Final Report: DEVELOPMENT OF AN ENERGY AND COST ANALYSIS SOFTWARE FOR EARLY STAGE DECISION MAKING

Department of Building, Civil & Environmental Engineering

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1 Context & Objective

1.1 Context

Simulead is a company specialised in building energy simulation. In order to guide property managers in their choices, it wants to develop a software, which estimates the cost of several hundreds of mechanical, architectural and lighting scenarios using energy simulations. This software is intended to be used in the first steps of building conception where the decision impact is the greatest [1]. Based on software results, the property manager will be able to select a couple of best scenarios based on his/her own criteria, which can be the lifecycle cost, the lifecycle saving or the discount payback period. By selecting the best mechanical and architectural solutions in early stage of the project, buildings will be more energy efficient, will provide more comfort to its users and its construction costs will be decreased. The software is also intended to be a part of BIM process and then, shall be able to transfer its information. The software is to be sold, then questions of properties and rights have to be raised.

1.2 Objective

This project aims at defining the functional design and architecture of the software. It is an early stage thinking process and, therefore, the first main objective is to determine what the software will do and how it will do it. The second objective is to determine what inputs have an impact on energy consumption and then shall be embodied in the software. Finally, Simulead considers important to emphasise the simplicity for the user. Consequently, consideration ought to be conducted to identify the inputs and outputs displayed for the end user and the ones hidden in the software but necessary for the analysis.

In order to illustrate the flow of the software, a case study has been created at the end of the report.

2 Energy simulations and cost analysis

Energy simulations have been developed in the 1960's by the governments, academia and industry when the computer technology enables it. The energy crisis in the United States in the 1970's increases its deployment and norms like ASHRAE have been developed [1] [2]. Today, energy simulations are mandatory to respect the codes and to achieve incentives or green energy labels. This tool is extremely powerful and provide results that could not be calculated by hand due to the complexity of the equations and the amount of inputs [3].

According to Simulead experience, energy simulations are most of the time performed when the design is already chosen. However, this process does not make the most of the simulation capacities. Indeed, to design the HVAC systems and the properties of the architecture, engineers and architects rely on their experience rather than calculation. Energy simulations could really analyse the impact of each decision made and validate their accuracy.

On a monetary point of view, energy simulations enable to compare the consumption of different scenarios and their monthly bills. However, optimising the building does not only decrease the energy consumption but also the cost of the equipment. Indeed, a change of one parameter can affect the entire design. For example, if the window thermal resistance is increased, the heating system dimensions can be decreased and so is the initial cost of the system. Therefore, energy simulations enable the shareholders to validate if an investment is worth it.

In order to provide an economic analysis, the software will consider the Net Present Worth (NPW), which is the better comparison tool for investment [4]. This tool considers the initial cost, the energy consumption, the maintenance and the salvage value of the building relating to the HVAC system. By selecting the least NPW, the owner suits best its interests. However, NPW can only be computed if the interest rate is known. Therefore, the software will also consider other tools like the discount internal rate of return and the payback period. Several recent studies highlight the benefits of coupling a cost analysis to energy simulation, which results in a decreased of the energy consumption and the initial cost. [4]

3 Competitors

Before the development of any software, a review of the possible competitors must be carried out. Three main competitors have been identified:

- Sefaira developed by Trimble [5]
- Insight developed by Autodesk [6]
- Building path finder by Morrison Hershfield [7]

Table 1 summarizes the features of these 3 pieces of software along with Simulead's future software.

Table 1 : Comparison of features for Simulead's and competitors' programs

	Insight	Sefaira	Building path finder	Simulead software
General information				
Cloud based	✓	✓	x	✓
Algorithm	Energy +			
Price		1 199 USD/year	Not sold	N.I.
Interoperability				
Import/Export gbXml	✓	✓	N.I.	✓
Revit Plug-In	✓	✓	N.I.	x
Sketchup Plug-in	x	✓	N.I.	✓
Architectural parameters				
Common parameters (1)	✓	✓	✓	✓
Automatic zoning (2)	x	✓	N.I.	✓
Mechanical systems (3)	Main Systems	Main Systems	Almost all systems	Almost all systems
Efficiency of the system: Fan, Heat Pumps, …	x	✓	✓	✓
Outputs				
Energy consumption	✓	✓	✓	✓

Energy cost	✓	✓	✓	✓
Plant sizing	✓ (along with Revit)	✓	N.I.	✓
Co2 emissions	✓	✓	✓	✓
Zone consumption	x	✓	x	✓
Features				
Model history	✓	✓	✓	✓
Comparison to benchmark	✓	x	N.I.	✓
LEED Points	x	x	✓	✓
Light and comfort analysis	✓	✓	x	Later
Creation of scenarios (4)	Automatic	Semi automatic	N.I.	Semi automatic
Graphical impact of parameters	All parameters	Selection of only 2 parameters	All parameters	All parameters
Economics				
Energy cost	✓	✓	✓	✓
HVAC system cost	x	x	✓	✓
O&M costs	x	x	✓	✓
Life cycle cost	x	x	✓	✓
Economic analysis	x	x	✓	✓
Parameter selection	x	x	✓	✓
Quality criteria				
Model visualisation	3D	2D	N.I.	3D
Visual appearance	Esthetic	Very Esthetic	Esthetic	Very Esthetic
Usability	Not very clear	Very clear	N.I.	Very clear
Geometry importation	Fundamental issues	Fundamental issues	N.I.	Must be almost perfect
Calculation capacity	Very high	High	N.I.	High
BIM friendly	✓	✓	N.I.	✓

(1) Common parameters are all parameters that can influence energy consumption of a building like the orientation, the thermal resistance of walls and windows, the solar shadings, etc…

(2) Zoning is the division of a building according to thermal loads.

(3) Mains systems referred to the systems the most used, see figure 2.

(4) Automatic means that the energy scenarios are calculated automatically whereas in semi-automatic scenarios, the user needs to click on a button to update the results.

At the moment, a Revit plug-in is not considered because of its creation complexity. However, Revit model can be used via the exportation of gbXml files. Regarding IFCs, the amount of information they content make the importation of any BIM model into simulation software very difficult. Therefore, importation of IFC is not considered at the moment, but may be developed in the future.

