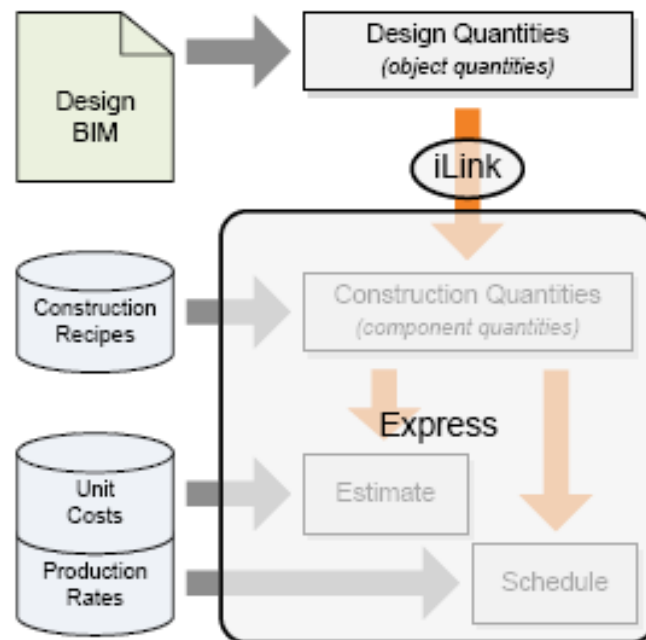
- ESTmep+ and ESTduct – ESTmep+ is MAP's estimating system for the creation and management of estimates for MEP contracts. It shares the same database with CADmep+ which is one of the products of MAP Building Software Solutions. This database is a collection of ductwork, pipe work and electrical components. The program is able to address three parameters, namely, material costs, workshop fabrication time and site installation time when preparing an estimate. The ductwork “takeoff” follows the standard and specifications present in DW144, SMACNA, etc. to meet the manufacturing standards. Some of the features include, ‘Quick Takeoff’ for generating Bill of Quantities, Schedule of Rates, Material Used, Bought out Lists, etc. It follows ‘Trace Estimating’ for fastest information generation. The models that are worked with can be viewed in multiple views such as isometric, plans, 3D, sections and elevations for obtaining accuracy of work. Also supports the integration with AUTOCAD where the changes can be made and brought back to the ESTmep+ for generating updated information. Therefore, adds/omits (change requests) can be appended to the estimate using the same schedule and price lists and history of changes can be recorded and printed as an audit-trail (Micro Application Packages Ltd, 2010).

3. TOCOMAN

- Tocoman iLink - BIM based Quantity Takeoff
This product is an add-on to Revit, ArchiCAD and Tekla which is used to analyze the models and calculate quantities from these models. These quantities can also be visible on Navisworks platform. Tocoman iLink is available for the BIM applications as stated in **Table 6**. (TocoSoft Oy, 2010).

Table 6: List of BIM Applications with TOCOMAN iLink Add-on (TocoSoft Oy, 2010)

AutoCAD Architecture	2006, 2007, 2008, 2009
Autodesk Revit Architecture	2009, 2010
Autodesk Revit Structure	2009, 2010
Graphisoft ArchiCAD	9, 10, 11, 12, 13
Tekla Structures	12, 13, 15,16

**Figure 10:** TOCOMAN iLink and Express Workflows. (Screen print from “BIM Based Quantity Take-off, Estimating and Scheduling”, TocoSoft Oy, 2010)

- Tocoman Express - BIM based Estimating
Tocoman Express integrates building information models to your existing cost estimating software. Tocoman Express is available for the leading cost estimating tools in Scandinavia and US as shown in **Table 7**. (TocoSoft Oy, 2010).

Table 7: List of estimating software having ‘TOCOMAN Express’ integration. (TocoSoft Oy, 2010)

Format	DK	FIN	NO	SWE	USA	Other
BidCon	✓		✓	✓		✓
MS Excel	✓	✓	✓	✓	✓	✓
Jydacon		✓				
MAP	✓	✓	✓	✓		
proXML		✓				
sbXML				✓		
TCM	✓					
Timberline					✓	✓

✓ - Linkage with estimating software

4. VICO SOFTWARE

- Vico Takeoff Manager – The building models from Revit, Tekla Structures and ArchiCAD can be brought into the Vico 3D environment for automatic quantity takeoff. And unique algorithm scans the 3D model to generate quantity takeoff’s defined by construction-oriented set of quantities. A bi-directional relationship exists between the model and the quantities. The building components with incorrect element properties can be easily detected and corrected. Additionally, a location-based quantity takeoff is also generated (www.vicosoftware.com, 2010).
- Vico Cost Planner – “Vico Cost Planner™ is the cost calculation, estimating, and value engineering module in the Vico Office Suite”. This application works with the quantities generated from Vico Takeoff Manager for cost estimating. The estimate can be made more detail oriented during the later phases of design as more and more detail is also obtained in the models over time. A ‘Library Manager’ is provided in the application where the user can create a knowledge database for estimation. The estimation is available in a spreadsheet form (www.vicosoftware.com, 2010).

4.9 Energy Simulation Software Currently in Use

1. eQUEST

This software is also called as the ‘Quick Energy Simulation Tool’. This achieved by combining the useful features of ‘building creation wizard’ and ‘energy efficiency measures wizard’ and is coupled with an interactive graphical display. The software allows in making assessments during the schematic design phase and the design development phase. This is possible due to the modeling capabilities during each of these phases with ‘Schematic Wizard’ and ‘Design Development Wizard’. The characteristics of the building elements and components are entered into the software similar to the information input in DOE-2. The ‘energy efficiency measures’ wizard helps in running the simulations for 9 different alternatives and obtaining the results in graphical formats for comparative analysis. The software provides an interactive display with 3D building model and components from the ‘tree’ on a vertical pane. DWG files can be imported into the application for generating the building layout and shell. Analysis period is for 1 year. It can study hundreds of day types in up to 52 seasons. There are 667 common long-term weather files of 300 North American locations (Energy Design Resources, 2010).

DOE – 2 is the energy simulation engine which estimates the energy performance of the building. The results are computed on hourly basis and the annual consumption by the building is displayed. The energy is calculated by considering the parameters, such as, the number of people, the location and specifications of walls, windows, the ventilation needs etc. The energy consumption by the equipments in the building is also considered. These equipments might include the lighting fixtures, appliances, HVAC components etc. (Energy Design Resources, 2010).

eQUEST does not provide any BIM interface directly. The only way to import 3D geometry information from a CAD program is indirectly by using a third party program Green Building Studio (GBS) that takes care of the transformation between the gbXML format model and the DOE2 input file, which is needed for eQUEST (Granlund, 2008).

2. DOE 2.2

A building energy analysis program that provides hourly information of energy use and energy cost of the buildings (Crawley et al., 2006). This software is available for free for use. The information that is required for performing the analysis is building layout, constructions, usage, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with the weather data (Building Energy Software Tools Dictionary, 2008). DOE 2.2 translates the input information with the help of inbuilt 'BDL Processor'. The input information is to be keyed in the data fields of subprograms LOADS, SYSTEMS, PLANTS and ECONOMICS (Crawley et al., 2006). Into the 'LOADS' field the nature of the materials in the building, occupancy, lighting, infiltration etc is keyed in, for 'SYSTEMS' the control conditions of the spaces and zone in the building and for 'PLANTS' data of the equipments need to be provided (Na et al., 2010).

It is suggested by James J. Hirsch & Associates to use eQUEST and PowerDOE since DOE-2.2 is the "simulation engine" contained within eQUEST and PowerDOE. The output results are usually in form of 20 user-selectable input verification reports; 50 user-selectable monthly/annual summary reports; user-configurable hourly reports of 700 different building energy variables.

"Effective 30 September 2009, DOE-2.2 is Qualified Software (DOE-2.2-047d) for Calculating Commercial Building Tax Deductions first enacted under the Energy Policy Act of 2005 (EPACT) and later extended by the Emergency Economic Stabilization Act of 2008" (EnerLogic and James J. Hirsch & Associates, 2009).

3. Energy Plus

EnergyPlus is a new-generation building energy simulation program based on DOE-2 and BLAST. EnergyPlus reads input and writes output as text files and has no graphical output reports (EnergyPlus Energy Simulation Software, 2010).

4. Autodesk Ecotect

This is sustainable building design solution from Autodesk. It is decidedly a visual energy analysis tool where the linkage between the interactive 3D model of the building and the simulations are established. The 3D models do have the capacity to work efficiently with complex building structures. The building models that are created in Revit Architecture, Revit Structures and Revit MEP can be imported into Ecotect since they are all Autodesk products (Autodesk Ecotect Analysis, Autodesk Inc., 2010).

It offers whole building energy analysis on the building model on annual, monthly, daily, and hourly basis, using a global database of weather information. Also includes the assessment of thermal performance of the building which takes into the factors of occupancy, infiltration, equipment etc. Water usage and the related costs can also be evaluated. Visualizes and calculates the effect of visible incident solar radiation on the glazed surfaces of the buildings. Also calculates the day lighting factors. An interesting feature is that it is able to sun's position and path relative to the building model (Autodesk Ecotect Analysis, Autodesk Inc., 2010).

The relationship of the building with the environment can be visually judged by the animation features present in the software. The changes in the building model, such as, its orientation, occupancy zones, material specifications, glazing and shading features, geometric and dimensional changes, the effect of outside elements entering into the built environment can be observed with an interactive changes occurring in the model for better and easy judgment. Displays results in graphical formats (Crawley et al., 2006).

5. Autodesk Green Building Studio

“Autodesk® Green Building Studio® web-based energy analysis software can help architects and designers perform whole building analysis, optimize energy efficiency, and work toward carbon neutrality earlier in the design process” (Autodesk Green Building Studio, Autodesk Inc., 2010).

This web service can be installed with an additional subscription for users of Autodesk Ecotect. The two main features in terms of energy analysis in this application are, design

alternative analysis and carbon emission reporting visible in the report shown in **Figure 11** (Autodesk Green Building Studio, Autodesk Inc., 2010).

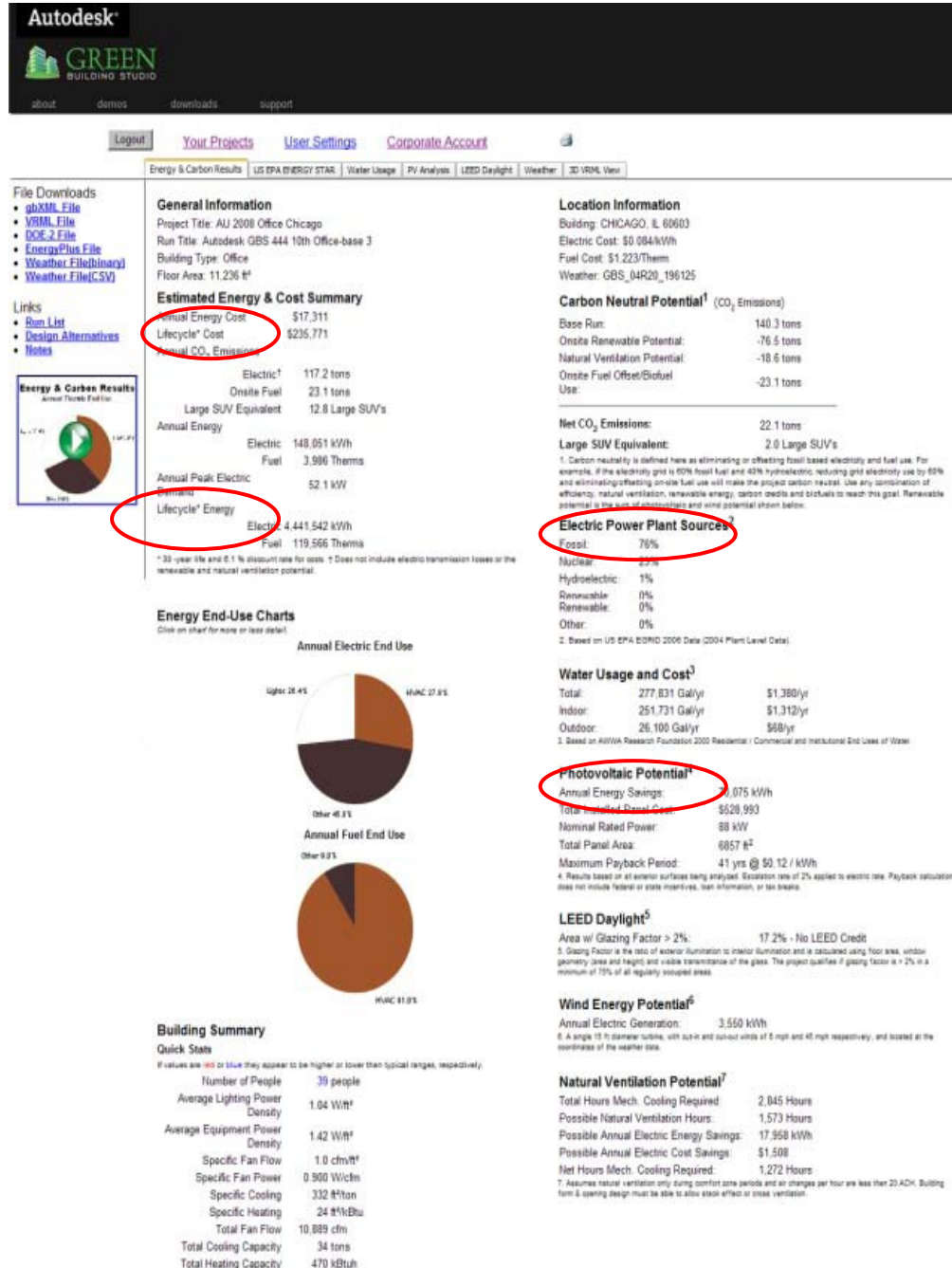


Figure 11: Energy Analysis. (Screen Print from Autodesk Ecotect Analysis, Autodesk Inc., 2010)

The energy analysis of the building model is carried out after the general project information is provided and the following results are displayed,

- Annual energy cost.
- Lifecycle energy costs (30 year).
- Annual energy consumption (electric and gas).
- Peak electric demand (kW).
- Lifecycle energy consumption (electric and gas).
- CO2 emissions are based on the on-site fuel use and the fuel sources for the electricity in the region.
- An equivalency using an SUV (driven 15,000 miles/year) is given to put the building's CO2 emissions into perspective (Autodesk Ecotect Analysis, Autodesk Inc., 2010)

The additional information available with the assessment is carbon neutral potential, electric power plant sources, water usage and cost, photovoltaic potential, LEED glazing score, wind energy potential, natural ventilation potential (Autodesk Ecotect Analysis, Autodesk Inc., 2010).