As shown by Table 1, none of the competitor's tools, except Morrison Hershfield's, provide the life cycle cost of the scenarios they compare. One may argue that Simulead's software is similar to Morrison Hershfield's. It is true that both tools provide an economic analysis using energy simulations, but given the few amounts of information about Building path finder, their structures and results may differ greatly.

4 OpenStudio Software

Openstudio Application is an energy simulation tool developed in collaboration by NREL, ANL, LBNL, ORNL, and PNN. Its Sketchup plug-in is an extension of the software that provides a 3D rendering of a model in Trimble Sketchup. One of its main advantage is to be open source. Therefore, its code can be edited to match the end user specific needs. Besides, the community using OpenStudio is important and experience and help are commonly exchanged. An other advantage of OpenStudio is the possibility to create Measures. These are small programs developed in Ruby that apply on the model and make automatic modification. Thus, several design scenarios can be created easy and very quickly. Finally, OpenStudio is BIM friendly and support gbXml and IFC files. [8]

5 Requirements Analysis

5.1 General description

The system is designed to be used online by architects, mechanical engineers or any professional who has an impact on the energy efficiency of a building. The software uses imported geometric models to set the shape of the building and enables the user to test several parameters. Via OpenStudio and an in-house cost database, the software provides the estimated energy consumption for each scenario tested along with some economic indexes.

5.2 Product perspectives

Simulead system will base its results on hundreds of simulations. To provide enough computing capabilities, it will be held on a cloud server. In order to perform energy simulation, it will rely on OpenStudio. If possible, OpenStudio will be implemented in Simulead cloud server so that users do not have to download it on their own computers. Moreover, the costs will be embodied in the server in a database that Simulead can frequently update.

5.3 Output Description

The outputs can be divided into two categories: energy and economic results.

The energy results (Table 2) are provided by the simulation software. Openstudio provides a great amount of results and some are not relevant for the end user but are used in the economic analysis. Table 3 illustrates the outputs from the economic analysis. These results should be graphical and easily downloadable by the user.

Table 2: Energy Outputs

Energy Results
Display to user & used for economic analysis
Consumption of electricity and gas per month and year
Repartition of consumption per energy use (heating, lighting, etc.)
Electricity and gas Peak Demand
Building envelope properties
Percentage of glazing
Average Lighting Power

Type of HVAC system
LEED Points
Greenhouse Gas Emissions
Used for economic analysis
Power of the system components (Fans, coils, etc.)
Air flow

Table 3: Cost Results

Cost Results
Initial Cost
Cost of Operation and Maintenance
Savings compared to Baseline
Internal rate of return
Net Present Worth or Net Present Cost (if no income)
Discount Payback Period
Allowable Incentives

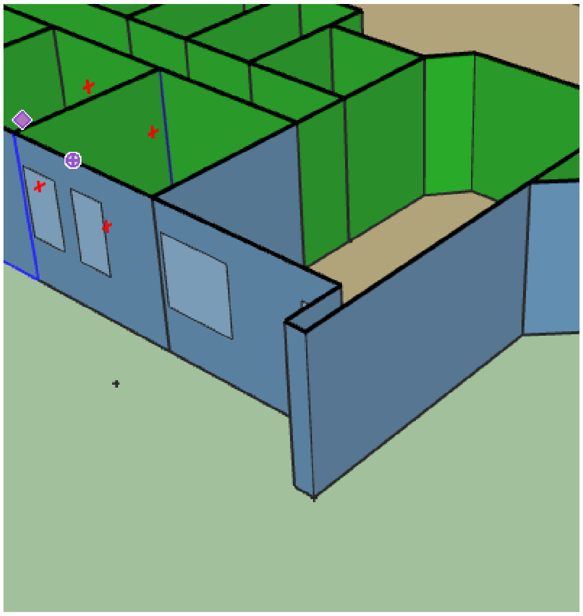
5.4 Functions

1) Function 0 – Customer project database

Project information and results for each customer is stored in a SQL database. The data is only accessible with the customer login information or by Simulead. The requirement of this database will be developed with the advice of a database expert.

2) Function 1 – File import and geometry control
   - Function 1.1: Import gbXml or Sketchup file
   - Function 1.2: Display nodes and walls of the geometry in an editable window
   - Function 1.3: Edit the geometry

Two errors can happen: either some surfaces are seen as outside but should be inside (Figure 2) or there are holes in the model because surfaces do not match. The first one is solved by clicking and the surface and changing its property. To fix the second issue, the software displays the edge nodes of each surface (Figure 1). Then it is easy to drag and match one node with an other.



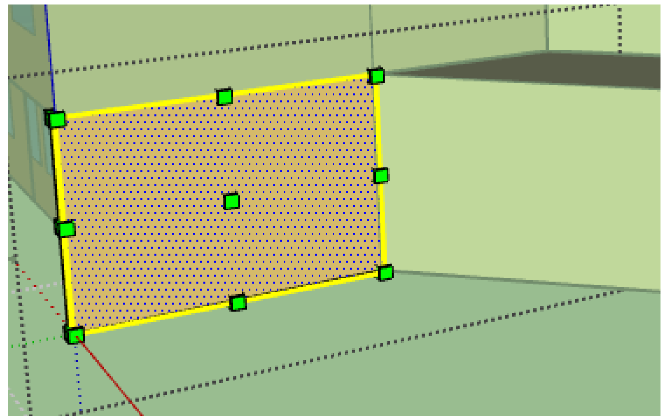


Figure 1: Display of the surface nodes - Example

Figure 2: Problem with Surface properties

3) Function 2 – Edit file
   - Function 2.1: Copy the file
   - Function 2.2: Delete the file

4) Function 3 – Zoning
   - Function 3.1: Zoning the building by perimeter and core
   - Function 3.2: Recognize spaces and zone the building accordingly

There are two ways to create thermal zones in a building: either a core and perimeter zones or rendering by the internal spaces (Figure 3). If spaces are provided in the imported file, the software must recognize them and divides the building in zones, according to the internal arrangement. Otherwise, the building is divided with a core and perimeters zoning. An OpenStudio measure may be developed to zone the building.