It also permits to run energy studies of different number of runs with changing alternatives to the building. The changes of each parameter are reflected in each of the output results. This allows in understanding the relationship between the lifecycle costs and the amount of carbon emissions from the building. Each of these runs is stored and can be referred back as and when required (Autodesk Ecotect Analysis, Autodesk Inc., 2010).

The building models from Autodesk Revit can be easily imported into the Autodesk Green Building Studio. Green Building Studio uses the DOE-2.2 simulation engine to calculate energy performance and also creates geometrically accurate input files for EnergyPlus and eQUEST (Autodesk Ecotect Analysis, Autodesk Inc., 2010).

The geometry data of the building can be viewed from the 3D VRML view tab. This view permits the selection of the building elements and highlights the type of surface of that particular element. The VRML file allows in detecting if the simulation has considered the surfaces and its properties for analysis (Autodesk Ecotect Analysis, Autodesk Inc., 2010).

It is not possible to import material properties into the Autodesk Green Building Studio from any BIM tool. They will have to be changed in form of design alternatives. The majority of construction, schedule and equipment defaults are ASHRAE 90.1-2004 compliant. However, some locations have energy codes that supersede ASHRAE 90.1, and in these cases the baseline energy simulation will be compliant with those regional codes. It cannot be used for daylighting studies (Autodesk Green Building Studio, Autodesk Inc., 2008).

6. DesignBuilder

This is a UK based energy analysis program with a superior modeling environment. DesignBuilder features an easy-to-use OpenGL solid modeler, which allows building models to be modeled in 3-D space using standard geometric parameters. Also provides interoperability with BIM models through its gbXML import capability. This allows you to import 3-D architectural models created in Revit, ArchiCAD or Microstation and other 3-D CAD systems supporting gbXML data exchange (Design Builder Software Ltd., 2005-2009).

Correction of missing surfaces and shading surfaces can also be easily important along with the standard building constituents. Building blocks can also be built from the 2D plans using the modeler (Design Builder Software Ltd., 2005-2009).

The energy analysis functions that are performed by DesignBuilder are;

- Evaluating a range of façade options for the effect on overheating, energy use and visual appearance.
- Checking for optimal use of natural light. Modeling lighting control systems and calculating savings in electric lighting.
- Calculation of temperature, velocity and pressure distribution in and around buildings using CFD
- Visualization of site layouts and solar shading.
- Thermal simulation of naturally ventilated buildings.
- HVAC design including heating and cooling equipment sizing.
- Communication aid at design meetings.
- Teaching building energy simulation (Design Builder Software Ltd., 2005-2009)

DesignBuilder uses the latest EnergyPlus simulation engine to calculate the energy performance of the building. EnergyPlus is a new-generation building energy simulation program based on DOE-2 and BLAST. ASHRAE worldwide design weather data and locations (4429 data sets) are included with the software and more than 2100 EnergyPlus hourly weather files are automatically downloaded as required (DesignBuilder Software Ltd., 2005-2009).

Parametric analysis screens allow you to investigate the effect of variations in design parameters on a range of performance criteria. Site shading analysis for any day of the year can be carried out. AVI movies of solar shading and scene orbit automatically generated (DesignBuilder Software Ltd., 2005-2009).

7. Integrated Environmental Solutions

IES' software can help you:

- Undertake energy performance snapshots to assess impact of design decisions
- Develop building loads and impact of conservation strategies
- Develop carbon Footprint reduction strategies
- Assess passive/hybrid/renewable strategies
- Assess the impact of daylight and solar
- Incorporate bulk airflow, ventilation and indoor air quality into the equation
- Assess compliance with a range of worldwide regulations and voluntary codes (Analysis and Green design, Integrated Environmental Solutions, 2010)

Interoperability and ease of connectivity between CAD/BIM modeling tools and our software allows working with building models from Revit®, Google SketchUp™ and Graphisoft® ArchiCAD® in IES <Virtual Environment> (Model Building, Integrated Environmental Solutions, 2010). Model merging is one of the key features which aid iterative studies. The updated models are merged together to work after the changes are made which allow studying alternative options. ModelIT has several fast-track functions that enable you to make swift changes to the model (ModelIT, Integrated Environmental Solutions, 2010).

The Google SketchUp™ IESVE plug-in can be easily used for carrying out performance analysis in terms of energy, carbon, daylight, solar and LEED (SketchUp™ plug-in, Integrated Environmental Solutions, 2010). The Revit® model when imported into the IES environment offers an interface which helps in 'Setting Model Properties' process step-by-step (Revit® plug-in, Integrated Environmental Solutions, 2010). VE-Ware, VE-ToolKits, VE-Gaia, VE-Navigators and VE-Pro are the solutions offered by Integrated Environmental Solutions. VE-Ware, VE-Toolkits, VE-Gaia and VE-Pro are the four levels of IES-VE. They are capable of performing specific tasks related to analyses of performance of the buildings and the sustainability of the same. Each of the tools needs to be applied at different stages of design and lifecycle (What Analysis When, Integrated Environmental Solutions, 2010). Geothermal Bundle (collaboration with Gaia Geothermal to offer tools for the detailed analysis and design optimization of geothermal

well fields, heat pumps and ground source heat exchanger systems (N.American Offers, Integrated Environmental Solutions, 2010).

Integrated Environmental Solutions (IES) <Virtual Environment> does support gbXML as BIM interface. All attempts to import the gbXML models were successful in the 'BIM import testing' study carried out by Granlund.

8. Bentley (Building Analysis and Design Products)

- Hevacomp – Building energy design, simulation and energy performance certification tools by using the industry-standard EnergyPlus analysis engine.
- Bentley Tas Simulator V8i – Full-featured building energy design and simulation using an custom analysis engine (Building Analysis and Design Products, Bentley Systems, 2010).

Bentley Building Mechanical System V8i is building information modeling (BIM) application that empowers mechanical engineers to create air-handling and plumbing systems for buildings and industrial plants. The software supports of DGN, DWG, gbXML, DXF, PDF, STEP, IGES, IFC, and other major industry standards, exports to CAM-Duct (M.A.P.) for automated fabrication and is able to exchange data with Energy Analysis programs such as EDSL/TAS, ECOTECH, Trace 700, Carrier HAP, Green Building Studio, etc. It is fully integrated with Bentley Architecture, Bentley Structural, Bentley® Building Electrical Systems etc (Bentley® Building Mechanical Systems, 2008).

4.10 Life Cycle Cost Analysis Software Currently in Use

1. BLCC

‘Building Life Cycle Cost’ is an application which was developed by ‘National Institute of Standards and Technology (NIST)’ to facilitate the process of LCC calculations (The Home of DOE-2 based Building Energy Use and Cost Analysis Software, 1998 – 2009). NIST believes that energy conservation projects are excellent examples for the application of LCCA (Life-Cycle Costing Manual for the Federal Energy Management Program, 1995). BLCC calculates comparative economic measures for alternative designs, including Net Savings, Savings-to-Investment Ratio, Adjusted Internal Rate of Return, and Years to Payback as shown in **Figure 12** and **Figure 13**. BLCC5 is latest version of this program (Building Life-Cycle Cost, Whole Building Design Guide, 2010).

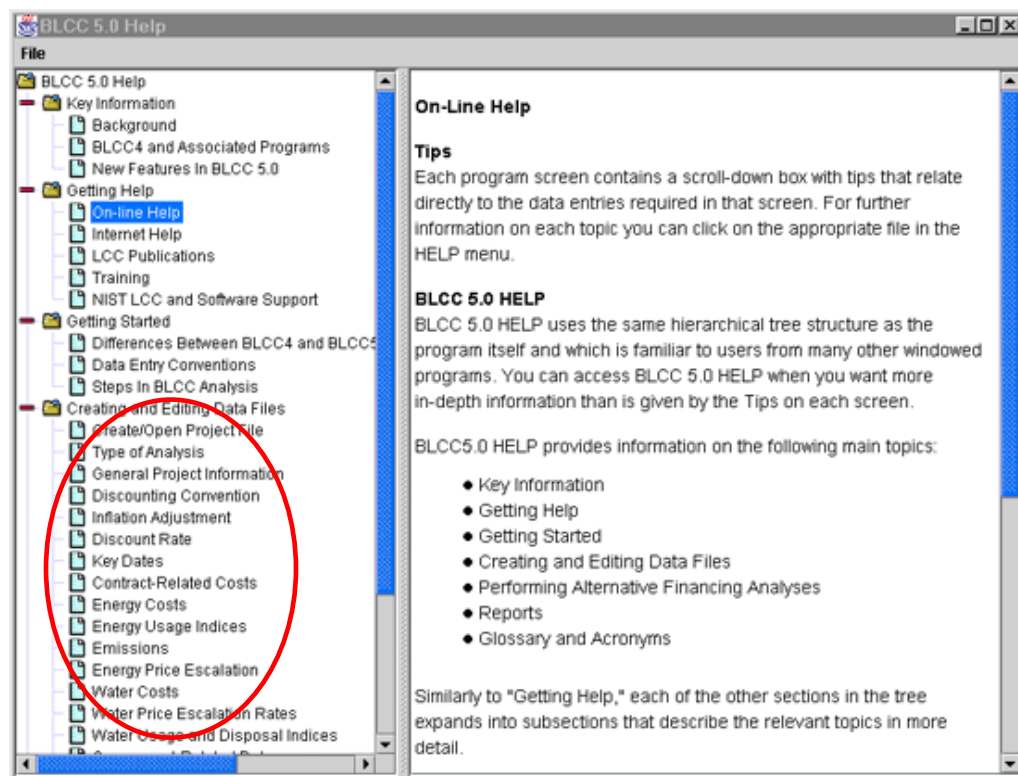


Figure 12: ‘BLCC’ Features. (Screen print from Building Energy Software Tools Directory, U.S. Department of Energy, 2008)

Comparative Analysis Report

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative	
Initial Investment Costs Paid By Agency:				
Capital Requirements as of Base Date	\$0	\$0	\$0	
Future Costs:				
Recurring and Non-Recurring Contract Costs	\$0	\$463,879	-\$463,879	
Energy Consumption Costs	\$822,018	\$372,060	\$449,957	
Energy Demand Charges	\$191,804	\$170,049	\$21,755	
Energy Utility Rebates	\$0	\$0	\$0	
Water Costs	\$0	\$0	\$0	
Recurring and Non-Recurring OM&R Costs	\$861,220	\$688,976	\$172,244	
Capital Replacements	\$0	\$0	\$0	
Residual Value at End of Study Period	\$0	\$0	\$0	
Subtotal (for Future Cost Items)	\$1,875,041	\$1,694,964	\$180,077	
Total PV Life-Cycle Cost	\$1,875,041	\$1,694,964	\$180,077	
Net Savings from Alternative Compared with Base Case				
PV of Operational Savings	\$643,956			
- PV of Differential Costs	\$463,879			
Net Savings	\$180,077			
NOTE: Meaningful SIR, AIRR and Payback can not be computed for Financed Projects.				
Comparison of Contract Payments and Savings from Alternative (undiscounted)				
Year Beginning	Savings in Contract Costs	Savings in Energy Costs	Savings in Total Operational Costs	Savings in Total Costs
Nov 2000	-\$16,940	\$6,604	\$16,912	-\$28
Nov 2001	-\$37,400	\$26,707	\$37,335	-\$65
Nov 2002	-\$44,000	\$33,850	\$44,807	\$807
Nov 2003	-\$44,000	\$34,345	\$45,643	\$1,643

Figure 13: 'BLCC Report'. (Screen print from Building Energy Software Tools Directory, U.S. Department of Energy, 2008)

BLCC version 5.3-10 contains the following six modules:

- FEMP Analysis; Energy Project: For energy and water conservation and renewable energy projects under the FEMP rules based on 10 CFR 436.
- Federal Analysis; Financed Project: For Federal projects financed through energy savings performance contracts (ESPCs) or utility energy services contracts (UESCs).
- OMB Analysis: Projects subject to the Office of Management and Budget (OMB) Circular A-94 for non-energy, Federal Government construction projects, but not water resource projects.

- MILCON Analysis; Energy Project: For energy and water conservation and renewable energy projects in military construction.
- MILCON Analysis; ECIP Project: For energy and water conservation projects under the Energy Conservation Investment Program (ECIP).
- MILCON Analysis; Non-Energy Project: For military construction designs that are not primarily intended for energy or water conservation. (Information Resources, U.S. Department of Energy, 2008)

The software is also equipped with 'Energy Escalation Rate Calculator' which helps in calculation of escalation rates based on the Energy Information Administration (EIA) energy price projections. These escalation rates are used for contract payments in Energy Savings Performance Contracts (ESPC) and Utility Energy Services Contracts (UESC) (Information Resources, U.S. Department of Energy, 2008). The program is in accordance with American Society for Testing and Materials (ASTM) and with NIST Handbook 135, Life-Cycle Costing Manual for the Federal Energy Management Program (1995 ed.). The program is updated annually on April 1st for discount rate and DOE-projected energy price changes (Building Energy Software Tools Directory, U.S. Department of Energy, 2008).

4.11 Data Access and Generation

1. Cost Estimating

- Sage Timberline –

This estimating software is equipped with an inbuilt database for estimating and also a ‘Database Builder Wizard’ to develop a customized database.

The database includes; Advanced Assembly Composite Database (> 100 assemblies), Advanced Assembly Commercial Database (> 60 assemblies), Advanced Assembly Residential Database (> 50 assemblies), Advanced Assembly Concrete / Masonry Database (> 30 assemblies), Advanced Assembly Site Work Database (> 20 assemblies) and Advanced Assembly Starter Database (> 30 assemblies) (Sage Construction and Real Estate, 2009).

The application also consists of Commercial Knowledgebase, Residential Knowledgebase and Electrical Knowledgebase which is backed by RS Means cost data (Sage Construction and Real Estate, 2009).

The RS Means cost data include Building and Construction Cost Data (BCCD), Green Building Cost Data, Civil Engineering Cost Data, Commercial Cost Data, Facilities Cost Data, Mechanical Cost Data, Electrical Cost Data, Plumbing Cost Data, Concrete Cost Data, Heavy Construction Cost Data, Interior Cost Data, Light Commercial Cost Data, Site Work/Landscape Cost Data, Repair and Remodeling Cost Data, Residential Cost Data and Square Foot Cost Data (Sage Construction and Real Estate, 2009).

Industry Databases are also provided with Sage Timberline where standard items are specified and prices need to be entered to generate the costs. These databases also have a feature of ‘Smart Assemblies’ where the takeoff quantities are required to be filled in and the costs of material and labor will immediately produced (Sage Construction and Real Estate, 2009).

- MC2

The working of MC2 is dependent on the inbuilt 'knowledge bases'. These knowledge centers consist of 'Construction Systems' that requires the user to enter the dimensions and specifications of the item to be estimated. Then the assembly logic and the formulas which are present in the system give out the estimates of the items. Modules are created to deal with specific construction elements. CSI Master Format divisions, 1 -14 are followed for the itemization. The changes in the estimate can be made with updates in the quantities and specifications and the new estimates are generated immediately (Management Computer Controls, Inc, 2010).

2. BIM Tools for Cost Estimating

- Innovaya

Innovaya Visual estimating has complete relationship with the estimating software, namely, Sage Timberline and MC2 – ICE. The building models which are created using the building modeling tools are converted into .INV files which are used for visual estimating and design estimating. The quantities are extracted from 'Innovaya Visual Takeoff' can be classified according to the CSI Master Format and Unifomat divisions. These quantities can be estimated in the construction systems, assemblies or items present in the MC2 – ICE and Sage Timberline engines. They can be opened directly in the Innovaya platform. The association between Innovaya estimating platforms and the modeling tools are such that the RS Means assemblies are linked with the 'Revit Categories' and dimensions are assigned directly to the assemblies. The estimates are based on the City Cost Index in North America (Innovaya, LLC, 2010).

- MAP Software Solutions

ESTmep+ and ESTduct are two estimating software which share the inbuilt databases with their designing software CADmep+ for easy transfer of information in terms of libraries, formats etc. The prices are calculated from the point of view of material content, workshop fabrication time and site installation time. The industry suppliers provide the information regarding the pricing of

'bought out' items. The handling of this type of information is made easy by the presence of import/export facilities helping in improved communication (Micro Application Packages Ltd, 2010).

- TOCOMAN

'TOCOMAN Express' is the solution offered which combines the models developed by the modeling software with the existing estimating applications used. The data is generated from the estimating software in use such as Sage Timberline, Excel etc (TocoSoft Oy, 2010).

- VICO Cost Planner

The estimating data in this software is managed by a 'Library Manager'. As stated on the website, the Library provides

- a. Construction activity sets for over 3,000 building elements coded by CSI Uniformat
 - b. Formulas to derive labor and material resources for over 6,000 individual constructions activities classified by CSI Master Format
 - c. Industry standard productivity rates and resource requirements for over 2,500 project tasks
- (VICO Cost Planner FAQ's, VICO Software, 2010).

If the company has an already developed data in MS Excel or Sage Timberline and wants to use it in the VICO Cost Planner, importing of this kind of data is possible. LEED data can also be incorporated (VICO Cost Planner FAQ's, VICO Software, 2010).

An estimator needs VICO Office Client, Takeoff Manager, Cost Planner, and Cost Explorer to incorporate BIM models into their estimating process (VICO Cost Planner FAQ's, VICO Software, 2010).

3. Energy Simulation Tools

- eQUEST

The simulation engine used by eQUEST is an advanced derivative of DOE-2. The weaknesses of DOE-2 engine have been overcome and an improved version is eQUEST. The heating and cooling loads are based on the contributions from walls, windows with shading, people, plug loads, and ventilation and simulated the performance of fans, pumps, chillers and all other energy consuming building equipments. The data generated in form of hourly, monthly and annual consumption of electricity in kWh/MWh, gas consumption in Btu etc. Parametric calculations can also be carried out between 9 alternatives (Energy Design Resources, 2010).

- DOE 2.2

The newest DOE-2 building energy simulation and cost calculation engine is DOE-2.2. DOE2.2 consists of a building simulation engine and a cost calculation engine. The energy simulation engine is used in eQUEST. In this new version, the 'SYSTEMS' and 'PLANT' modules have been combined into 'HVAC'. And then the utility rates are calculated by 'ECONOMICS'. The new version also has, a new command called the 'MATERIALS-COST' which defines the costs associated with a given primary equipment component. These costs include first costs, operating costs (other than energy), maintenance costs and intervals, etc. Components such as CIRCULATION-LOOPS, PUMPS, and CHILLERS reference this command. The utility rates are calculated by the use of ELEC-METER command which defines 3 levels of meters. As with ELEC-METERS, one can define multiple FUEL-METERS and define the TYPE of fuel used. Each FUEL-METER is then connected to a UTILITY-RATE for calculation of costs (Overview of DOE2.2, University of California and James J. Hirsch, 1998).

- Energy Plus

It has combined the best capabilities of BLAST and DOE-2. The input and the output are in the form of text files.

- Autodesk Ecotect

The 3D interactive space allows in importing building models from Revit for analysis. The types of analysis that can be carried out are acoustical analysis, determining artificial lighting loads, daylighting requirements, shadow and reflection analysis, solar radiation analysis, ventilation and airflow analysis, thermal and analysis.

- **Shadows and Reflections**

As stated by Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals (2004 – 2009); Autodesk Ecotect estimates the position of the sun relative to the location of the building. This allows in understanding the relationship between sunlight and its effect on the spaces of the building. The window systems display the path in sunlight enters the building spaces. The shadow areas and the illuminated areas can be tagged for better visualization shown in **Figure 14**.

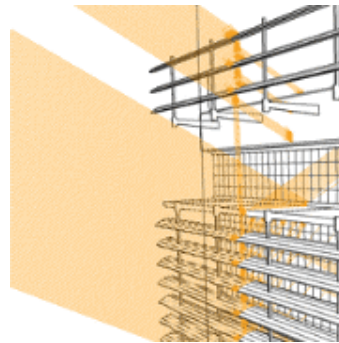


Figure 14: Shadows and Reflections. (Screen print from Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals, 2009)

- **Solar Analysis**

As stated by Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals (2004 – 2009); Autodesk Ecotect, is able to visualize incident solar radiation on windows and surfaces, of the building depending in the site characteristics. The incident solar

radiation can act as a source of energy. Therefore, the location of the site where the number of buildings present and the obstruction offered to the solar rays reaching the building are clearly visible, **Figure 15**.

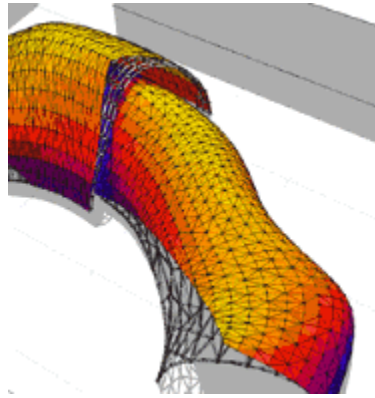


Figure 15: Solar Analysis. (Screen print from Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals, 2009)

- **Photovoltaic Array Sizing and Load Matching**

As stated by Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals (2004 – 2009); calculate the amount of solar radiation falling on any object, along with shading and reflection percentages. This is helpful in estimating the energy production by calculating the solar radiation received during the entire year and helps in analyzing the sizing and orientation of photovoltaic panels.

- **Lighting Design**

As stated by Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals (2004 – 2009); calculate daylight factors and luminance levels at any point in the model which helps in determining the savings in electricity costs by efficient daylight studies which can be easily visualized in the 3D environment. **Figure 16**

displays the amount of area under light from the windows and the area requiring artificial lighting.

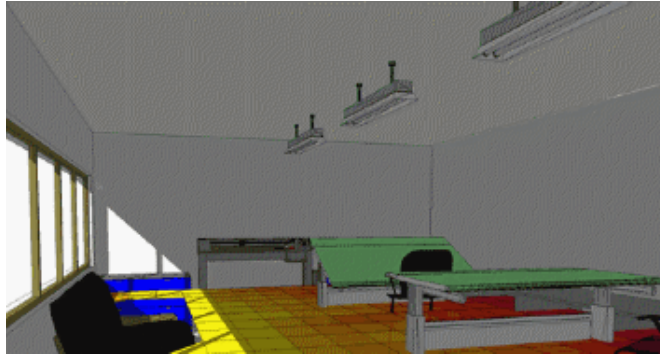


Figure 16: Lighting Design. (Screen print from Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals, 2009)

- **Right-to-Light**

As stated by Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals (2004 – 2009); analyze site projection angles, assess obstructions, calculate vertical sky components for any point or surface, and visualize the no-sky line in any space. Estimates the incident light planes and angles entering into the building areas shown in **Figure 17**.

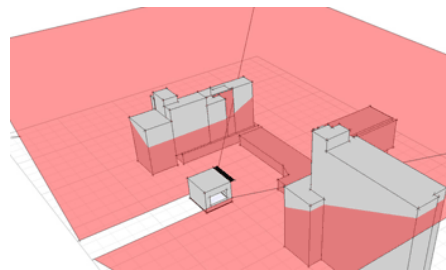


Figure 17: Right to Light. (Screen print from Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals, 2009)

- **Acoustic Analysis**

As stated by Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals (2004 – 2009); acoustic analysis options range from simple statistical reverberation times to sophisticated particle analysis and ray tracing techniques seen in the **Figure 18**.

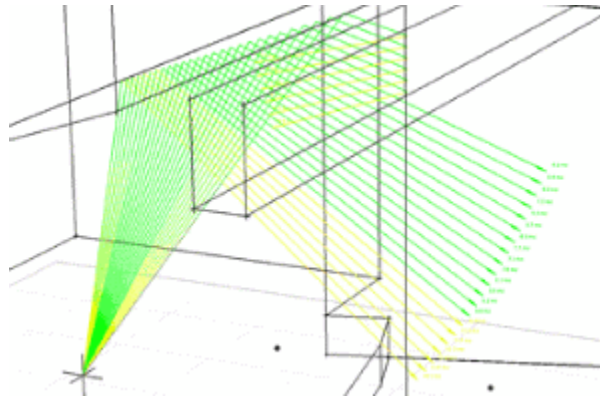


Figure 18: Acoustical Analysis. (Screen print from Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals, 2009)

- **Thermal Analysis**

As stated by Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals (2004 – 2009); thermal analysis primarily includes the computation of the load requirements of the building depending on the geometry, orientation and the number of zones. The material properties of the building elements are to be assigned and the thermal performance of the facility depending on the number of people, infiltration and the equipments in the building.