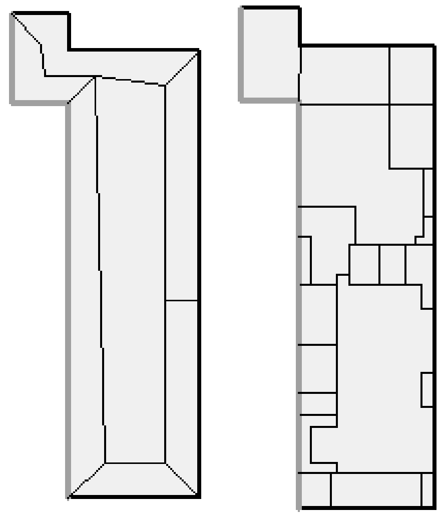


Figure 3: Examples of Core&Perimeter Zoning (Right) and Zoning per space (Left)

5) Function 4 – Assign properties

The user chooses the building properties he wants to test.

- Function 4.1: Assign weather file according to location

Weather files are located in a data base and linked with the major city names. Those names can be selected in a dropdown menu.

- Function 4.2: Assign Architectural properties

Figure 4 shows Sefaira's interface for the architectural properties. The page is user friendly and hence it could be an example to follow. Table 4 summarizes the different properties that must be edited and tested. Default thermal resistances are provided depending and the norm chosen (Function 4.3). Then, the user selects the interval of values he/she wants to test.

Table 4: Architectural properties

General	Elements
Orientation	Windows to Wall ratio per orientation
Type of building	Thermal resistance
Period of analysis	Overhangs/ Shadings

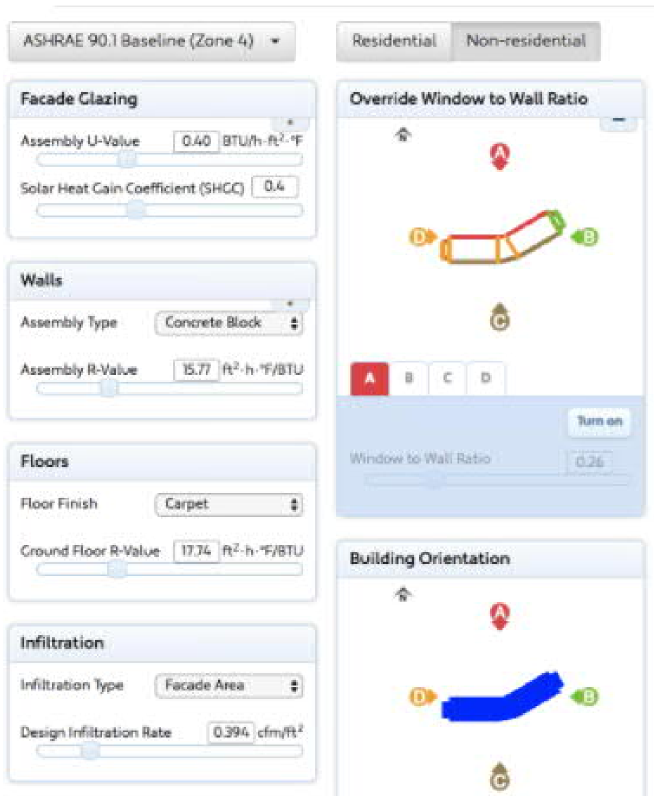


Figure 4: Sefaira's architectural properties page [5]

6) Function 4.3: Assign loads

The user is asked to selection the norm he/she wants to compare the model to (Table 5). The properties of the norms are stored in a database. Given the simplicity of the database, it is created as a CSV file. The loads (Table 6) are assigned either for each floor or for the entire building. The user defined the percentage range of economy or the values he/she wants to test. The schedules and thermostats are provided depending on the norm and the type of building from the norm database.

Table 5: Norms available in the software

Norms	
ASHRAE 90.1 2004	CMNEB 1997
ASHRAE 90.1 2007	CNEB 2011
ASHRAE 90.1 2010	CNEB 2015
	CNEB Qc

Table 6: Editable loads

Loads	
Lighting Power	Equipment Power
Occupancy	Infiltration

7) Function 5 – Implement HVAC systems

The different HVAC systems and the editable parameters are illustrated in Table 7. Default values are provided depending on the building type so that professionals who are not familiar with HVAC system can use the software. Outside air is calculated according to ASHRAE 62.1 simplified method but is editable.

Table 7: HVAC system available and their editable parameters

HVAC System	Editable parameters
ASHRAE Systems (Figure 5)	Percentage of Outside Air
VRF	Efficiency of boilers and fans
Water loop heat pump	Heat Recovery
	Humidistat

System No.	System Type	Fan Control	Cooling Type	Heating Type
1. PTAC	Packaged terminal air conditioner	Constant Volume	Direct Expansion	Hot Water Fossil Fuel Boiler
2. PTHP	Packaged terminal heat pump	Constant Volume	Direct Expansion	Electric Heat Pump
3. PSZ-AC	Packaged rooftop air conditioner	Constant Volume	Direct Expansion	Fossil Fuel Furnace
4. PSZ-HP	Packaged rooftop heat pump	Constant Volume	Direct Expansion	Electric Heat Pump
5. Packaged VAV w/ Reheat	Packaged rooftop variable air volume with reheat	VAV	Direct Expansion	Hot Water Fossil Fuel Boiler
6. Packaged VAV w/PFP Boxes	Packaged rooftop variable air volume with reheat	VAV	Direct Expansion	Electric Resistance
7. VAV w/Reheat	Packaged rooftop variable air volume with reheat	VAV	Chilled Water	Hot Water Fossil Fuel Boiler
8. VAV w/PFP Boxes	Variable air volume with reheat	VAV	Chilled Water	Electric Resistance

Figure 5: ASHRAE HVAC systems [9]

8) Function 6 – Simulations

The software runs the simulations with OpenStudio. Simulation parameters (hourly step calculation, convergence of results, etc.) are set by default and the user can not change them. The analysis is launched manually by clicking on the Button ANALYSE. It does not prevent the user to make changes on other models. The output presented in Table 2 are then stored in a Result database.

9) Function 7- Require Cost Data

The software is linked with a cost database (7 Database Requirements) and searches the cost associated with the energy results. The search algorithm looks for the cost of the element related on the city of the project and the year of the construction. If there is no match in the year, the costs for a default year are provided and a time index are applied to them.

10) Function 8 – Economics analysis

According to data entered by the user, simulation results and the database including prices, the software provides an economics analysis.

The entered pieces of data are:

- Holding period
- MARR if known. Otherwise user can choose between low (3%), medium (8%) or high (15%) MARR.
- Quality of maintenance, monthly, annually, percentage of the energy consumption. An objective way to measure the quality of maintenance must be evaluated.

From the simulation results, the information above and the cost provided by the cost database, the software computes the initial cost of each scenario and the annual costs of operation and maintenance. A cash flow diagram can be drawn. Then the software carries out an economic analysis providing the net present worth/cost, the internal rate of return and the discount payback period.

11) Function 9 – Output display

Energy and economics outputs (see 5.3 Output Description for more details) are provided based on simulations. Two types of graphs are available: A Sankey diagram (Figure 6) which represents the repartition of the energy consumption or the loads and a graph similar to Figure 7 which links the scenario properties to their costs. The user can narrow the number of scenarios according to several parameters like the budget or the LEED points wanted (Figure 7).

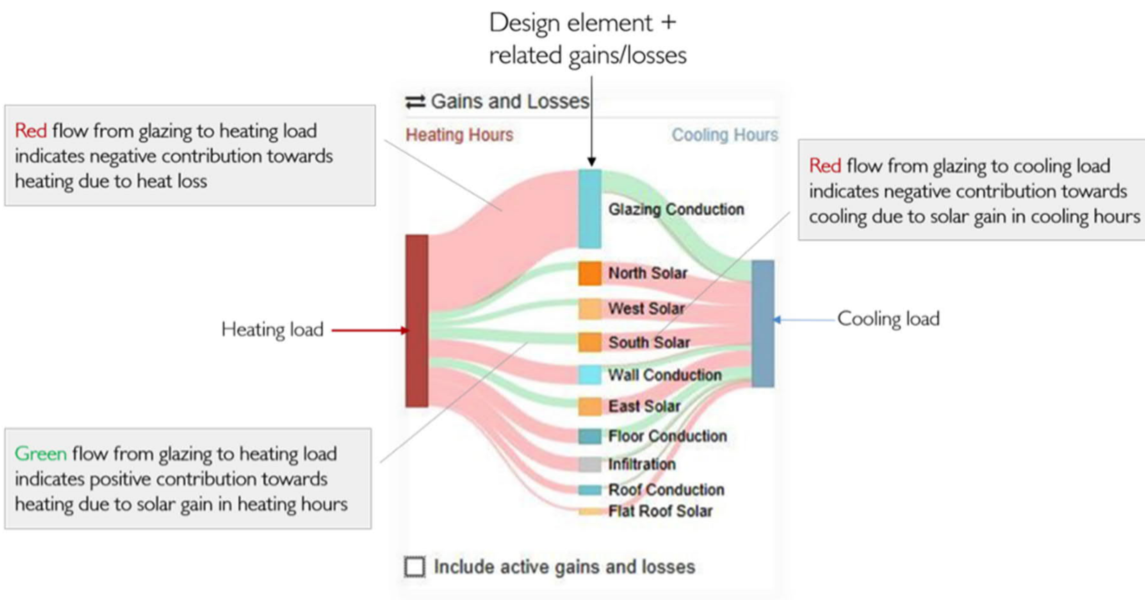


Figure 6: Example of a Sankey diagram [10]

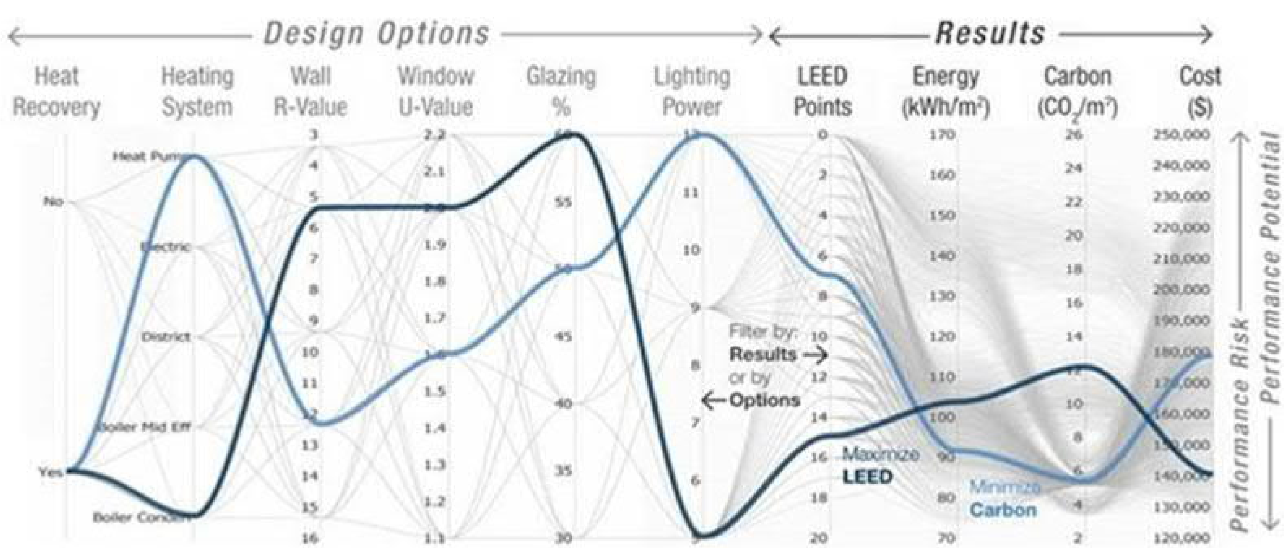


Figure 7: Morrison Hershfield's result graph [11]

12) Function 10 – Export reports

Reports summarizing the project information, the simulation assumptions and the results can be automatically exported as a pdf file. Table 8 presents an example of the data that can be exported in a report. CSV files which contains the hourly results and loads can also be issued.

Table 8: Example of parameters exported in a report

Project information	Building information
Localisation Year Analysis Period	Windows to wall ratio tested Lighting loads tested Orientations tested Thermal properties tested HVAC systems tested
Energy & Cost Results	
Annual consumption for each scenario Savings compared to baseline Sankey Diagrams LEED Points	Total cost for each scenario Discount payback period Allowable Incentives

13) Function 11 – Export Energy+ file

OpenStudio relies on Energy+ algorithm to perform the energy simulation and then create an Energy+ file. This file can be exported for reviewing purposes or interoperability with other software like Design Builders.