- **Ventilation and Airflow**

As stated by Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals (2004 – 2009); it is possible to generate grids or patterns for analysis for airflow. These are imported into CFD tools

which perform investigations. These can again be placed into the building geometry for visualizing the movement of air in the building. The grids and the airflow are represented in **Figure 19**.

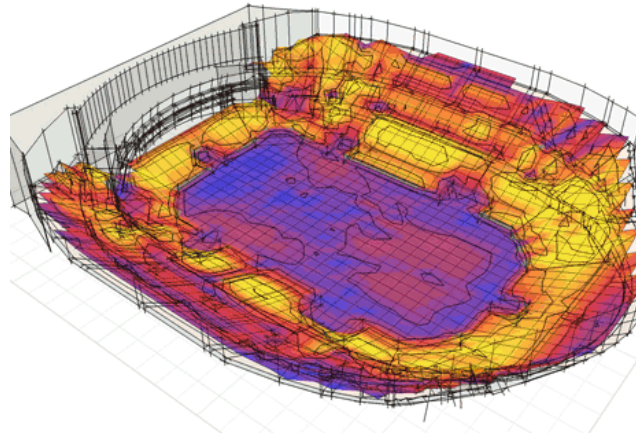


Figure 19: Thermal Analysis. (Screen print from Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals, 2009)

After performing the above functions Autodesk Ecotect, the changes that are required in the design for achieving the desired performance can be made easily, for example, resizing the shape of openings, play with the zoning of the spaces in the building; choose materials for the building elements depending on the daylight factors, thermal behavior, glare protection, acoustic comfort etc. (Questions and Answers, Autodesk® Ecotect™ Analysis 2010, 2009).

The software is equipped with a customizable material's library where the properties and specifications can be altered as per requirements and implementing design changes. The changes to the material properties are stored and are available to the different users. Autodesk Ecotect Analysis uses the Chartered Institute of Building Services Engineers (CIBSE) Admittance method for its internal thermal calculations. The software can also export to a range of other thermal analysis tools such as the Autodesk Green Building Studio web-based service, EnergyPlus, HTB2, and ESP-r. It is also important to note that, the analysis can be carried out at the conceptual schematic design phase to yield

the desired level of information. The basic building layout with defined zones, wall partitions, orientation is able to give detailed results. A more detailed building model will not necessarily give an improved set of results (Questions and Answers, Autodesk® Ecotect™ Analysis 2010, 2009).

The weather data for any location can be obtained by importing the weather data from 'Building Technologies Program' by the U.S Department of Energy and loading it into the Autodesk Ecotect platform. These weather data are present in the EnergyPlus format.

- Autodesk Green Building Studio

This is a web-based service from Autodesk for whole building energy, water and carbon analysis. By 2007 its analysis results had met ASHRAE Standard 140 and were certified by the U.S. Department of Energy (BIM and the Autodesk Green Building Studio, 2008).

It uses DOE-2.2 energy simulation engine for building energy analysis and carbon footprint calculations. The carbon emissions are inclusive of the emissions from the building site due to its functioning and the emissions released by the power plants which supply electricity to the building for the fuel type under use. Water usage and the related costs can also be calculated depending on the building type and number of people. Alternatives in terms of efficient water usage can be studied, for example, the use of natural vegetation, water-saving fixtures etc. The LEED credits for these alternatives can also be measured. The capacity of the external surfaces of the building to be used as a source of energy from photovoltaic's can also be measured and is enlisted in the results. Each building design receives a United States Environmental Protection Agency ENERGY STAR® score. The ENERGY STAR score is the basis for the Architecture 2030 goals for carbon and fossil fuel reduction. The report also includes the points that can be achieved for LEED daylighting credits. A few unique features that Autodesk Green Building Studio calculates are the wind energy potential and natural ventilation potential of the building under analysis.

The wind energy potential specifically computes the amount of electricity generated by the 15-foot wind turbine every year based on the location of the building. Depending on the wind data of the location, it assess if natural source of outdoor air can be used for cooling the building in place of depending on the artificial mechanisms. The results are used to make the necessary changes in the design of the building (Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals, 2004 – 2009).

A Google Maps™ view displays weather stations, distances, and land and water features, to precisely locate the project. This location is essential for deriving the electricity and the water usage costs. As shown on the **Figure 20** and **Figure 21** the water prices are being estimated (Duncan and Parnell, Solutions for Architects, Surveyors, Contractors and Design Professionals, 2004 – 2009).

As shown in the image below, the costs generated in term of energy consumption, water usage, electric power sources, life cycle, carbon emissions are generated in the report after the analysis. The users of this application can assign varying alternatives to recalculate the costs related to the changes in the design. The alternatives can be applied in the building model and the changes can be studied and then again rerunning the analysis (BIM and the Autodesk Green Building Studio, 2008).

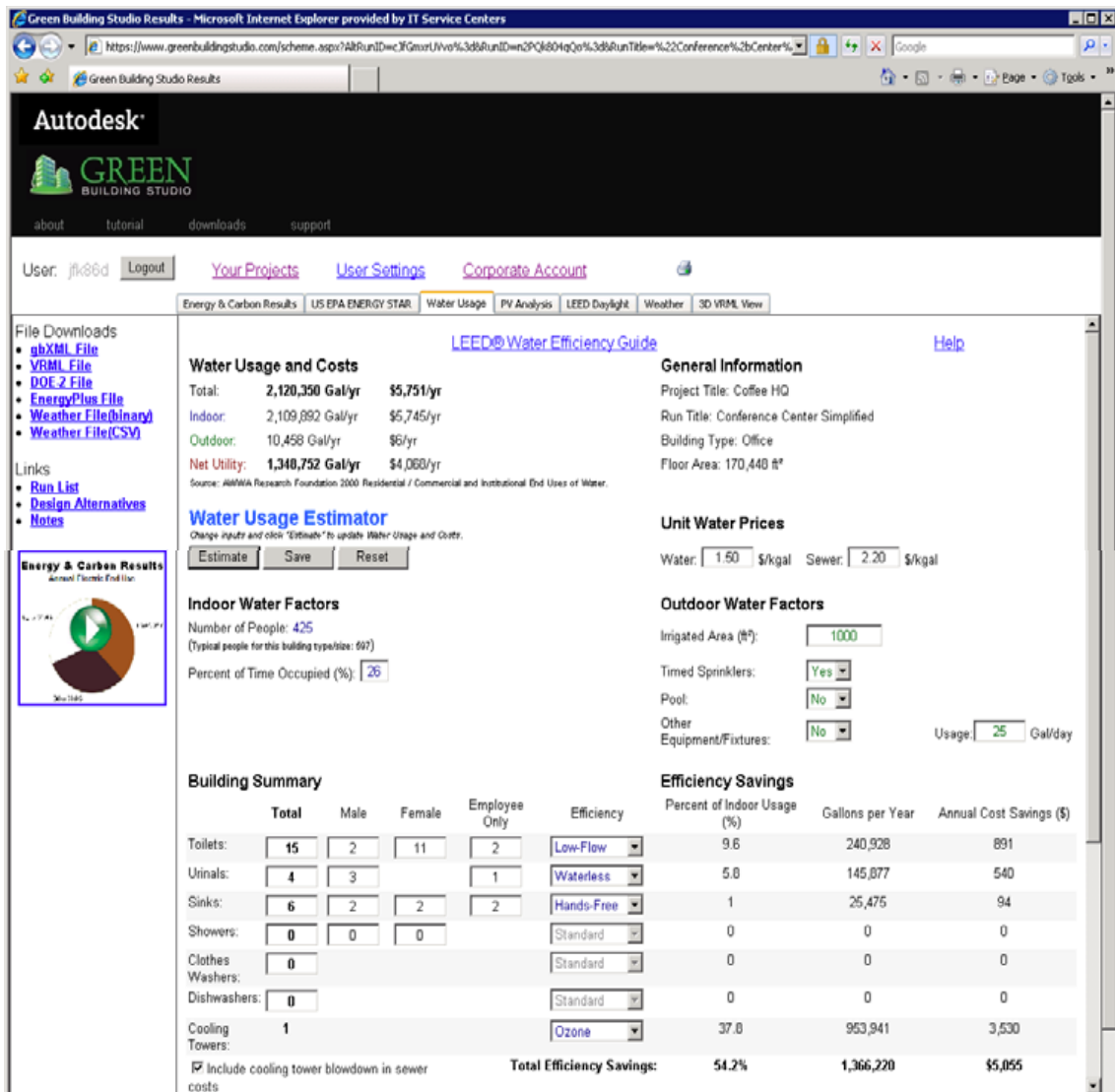


Figure 20: Water Usage and Costs. (Screen print from BIM and the Autodesk Green Building Studio, 2008)

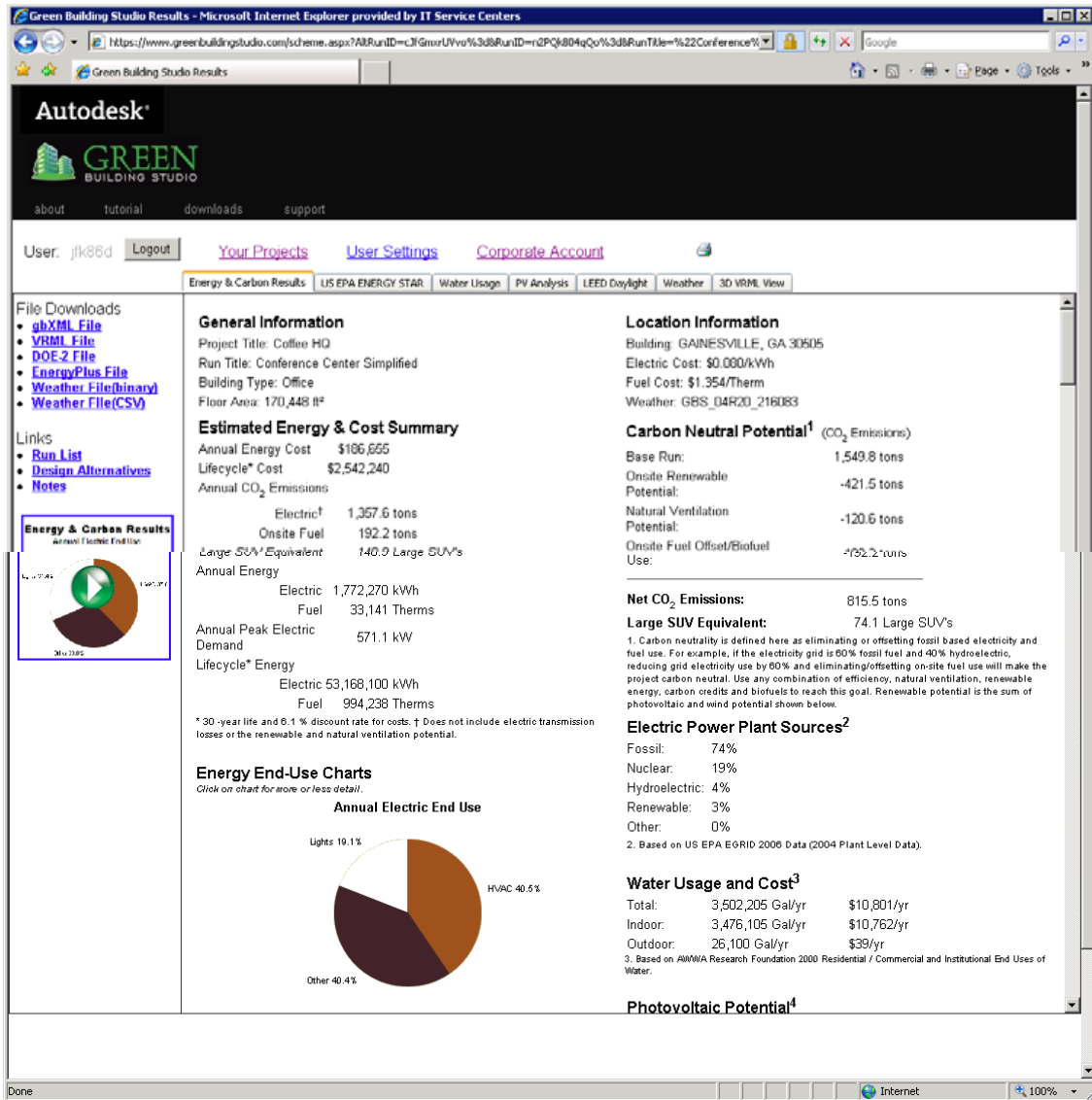


Figure 21: Estimated Energy and Cost Summary. (Screen print from BIM and the Autodesk Green Building Studio, 2008)

- DesignBuilder

The data that is used for energy analysis in DesignBuilder are Latest ASHRAE worldwide design weather data and locations (4429 data sets) are included with the software and over 2100 EnergyPlus hourly weather files and UK NCM databases and also equivalent ASHARE construction, activity and schedule data (DesignBuilder Features, 2005-2010).

The National Calculation Method for the EPBD (Energy Performance of Buildings Directive) is defined by the department for Communities and Local Government (CLG). This is a procedure for demonstrating compliance with the Building Regulations for buildings. Both calculations make use of standard sets of data for different activity areas and call on common databases of construction and service elements. The NCM therefore comprises the underlying method plus the standard data sets (National Calculation Method, 2009).

The software has a link with 'Radiance' daylight simulation software which is used for performing the daylight simulations which is inclusive of the following features, dealing with sky models, evaluating daylight indoors from the point of view of illuminance levels, daylight measurements along with measuring sky brightness etc. As quoted by John Mardaljevic, "'Radiance' system can be used to predict illumination levels and visual appearance under daylight conditions for virtually any building design" (Mardaljevic, 1998).

The behavior of airflow rates, surface temperatures and requirements of thermal comfort are observed by using 'Computational Fluid Dynamics' for in-depth analysis. The CFD analysis can also include results from EnergyPlus simulations. DesignBuilder has an interface with EnergyPlus and the model can be imported onto the EnergyPlus platform for ASHRAE 90.1 compliance work and for evaluating LEED credits (Building Performance Analysis Software, DesignBuilder, 2005 - 2009).

Simulation of building performance is carried out at two levels, namely, by using their proprietary simulation engine 'DSim' and detailed analysis by using the EnergyPlus environment. DesignBuilder is supplied with a large database of common constructions, glazing systems, usage patterns, HVAC and lighting systems and ASHRAE international weather data. DesignBuilder comes with 4500 international locations and design weather data sets, and over 2200 hourly weather data locations (Building Performance Analysis Software, DesignBuilder, 2005 - 2009).

The additional weather data for unavailable locations obtained from 'Meteonorm' which encompasses the meteorological information of any location across the world. This information can be accessed and used as essential data that is required for design of building systems and evaluating them in terms of solar studies, weather details etc. Also has the calculation procedures enlisted. (Meteonorm, 2010).

'SBEM' (Simplified Building Energy Model) is a simplified tool which provides an analysis of a building's energy consumption primarily for the purposes of assessing compliance with Part L (England & Wales), Section 6 (Scotland) and Part F (Northern Ireland) of Building Regulations and eventually for building performance certification EPBD in UK. This form of calculations can be performed by Design Builder and are thereby useful in determine BREEAM credits (Building Energy Software Tools Directory, 2008).

- Integrated Environmental Solutions

VE-Ware is a completely free whole-building annual energy and carbon usage tool. This tool utilizes 'ApacheSim' dynamic thermal analysis software to provide indicative comparison results. This is in-house facility from IES <Virtual Environment>. Some of the application areas of 'ApacheSim' are Thermal performance analysis, Building fabric design, Occupant comfort analysis, Natural ventilation studies, Façade analysis, Energy consumption prediction, Plant design and sizing, Mixed-mode design, Carbon emissions etc. It works on 'Integrated Data Model (IDM) platform'. The links of the software are with 'ApacheHvac' for HVAC simulation, MacroFlo for air flow and natural ventilation, 'SunCast' to account for external shading and internal solar tracking and 'ApacheCalc' for heat calculations (ApacheSim – dynamic thermal simulation, 2006).

The type of input data available with 'ApacheSim' are wide-ranging database of global weather data, thermophysical properties of building elements, glazing systems, Sensible and latent gains from lights, equipment and occupants, fuel characteristics etc (ApacheSim – dynamic thermal simulation, 2006).

The output data that is received are in terms of calculated totals of room and ventilation loads, HVAC loads, carbon emissions for system and building, optionally broken down by fuel etc. It also supports compliance with 'UK Building Regs Part L and Part J (ApacheSim – dynamic thermal simulation, 2006).

The software enables target performance of the building models under study against 'Architecture 2030' requirements of North America and VE-SBEM tool for regulation compliance and Energy Performance Certificate (EPC) generation for the UK (VE-Ware, 2010).

'VE-Toolkit' is used for mapping the progress of the design in terms of building performance. It gives us immediate feedback on the temporary designs and acts

as a confirmation tool to the design approach. From the sustainability standpoint, 'VE-Toolkit' is equipped with climate metrics where the analysis of the climate location is carried out with the required design responses. The output is on ASHRAE/Koeppen-Geiger climate classification, temperature, moisture/humidity, wind, precipitation, solar energy, diurnal swing and Mahoney comfort stress analysis. The in-house IES building rating index performs a global comparison in terms of energy usage of the building depending on the climatic conditions. The natural resources are also tabulated. Also, understands the characteristics of the building, such as, glazing properties, skin of the building, ventilation etc. along with a materials review. Energy simulation against Architecture 2030 Challenge, water reduction measures with LEED, BREEAM and Green Star calculation approaches, daylight assessment, low/zero carbon technologies are additional tools (VE-ToolKits, 2010).

Following LEED credits indicators are assessed, daylighting LEED Credit EQ 8.1, comfort LEED credit EQ7.1, LEED credits for water, renewables LEED credits EA2 and EA6. Green Star credits in the categories of daylighting, water and comfort are also analyzed. VE-Toolkit for LEED India is also provided (VE-ToolKits, 2010).

'VE-Gaia' is the comprehensive and a more detailed analysis of the building models with a series of workflows and tasks (VE-Gaia, 2010). The IES 'VE-Navigators' is a tool for investigating the conformance of the building design with the global codes and standards (VE-Navigators, 2010). They share an interface with the VE products such as VE-Pro and VE-Gaia, which can transport the data into VE-Navigator for assessment for LEED credits, Green STAR score etc (VE-Navigators, 2010).

The core of the <Virtual Environment>, VE-Pro is IES' is one of the more in-depth suites of building performance analysis tools. The unique feature is the Value/Cost option. This option provides evaluation on three bases, namely, Deft

– value engineering approach, CostPlan – capital cost forecasts, Lifecycle – LCC calculations (VE-Pro, 2010).

Deft – Based on the value engineering approach, Deft promotes the comparative analysis between different design options. A ‘base case’ scenario is established and a number of parameters are tried against the base scenario. The parameters are judged by an all inclusive discussion between the players of the design. These parameters are also assigned ‘weighting factors’ to reflect the importance of the option. The assessment parameters range from building characteristics, energy performance, capital costs, lifecycle costs etc (VE-Pro, Deft, 2010).

CostPlan – This feature develops the capital cost of the whole building and systems costs, including pipework, ductwork and electrical cables. The CostPlan carried out the measurements of the building and creates code for each element quantified and the costs can be assigned to these codes to generate an estimate. The similar such function is carried out for the mechanical and electrical systems. The ‘Bill of Quantities’ can be updated along with the changes in the model as we go further with the design (VE-Pro, CostPlan, 2010).

LifeCycle – This is primarily to perform LCCA investigations. It has been realized by IES that besides the capital costs of the building, operating costs contribute to a greater risk in the performance of the building over its lifetime. The cost items considered are the capital costs, electricity and fuel costs, maintenance costs and repair costs. The period for analysis can be maintained from 26 to 50 years. LifeCycle calculates the Net Present Value (NPV) for the particular option, based on inflation rates and the anticipated life of the building. The costs for each of these items need to be entered to get the desired results along with the inflation rates for power and fuel (VE-Pro, LifeCycle, 2010).

VE – N.American is equipped with a unique feature where design and performance of geothermal systems can be investigated. Geothermal systems involve specialized equipments such as, bore wells, horizontal/vertical

circulation loops etc. The thermal loads that have been calculated by 'ApacheSim' will be transferred directly in 'Ground Loop Design' (GLD) software where the analyses from the point of view of geothermal requirements are carried out. This software enables the designers to estimate the sizing of equipments, lengths of the bore/pipe, decide the layout of the circulation pipes. The GLD software is also able to perform energy analysis or estimate the performance of the system. This allows in also computing the lifetime associated costs required for functioning of the geothermal system. The uses and implications of the system can be understood from this evaluation (VE-N.American Offers, 2010).

- Bentley (Building Analysis and Design products)
The Bentley Solutions follow ISO, CIBSE, and ASHRAE standards. Compliance with U.K. part L2, Australia part J, and the U.S. Green Building Council's LEED program can be judged. Bentley Hevacomp Simulator V8i provides a quick and easy way to perform building energy analysis using Dynamic Simulator with EnergyPlus. The simulation results are used for calculating the sizing requirements of the entire system which are enlisted in form of schedules. Annual energy consumption can be computed, together with fuel cost and CO₂ consumption. (Bentley Hevacomp Simulator V8i, 2008)
Hevacomp Pro EP Cert is a fully accredited standalone CAD EPC (Energy Performance Certificate) program for the energy assessment industry (Building Analysis and Design Products, 2010).

4. Life Cycle Cost Analysis Software:

- Building Life Cycle Cost Program (BLCC)
This is a life cycle cost analysis tool, specifically targeted at energy conservation and water efficient federal projects. BLCC complies with ASTM standards related to building economics and the NIST's handbook. The changes in the energy prices are updated regularly in this program because they are linked to the U.S. Department of Energy data.

Reports by project alternative:

- Input data file listing
- Summary of life-cycle cost analysis
- Detailed life-cycle cost analysis
- Yearly cash flow analysis

Reports comparing project alternatives:

- Identification of lowest life-cycle cost alternative
- Comparative economic analysis between any two alternatives, including Net Savings
- Savings-to-Investment Ratio, Adjusted Internal Rate of Return on investment, Payback Period, annual energy savings (in physical units), and reductions in air pollution emissions

Figure 22: Reports Generated by BLCC. (Life Cycle Costing Manual for Federal Energy Management Program, 1995)

The software can also be used for general projects, but the data relating to financing variables and tax-related variables have to be entered by the user. The input data is keyed in to the program in a step-wise process. The inputs are initially for the lifecycle period, construction period, discount rate, resale value at the end of the period. The other set of data is concerned with the annual energy and water consumption and their related costs. For the federally managed projects financing variables and tax-related variables are available by DOE and NIST. BLCC diskette also includes a stand-alone program DISCOUNT which computes present values of future and periodic amounts, future values of present and periodic amounts, and annual equivalents of present and future amounts. Another stand-alone program is ERATES which generates rates for electricity prices. The output reports are according to the **Figure 22**.

- eVALUator

This tool is used for calculating the life cycle benefits of the design options that are applied to a project. It targets the benefits related to measures that reduce the energy costs. An eVALUator financial analysis considers the following factors over the life of a project: financing costs, tax implications, energy costs, replacement costs and intervals, operation and maintenance costs, opportunity costs for money (discount rates), the impact of inflation and non-energy benefits

(such as improved occupant productivity and tenant retention). Net present value of lifecycle costs and savings, savings-to-investment ratio and adjusted internal rate of return are calculated. Unique feature of this program is that all the results are tied to uncertainty parameters. eVALUator's uncertainty analysis also helps quantify the level of risk associated with specific decisions. "In addition, the uncertainty values used are related to the project design and development timeline, which means that the default uncertainty values will change over time according to the features of the project under study".

- There are many spreadsheet applications that in use by government agencies tailored to their requirements. For example, ELCCA (Energy Life Cycle Cost Analysis) used by General Administration, State of Washington and Life Cycle Cost Assessment Model developed by Government of California for their 'Green Initiative' program.

5. ANALYSIS

5.1 BIM integration with LCCA

5.1.1 BIM and Quantity Take-off and Estimation

The features BIM software performing quantity takeoff and estimation are summarized in **Table 8**.