5.5 Use Cases

5.5.1 Detailed

1) Creating, Editing and Erasing Model

On the main webpage, the user previous analyses are displayed. The user can decide to copy or erase a model or create a new one.

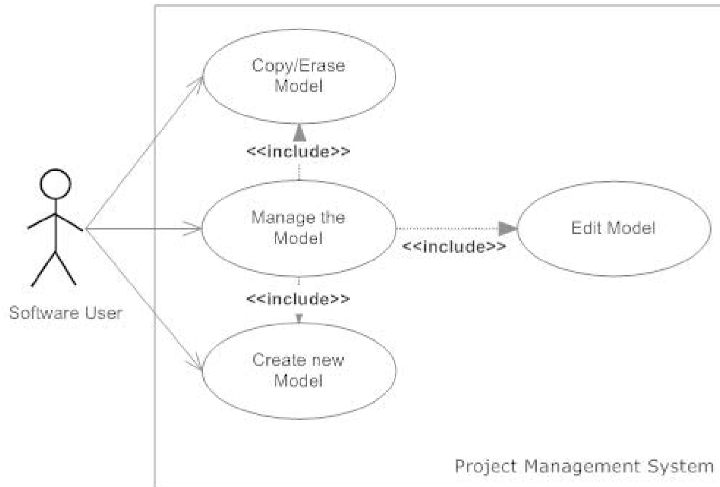


Figure 8: Use Case - Project Management System

2) Uploading and Fixing a model

The user uploads the model into the software [Function 1.1]. A graphic representation of the model is displayed so that the user can validate it [Function 1.2]. If there is any small inconsistencies or holes in the model, it is possible to fixe the model directly in the display window [Function 1.3]. Given that an OS file is a text file, a method to correct the holes could be by replacing the coordinates of a point to match the correct localisation. This method must be investigated in further details.

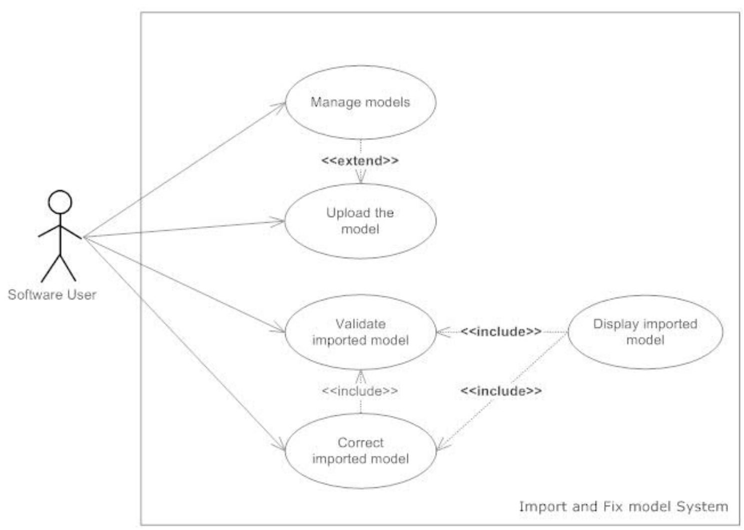


Figure 9: Use Case - Import and Fix model System

3) Zoning and Building properties

Once the geometry is ready, the user chooses the zoning pattern: by spaces if the model has an internal arrangement or by perimeter/core. A 2D model is displayed to control the zoning. Then the user choses the norm used for the simulation and enter the properties and loads he/she wants to test.

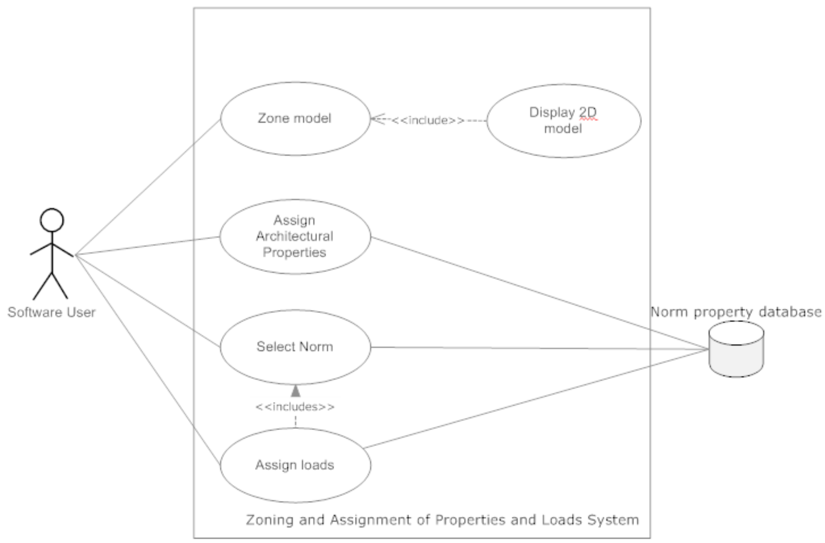


Figure 10: Use Case - Zoning and Assignment of Properties and Loads System

4) Economic Analysis [Function 7&8]

Once the results are provided by OpenStudio, the software collect them in a Result database. Then, the search algorithm implemented in the software finds the costs for each element of the model and fills the Result database with the information. The software carries the calculation in order to obtain, first, the cost of the element and then the cost outputs illustrated in Table 3. A simplify flow diagram of the economic analysis is provided by Figure 11.

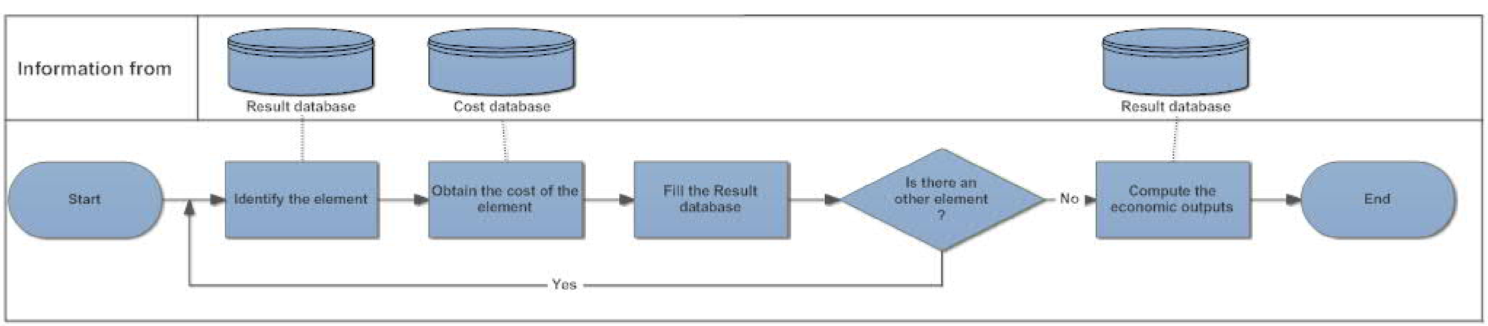


Figure 11: Workflow of the economic analysis

5.5.2 General

Goal in context: At the early stage of the project, the user wants to test several architectural designs. Then, he will upload several files.

Precondition: User has an account and has successfully logged in.

Success End Condition: Energy and economics results are provided by the software to the user. He/she can compare several scenarios and export reports.

Primary Actor: Architect

Trigger: User logs into system

MAIN SUCCESS SCENARIO

1. The user creates a new file. See Use Case Creating, Editing and Erasing Model
2. The user uploads a gbXml or Sketchup file and fixes the model if necessary. See Use Case Uploading and Fixing a Model
3. The user chooses the perimeter and core zoning and enters the building properties to be tested. See Use Case Zoning and Building properties
4. The user enters economics data.
5. The user clicks on the Button Analyse.
6. The software launches the simulations and analyses. See Use Case Economic Analysis
7. In the meantime, the user copies the model with the button Copy and a second model is created. See Use Case Creating, Editing and Erasing Model.
8. The user uploads an other 3D model that erases the previous model.
9. The user follows steps 1 to 5 for the new architectural model.
10. Energy and economics results are provided to the user for both the architectural model. He/she can compare them. [Function 8]
11. The user can export reports with chosen outputs. [Function 9]

6 Software Architecture

6.1 UML diagrams

Unified Modeling Language (ULM) diagrams are a common language for business analysts and software developers to describe and understand the structure of a software [12]. Figure 12 and Figure 13 presents respectively the class and packaged diagrams for Simulead's software. A class is element that describes different instances having common features and a package is group that gather related element. Both the diagrams represent the structure of the system and the relationship between the elements. [12]