Table 8: Building Modeling Tools Performing Quantity Takeoff and Estimation

No.	Software	Solution	Supports importing building models	Link with estimation software
1.	Innovaya	Innovaya Visual Takeoff and Innovaya Visual Estimating	Revit Architecture, Revit MEP, Revit Structures, Tekla Structures	Sage Timberline and MC2 – ICE
2.	MAP Software	EstMAP and EstCAD. No Quantity Takeoff	CADmep+	---
3.	TOCOMAN	Tocoman iLink and Tocoman Express	Revit Architecture, AUTOCAD Architecture, ArchiCAD, Tekla Structures	Sage Timberline, MS Excel and BidCon
4.	Vico Software	Vico Takeoff Manager and Vico Cost Planner	Revit Architecture, Revit MEP, Revit Structures, Tekla Structures, ArchiCAD	Vico Cost Planner performs estimation

5.1.2 BIM and Energy Simulation Software

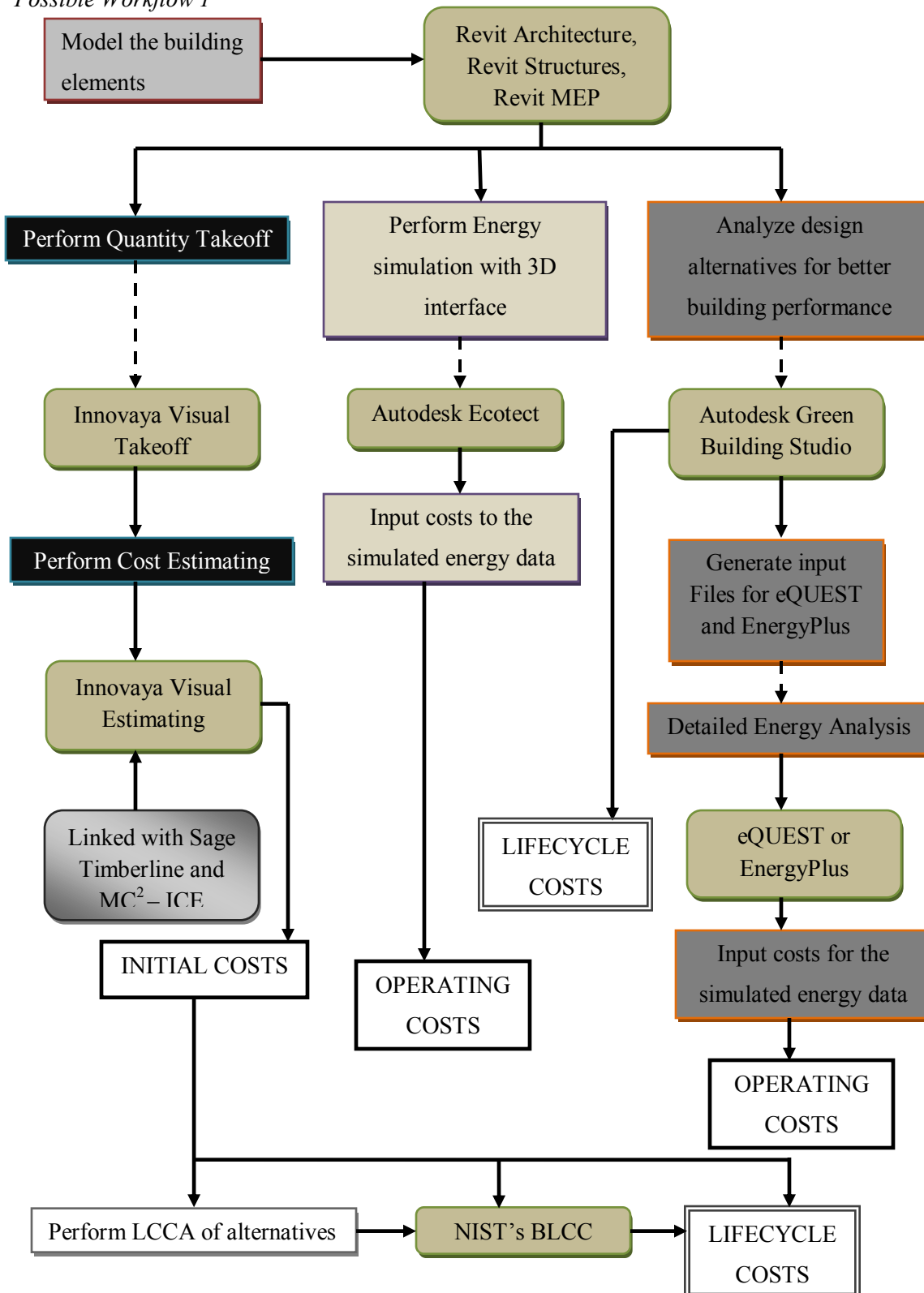
The features BIM software that can perform or facilitate energy simulation is listed in **Table 9**.

Table 9: Building Modeling Tools Performing/Facilitating Energy Simulation

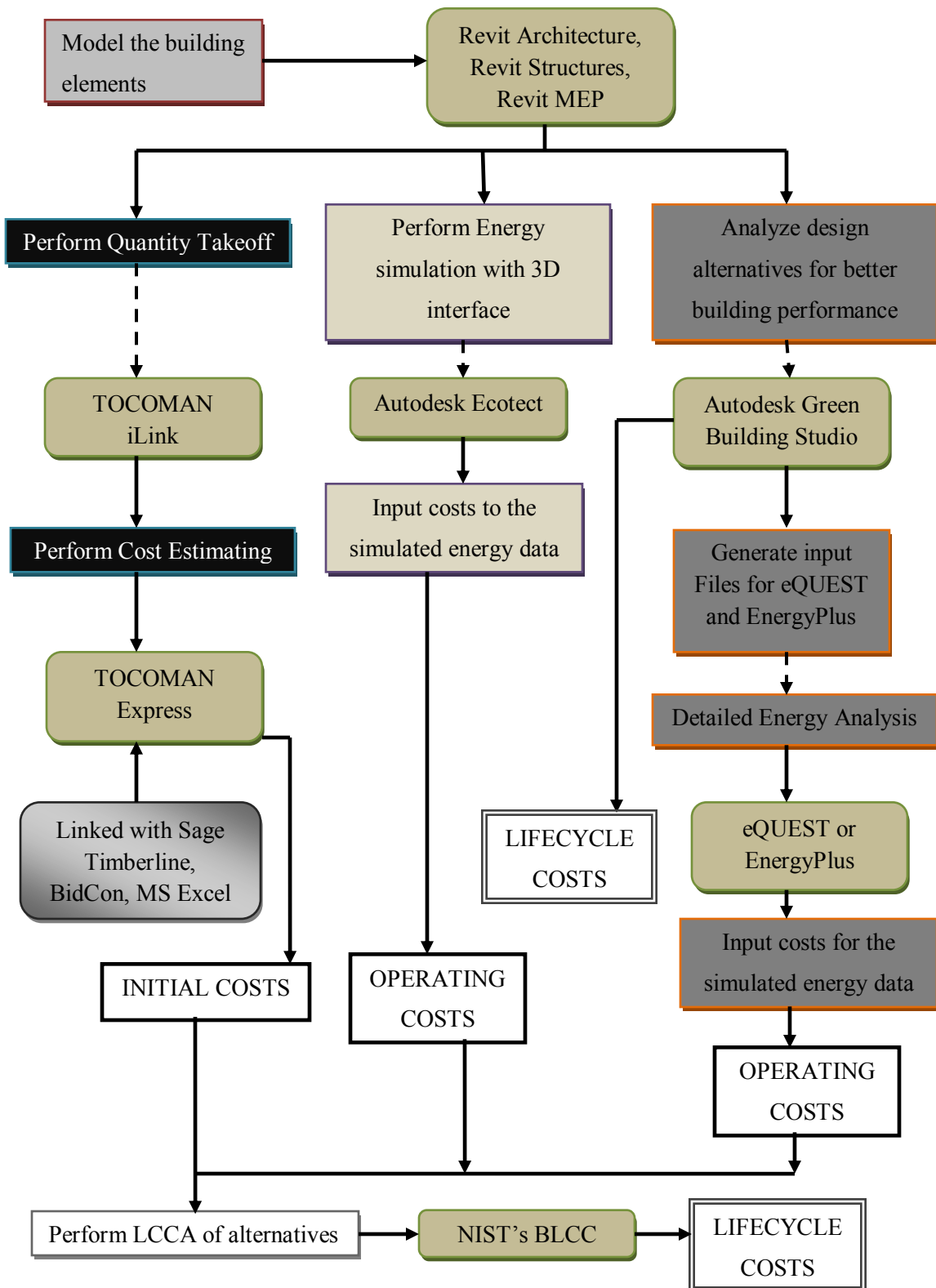
No.	Software	3D Graphical Interface	Supports importing building models	Energy Simulation
1.	eQUEST	3D interface provided to model buildings	Cannot import 3D building models. Can import DWG files.	Interactive version of DOE-2
2.	DOE 2.2	---	---	
3.	Energy Plus	---	---	Based on DOE-2 and BLAST
4.	Autodesk Ecotect	3D interface provided to model buildings and import 3D models	Revit Architecture, Revit MEP, Revit Structures	DOE – 2
5.	Autodesk Green Building Studio	No graphical interface. Allows to import 3D models	Revit Architecture, Revit MEP, Revit Structures	DOE – 2
6.	Design Builder	3D interface provided to model buildings and import 3D models	Revit Architecture, Revit MEP, Revit Structures, ArchiCAD, Bentley Microstation	DSim and EnergyPlus
7.	Integrated Environmental Solutions	3D interface provided to model buildings and import 3D models	Revit Architecture, Revit MEP, Revit Structures, Google Sketchup and ArchiCAD	ApacheSim
8.	Bentley	3D interface provided to model buildings and import 3D models	Integrated with Bentley products	EnergyPlus