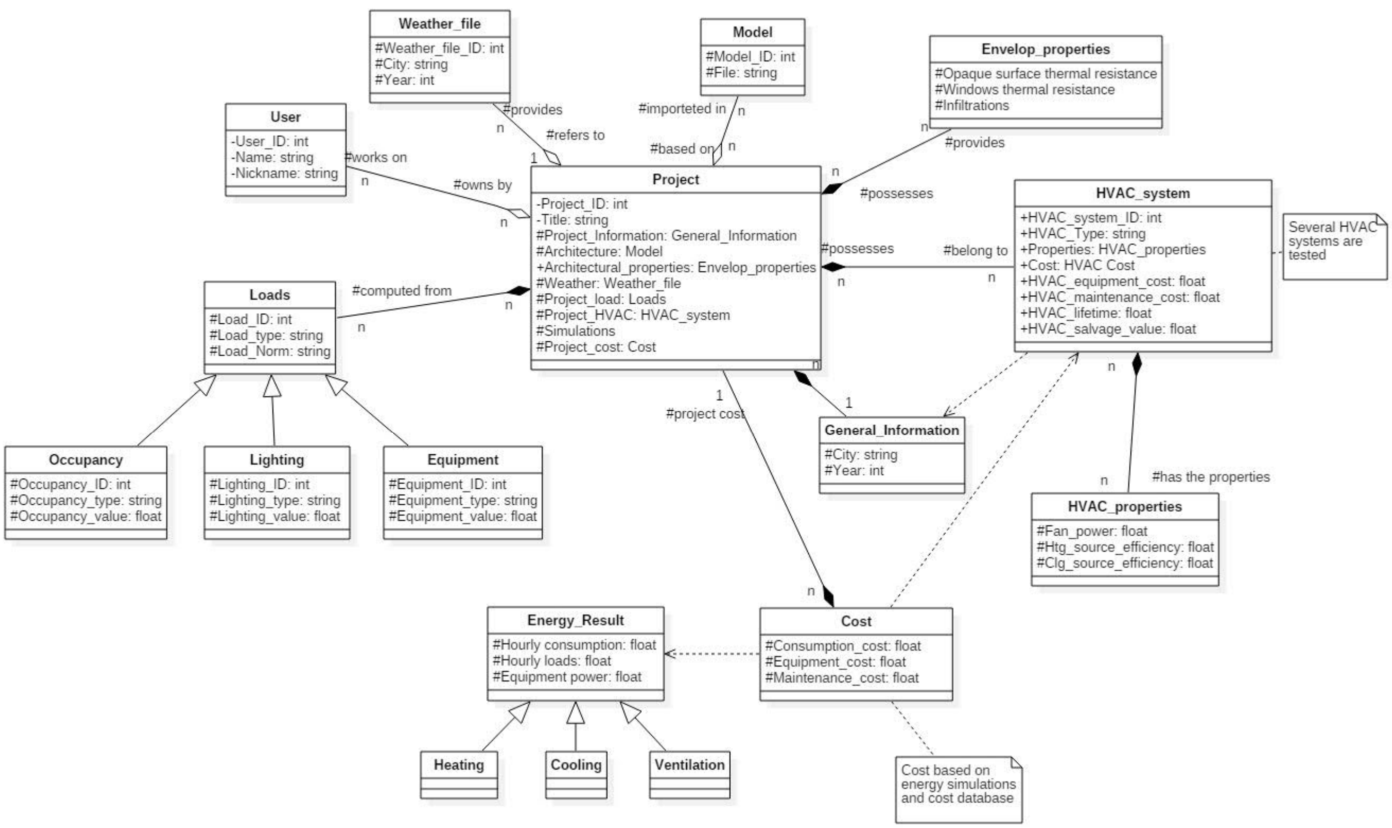


Figure 12: Simulead'software class diagram

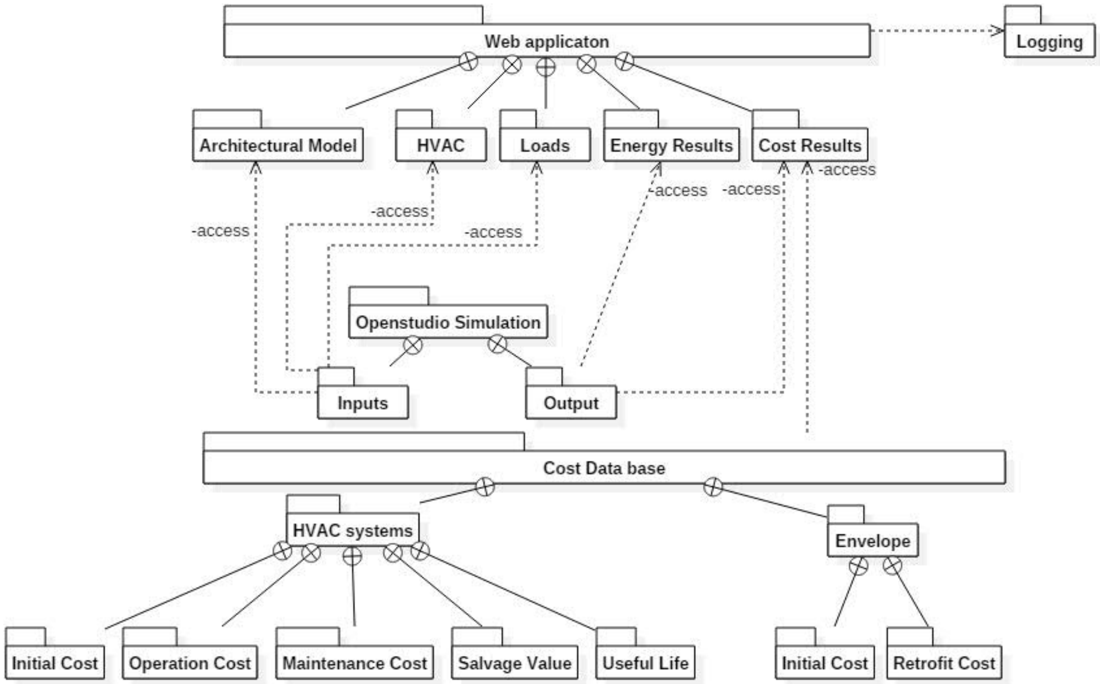


Figure 13: Simulead's software package diagram

6.2 Flow line

6.2.1 General

Figure 14 presents the general program workflow. It is composed of three main parts which are Simulead's software, Openstudio and the in-house database. The three of them interact together in order to provide the energy and cost results. The model and the properties of the building are first entered in Simulead's software. Then all the information is transferred to OpenStudio, which perform the energy simulation. Once the simulations are performed, Simulead's software fills its result database with the OS results. Then the software searches in the cost database the costs needed depending on the year of analysis and the location. For example, to obtain the cost of a fan for a new construction in Montreal in 2017, the software searches the cost per watt of a fan in 2017 in Montreal and then multiply it with the fan power providing by the simulation. The software result database is then filled with the cost results.

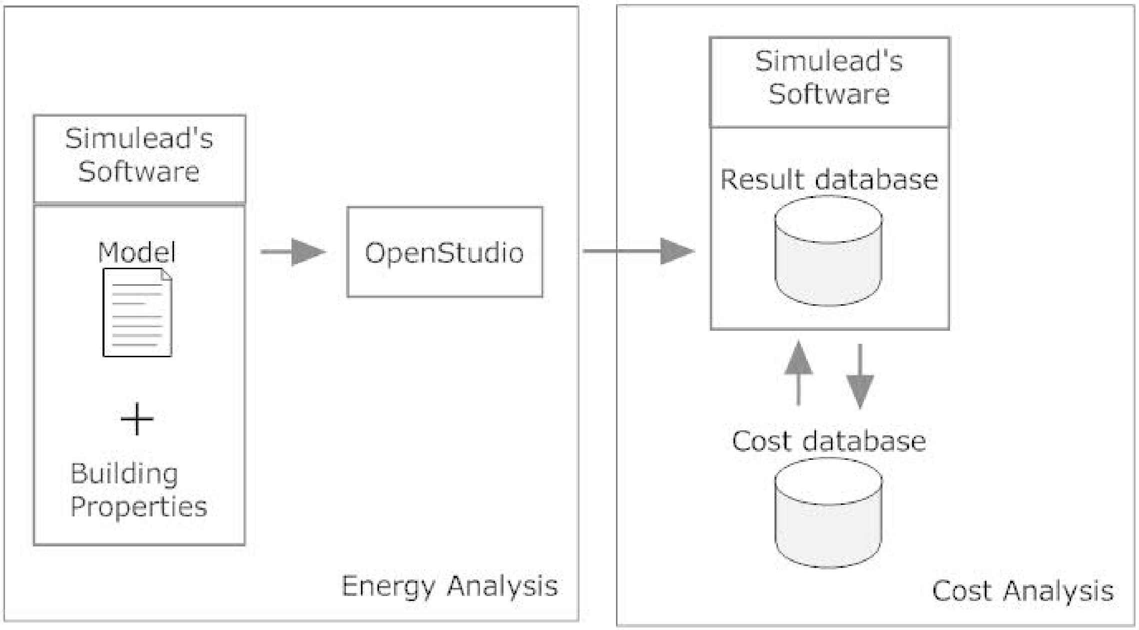


Figure 14: Simplified workflow

6.2.2 Detailed

A detailed workflow has been developed and is shown in Figure 15 and Figure 16. Depending on the end user, the workflow can change.