5.1.3 Possible BIM Workflows

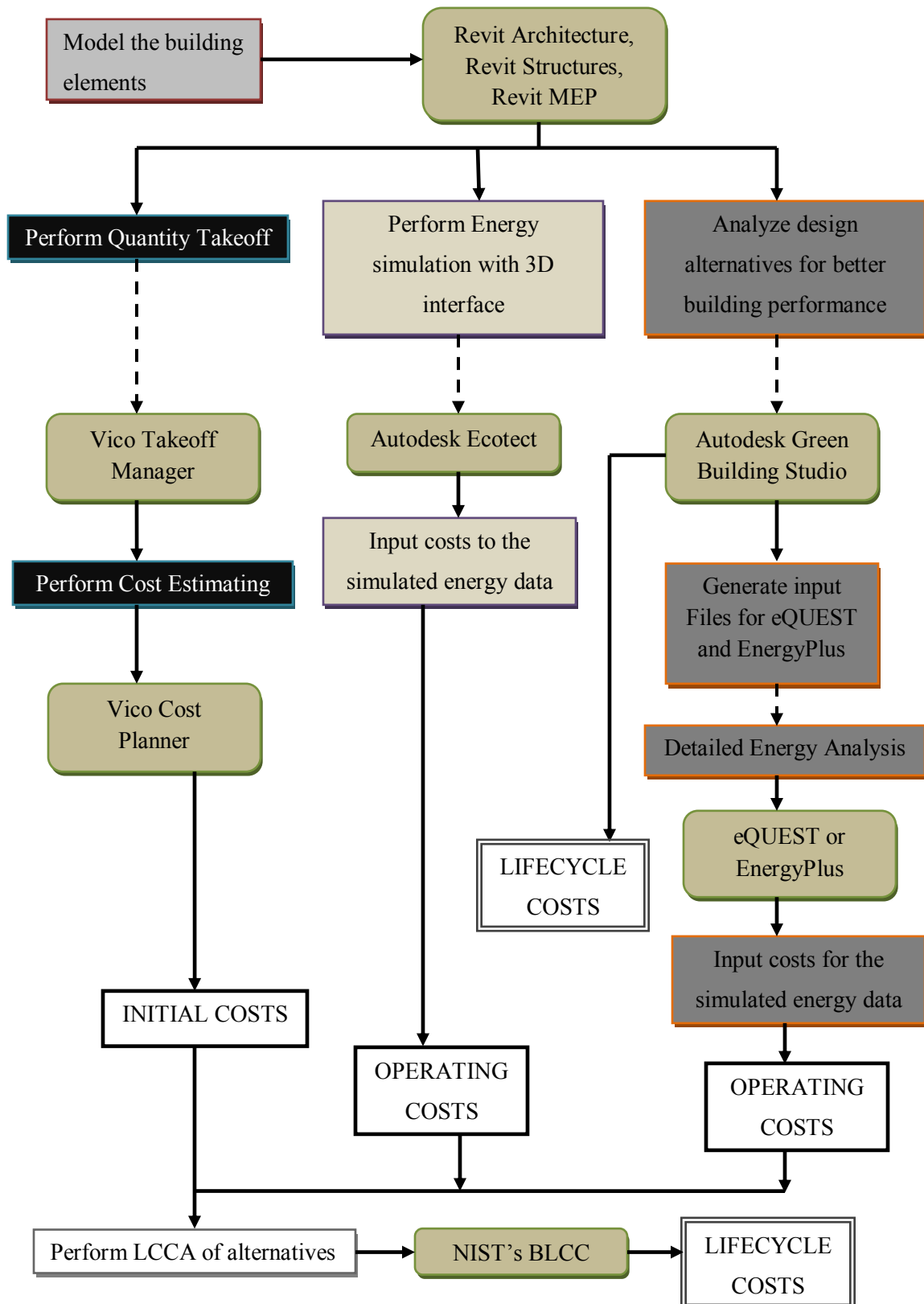
Possible Workflow 1



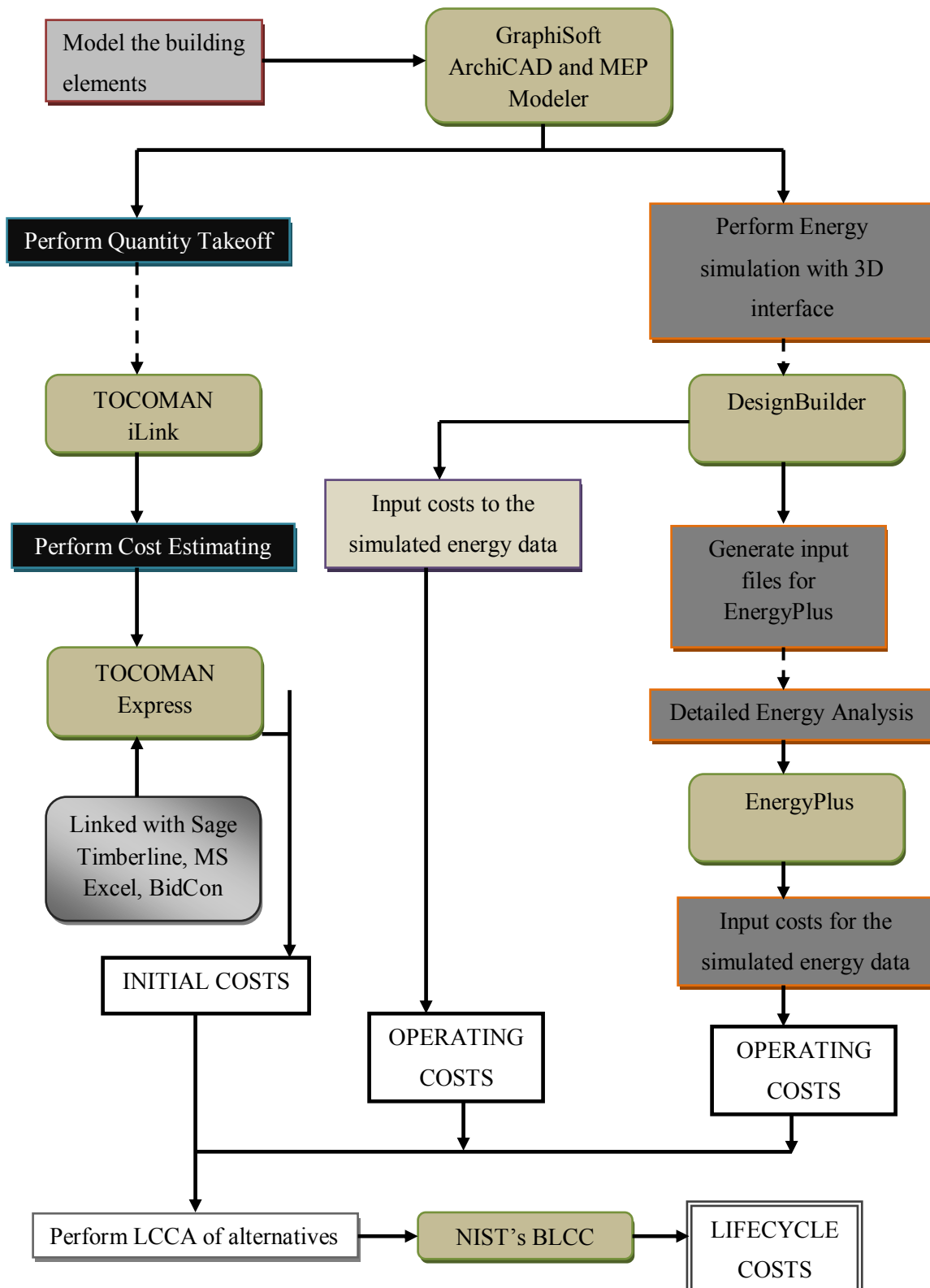
Possible Workflow 2



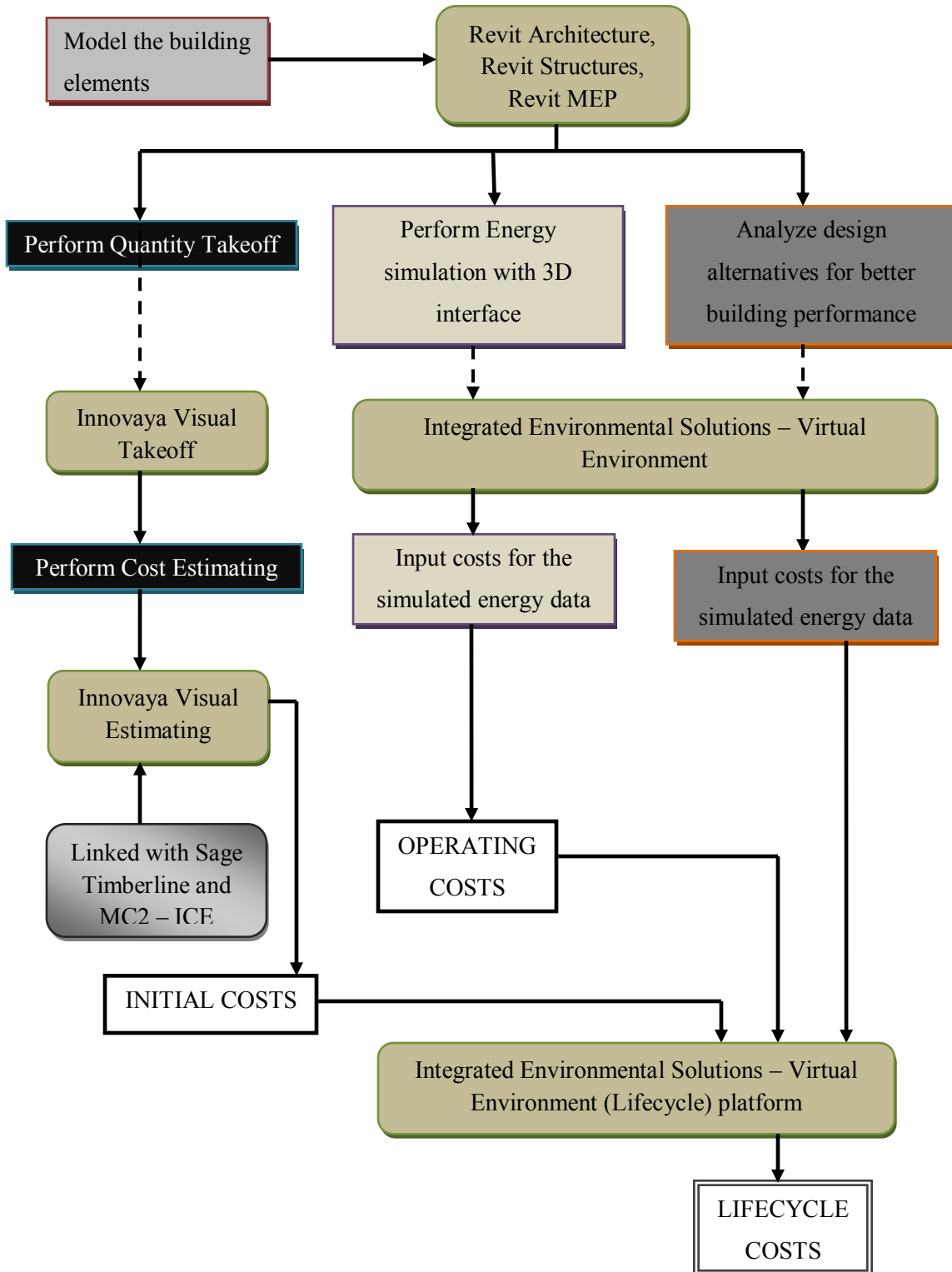
Possible Workflow 3



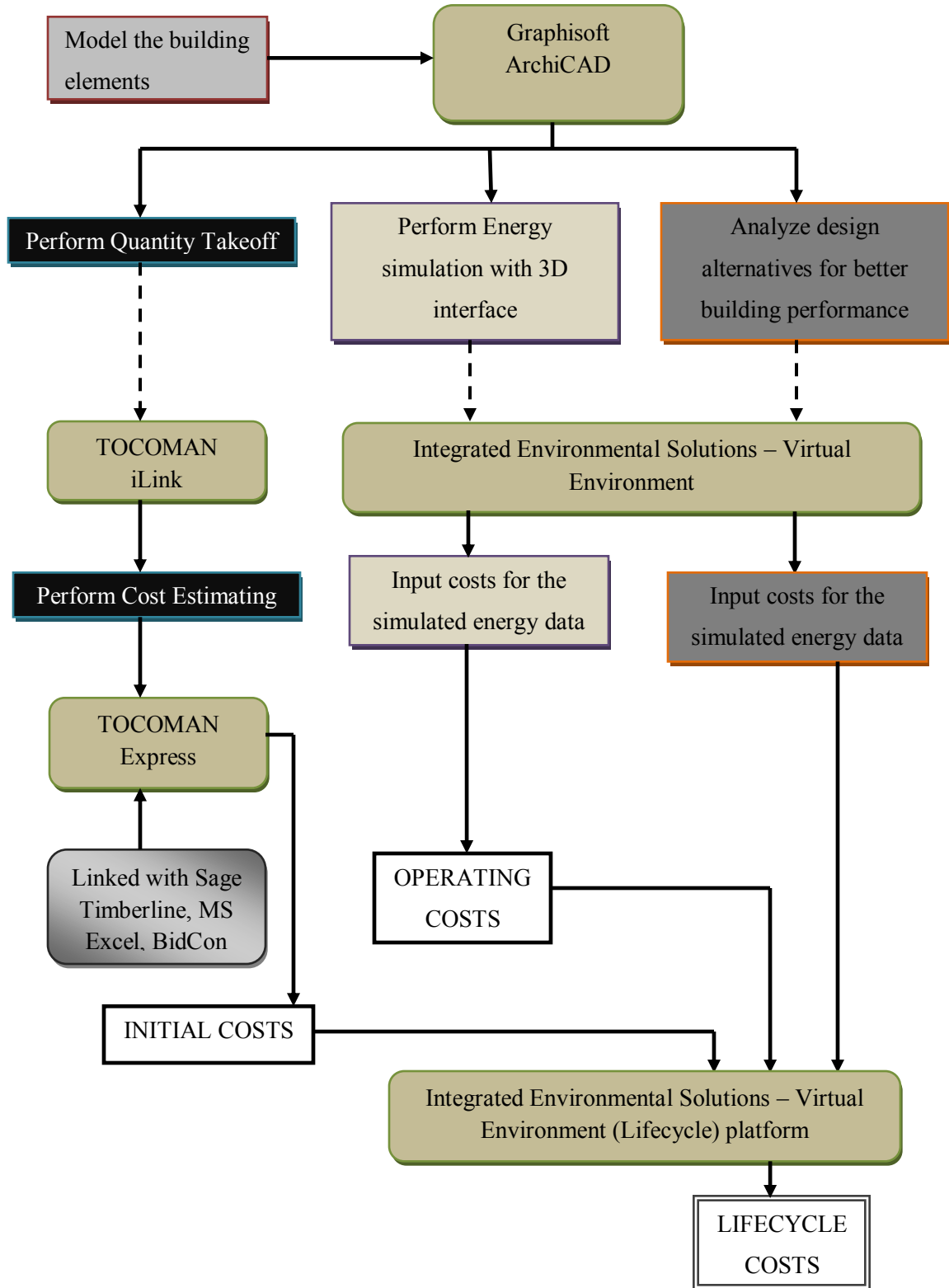
Possible Workflow :



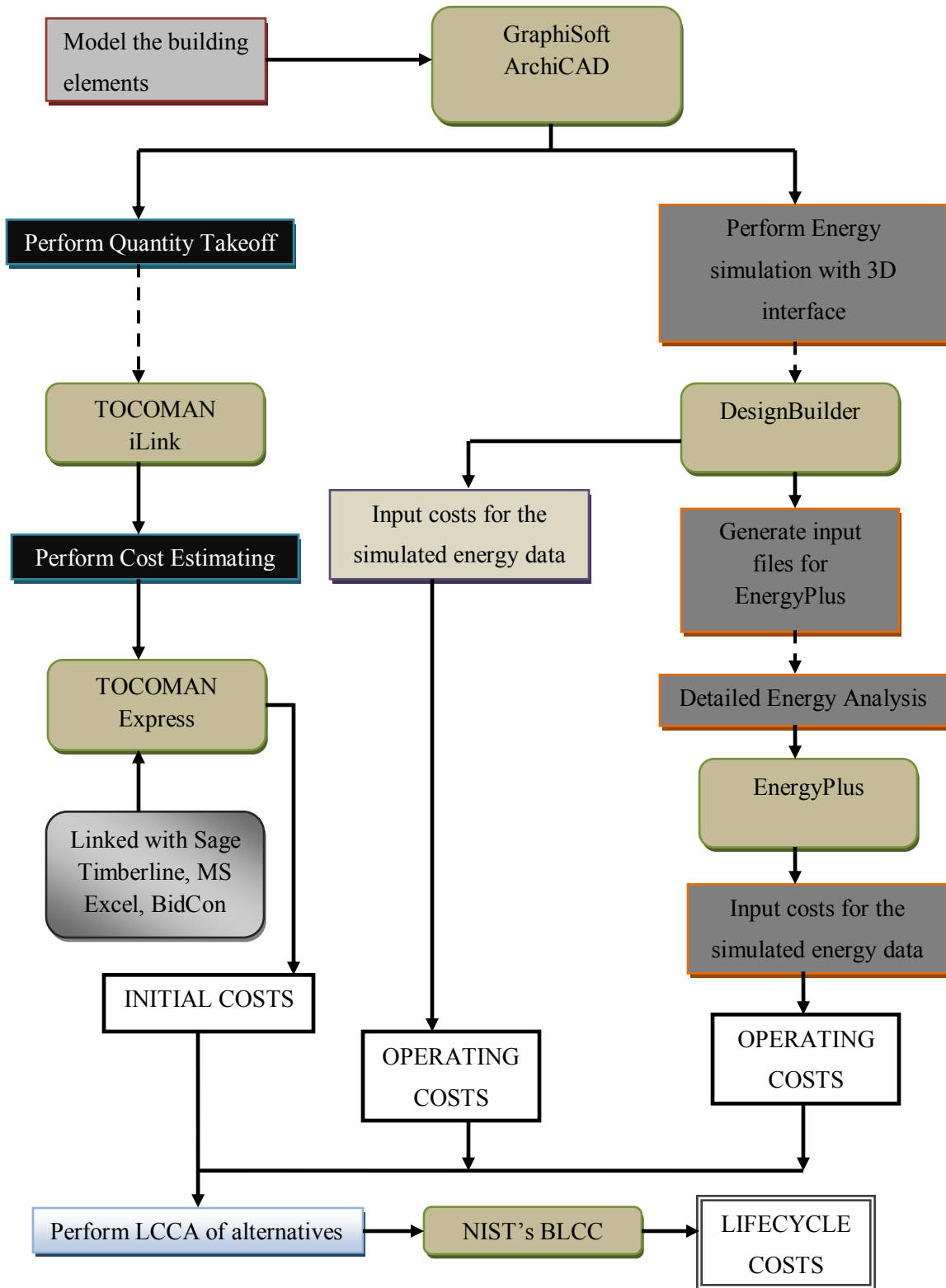
Possible Workflow 5



Possible Workflow 6



Possible Workflow 7



5.1.4 Features of BIM Software Performing Quantity Take-off and Estimation

The features of BIM software performing quantity take-off and estimation are listed in **Table 10**.

Table 10: Features of BIM Software Performing Quantity Take-off and Estimation

No	Features/ Software	Innovaya	TOCOMAN	VICO Software
1.	Visual 3D platform	Innovaya Visual BIM	Add-on to modeling software	VICO 3D environment
2.	Quantity Take-off Solution	Innovaya Visual Quantity Take- off	TOCOMAN iLink	VICO Take- off Manager
3.	Cost Estimating solution	Innovaya Visual Estimating, Innovaya Design Estimating	TOCOMAN Express	VICO Cost Planner
4.	Tracking of elements quantified	✓	X	✓
5.	Element Correction	X	X	✓
6.	Color coding of quantified building elements	✓	✓	✓
7.	Quantities according to CSI Master Format divisions	✓	X	✓
8.	Quantities according to Unifomat divisions	✓	X	✓
9.	Access to RS Means Cost Data	✓	✓	✓

✓ – The software is capable of performing this task

X – The software does not offer this capability

Table 10: Continued

No	Features/ Software	Innovaya	TOCOMAN	VICO Software
10.	The data visible on Autodesk Navisworks application	X	X	✓
11.	Incorporation of LEED data for estimation	✓	✓	✓
12.	Assembly Take-off by using Sage Timberline's 'Smart Assemblies' feature	✓	✓	✓
13.	Ability to incorporate Subcontractor's data into the estimate	✓	✓	✓
14.	Develop customized database	✓	✓	✓

✓ – The software is capable of performing this task

X – The software does not offer this capability

5.1.5 Features of BIM Software Performing Energy Simulation

The features of BIM software performing energy simulation are listed in **Table 11**.

Table 11: Features of BIM Software Performing Energy Simulation

No.	Features/ Software	eQUEST	DOE 2.2	Energy Plus	Autodesk Ecotect	Autodesk Green Building Studio	Bentley Hevacomp	Design Builder	IES - VE
1.	3D Environment	✓	X	X	✓	✓	✓	✓	✓
2.	Design during all phases of design	✓	✓	✓	✓	✓	✓	✓	✓
3.	Graphical reports of results	✓	✓	X	✓	✓	✓	✓	✓
4.	Analysis of alternatives by changing particular parameters	✓	X	X	X	✓	X	X	✓
5.	Lifecycle costs	X	X	X	X	✓	X	X	✓
6.	Access to global weather database	✓	✓	✓	✓	✓	✓	✓	✓

✓ – The software is capable of performing this task

X – The software does not offer this capability

Table 11: Continued

No.	Features/ Software	eQUEST	DOE 2.2	Energy Plus	Autodesk Ecotect	Autodesk Green Building Studio	Bentley Hevacomp	Design Builder	IES - VE
7.	Lighting loads calculation	✓	✓	✓	✓	✓	✓	✓	✓
16.	Analysis of photovoltaic potential	X	X	X	✓	✓	X	X	X
17.	Analysis of Natural ventilation options from the building location	X	X	X	✓	✓	X	X	X
18.	Generation of CFD files for airflow analysis	X	X	X	✓	X	X	✓	✓
19.	BREEM Credits	X	X	X	X	X	X	✓	✓

✓ – The software is capable of performing this task

X – The software does not offer this capability

Table 11: Continued

No.	Features/ Software	eQUEST	DOE 2.2	Energy Plus	Autodesk Ecotect	Autodesk Green Building Studio	Bentley Hevacomp	Design Builder	IES - VE
20.	UK Building Regulation, Part L and Part J	X	X	X	X	X	✓	✓	✓
22.	GREEN STAR	X	X	X	X	X	X	X	✓
23.	Generation of capital costs of design	X	X	X	X	X	X	X	✓
24.	Geothermal Analysis	X	X	X	X	X	X	X	✓
25.	UK Energy Performance Certificate	X	X	X	X	X	✓	✓	✓
26.	Energy Cost calculations	X	✓	X	X	✓	✓	X	X

✓ – The software is capable of performing this task

X – The software does not offer this capability

Table 11: Continued

No.	Features/ Software	eQUEST	DOE 2.2	Energy Plus	Autodesk Ecotect	Autodesk Green Building Studio	Bentley Hevacomp	Design Builder	IES - VE
27.	SBEM (Simplified Building Energy Model) for UK	X	X	X	X	X	X	✓	✓
28.	Daylighting Design	X	X	X	✓	X	✓	✓	✓
29.	Shading Design	X	X	X	✓	X	✓	✓	✓

✓ – The software is capable of performing this task

X – The software does not offer this capability

6. CONCLUSION

6.1 Summary of Findings

The study of the LCCA process has highlighted the need for a platform where the data generation, data handling and data analysis can be carried out with ease. The buildings are analyzed at different stages of design with an aim to include more than one parameter to the building design. The target is to have a 'best value' design. Since, these energy saving solutions have a greater initial investment and they need to be analyzed from the lifecycle standpoint. Given that, multiple design alternatives are analyzed for a single facility or a building, it becomes necessary to have a framework where large amount of data can be efficiently handled. To facilitate LCCA process, application of BIM solution is suggested. The target of the study is to have a look at the currently available BIM solutions and decide their capabilities in order to answer LCCA requirements. The findings have suggested that there are BIM solutions which do cater to LCCA process for computing energy saving options.

- For ease in data handling and data generation of first costs and energy costs which are a part of LCCA process, the BIM software which could satisfy the above requirements are needed.
- There are a different set of tools which perform namely 4 functions, building modeling, quantity take-off, cost estimation and energy performance analysis.
- The software which is used for performing LCCA calculations are not interoperable with these BIM tools and the data generated has to be keyed-in manually to generate results.
- As, there is single BIM software that are able to perform all the functions various workflows need to be worked out and adopted as required by the user. Seven (7) possible workflows have been suggested depending on interoperability between the different software.
- It is necessary to note that modeling tool Microstation provided by the Bentley Solutions does not have any linkages with the quantity take-off and estimation tools. Therefore, a complete workflow could not be suggested. It does have association with energy simulation tools like Ecotect and EnergyPlus.

- Built-in capabilities of the software allow quantity take-off to be performed by the mentioned BIM solutions. They are interoperable with almost all the popular modeling tools, exception being, Bentley Microstation.
- All of the BIM cost estimating tools allow an estimating database to be built by the user. But all of the BIM costs estimating tools have linkage with Sage Timberline for estimation. All the features of Sage Timberline are available for use within these software.
- Sage Timberline is the only cost estimating software that has associations with all the mentioned BIM tools due which an obvious workflow for quantity take-off and estimation can be adopted.
- Autodesk energy simulation tools have associations with Autodesk modeling software. On the other hand, Design Builder and IES-VE have linkages with other modeling software along with Autodesk products.
- Except for Autodesk Green Building Studio, all the BIM energy simulation applications provide a 3D interface for understanding the interaction between spaces of the building and location of the building.
- Autodesk Green Building Studio is able to perform analysis of alternatives by changing few of the parameters of design and running simulations multiple times. This particular software is able to estimate carbon emissions and perform whole building energy analysis. This is the only software that generates the lifecycle costs for energy along with annual energy costs.
- Autodesk Green Building Studio is also the only tool for analyzing the electric power plant sources, wind energy potential and natural ventilation potential depending on the site location of the building.
- One of the unique features of IES-VE is that it is able to perform the estimate the quantities of capital costs of the building and also the costs of the pipe work, duct work and electrical cables. These quantities have to be manually entered into the estimation software. This can eliminate the requirement of BIM quantity take-off solutions.
- IES-VE is the only tool which provides with geothermal analysis capacity. It has compatibility with the 'Ground Loop Design' software for analyzing the horizontal, vertical loops, equipment sizing etc.

- All the BIM based energy simulation tools have compatibility with detail energy analysis tools like eQUEST, DOE-2.2, EnergyPlus etc. If required they can be used for detailed analysis of a final design alternative selected. They can be used in the workflows depending on the necessity of further analysis.

The LCC calculations are usually carried out by using spreadsheet applications. But, BLCC is a program which is developed by NIST that provides an efficient framework for carrying out lifecycle analysis for buildings. It can use the data present for federally managed projects which aim at energy and water cost savings. eVALUator is capable of carrying out uncertainty analysis of the design options. It is important to note that, there is no interoperability of data of the LCC software with the other BIM solutions. The data has to be manually entered into the software to generate results.

There is necessity of the user to analyze the needs of the projects in order to decide on the type of workflow is to be adopted. It is also necessary to observe investment costs of these tools and arrive at optimum solution. The aim is to understand the behavior of different applications with each other.

6.2 Original Contribution

This study has helped in understanding the potential use of BIM applications to conduct LCC calculations. It has also been possible to realize that if the use of BIM technology is able to offset some of the problems that are associated with a better adoption of LCC.

There is no evident attempt to make the BIM applications LCCA oriented. Even though, there is a possibility that the recent BIM tools are able to contribute to the LCC calculations, there is no indication that such attempts have been tried. The study aims at starting at the initial stage in incorporating BIM into LCCA. This is the beginning of understanding the dimension of BIM as part of workflow with LCCA. The study is a snapshot in time to analyze the capabilities of current BIM solutions to answer LCCA questions. It can also allow the product developers to understand the requirements that are to be fulfilled in developing the BIM products to make them more LCCA focused. This discussion will help provide guidelines for future researchers to propose more competent software to solve the LCC questions.

7. FUTURE RESEARCH

Following are the suggested areas of future research,

- The main reasons for carrying out LCCA have to be evaluated. There is a likelihood there is preference of performing this study for achieving particular kind of results. The analysis of case studies needs to be extended further.
- LCCA involves a range of significant costs for complete analysis. They are typically annual maintenance costs, replacement costs, salvage value etc. It has to be seen if there are any BIM software available that can incorporate these costs in the workflows.
- Prototype building models have to be used for the calculation of first costs and energy costs following the suggested workflows. This will be helpful in understanding if the software programs work seamlessly with each other.
- The resources that are equipped with supplying this kind of data needs be studied and analyzed and seen if they can be integrated with the BIM software. For example, Sage Timberline has complete access to RS Means Cost Database along with Industrial Databases which is able to provide the data needed for estimation. And they share interface with BIM solutions. Similarly, it has to be understood if such kind of databases are available and can they be incorporated with BIM software.
- The current reach and extent of use of each of these software needs in the AEC industry needs to be studied. The principal tasks for which these programs are used have to be studied. The possible hindrances have to be highlighted.
- There is also a dependence on spreadsheet applications for LCCA. It is necessary to find the reasons for such dependence and understand that if the software programs are able to satisfy the user requirements.
- There is also a need for having a ‘Whole Building Design’ approach for maximizing the effectiveness of the suggested workflows. It needs to be investigated, if the suggested possible workflows have the capacity of fulfilling the requirements of some another form of analysis and assessments. For example, there is a possibility that the workflows can help in meeting the needs of LCCA and LCA processes.

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