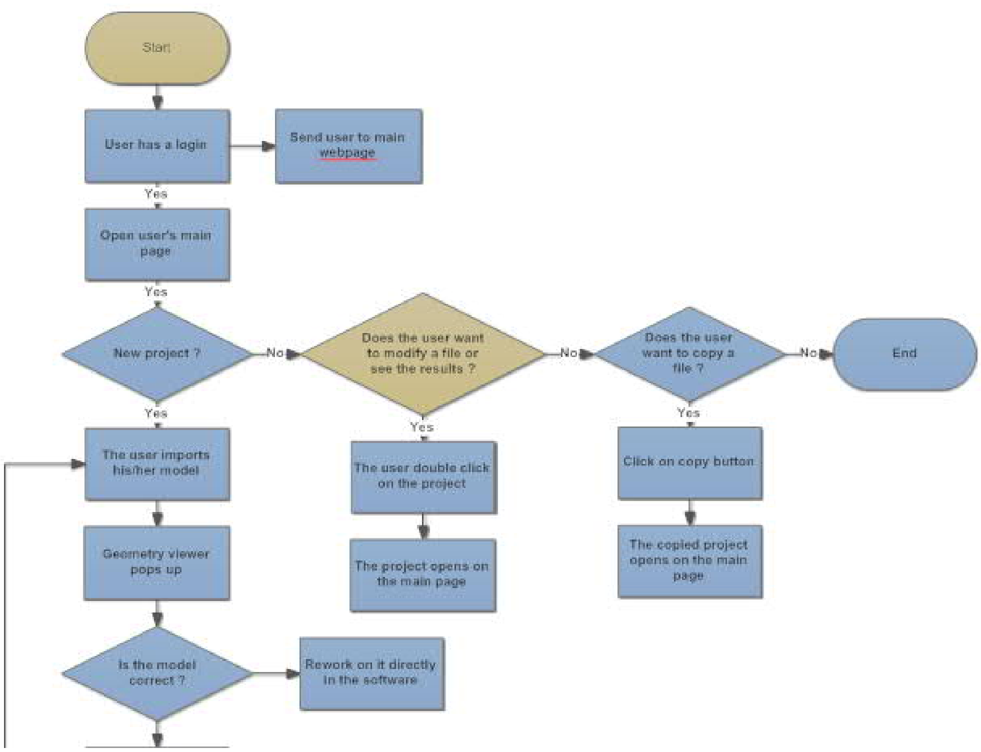


Figure 15: Detailed Workflow - Part 1

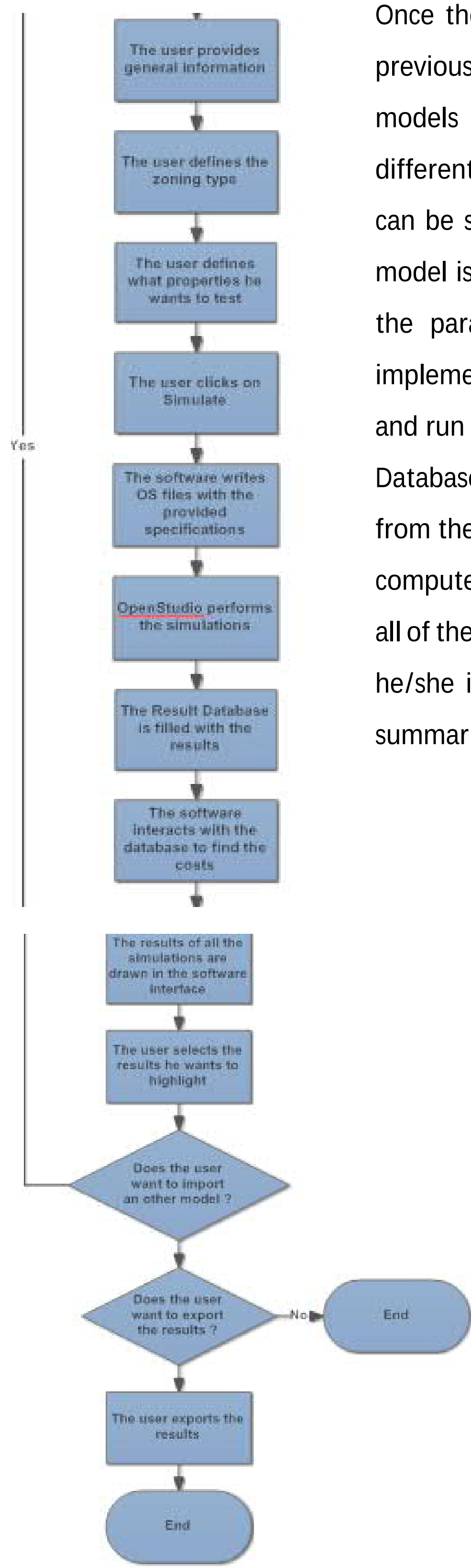


Figure 16: Detailed Workflow - Part 2

Once the user logged in, he can either choose to work on a previous project or create a new one. In each project, several models can be uploaded so that it is possible to compare different architectural designs. As seen previously, the model can be slightly edited to fix the importation issues. Once the model is set, the user defines the zoning pattern and enter all the parameters he/she wants to test. Then the software implemented this information into OpenStudio with Measures and run the simulations. The results are then stored the Result Database and the software obtain the cost for each element from the Cost Database. With all the information, the software computes the economic analyses for each scenario and displays all of them in a common diagram. The user can select the results he/she is interested in and export them in reports that also summarise the inputs and assumptions.

7 Database Requirements

7.1 General information

Alongside the development of Simulead's analysis software, a database including costs must be created and linked to it. Simulead's tool provides thousands of simulation results and from them, it must be able to acquire accurate cost from the database. Given that Simulead does not have yet an in-house database, RS-means data is likely to be used as a start. Therefore, the cost database must be compatible with RS-means database. Simulead database is likely to be developed in SQL. However, the interoperability will be discussed with an expert of database.

The database will be improved alongside the software. Hence, the more developed the software is, the more developed the database will be. The database will be divided in two sub databases: inhouse data and RS-Means data. The second one will be used at the beginning when Simulead does not have inhouse data. Once the inhouse database has enough information and can be relied on, the software will possess an internal algorithm that will choose which sub database to use for each component.

It is well known that any cost estimation does not give the actual building cost and Simulead's software will not be the exception. The goal is to compare rather than providing an accurate cost estimation so that the best scenario can be chosen.

7.2 Functions

1) Function 1: Communicate with Simulead's software

The software must be able to search for costs in the database. The search algorithm searches for the location of the project, its analysis year and the name of the component requested, for example "Fan". If there is no match in the year, the costs for a default year are provided and a time index are applied to them.

2) Function 2: Return cost value for each item

An administrator must be able to find a value by searching it. Example: Cost of a pump in Montreal in 2015. If there is no corresponding value, an error message is shown.

3) Function 3: Edit the database

An administrator must be able to edit the database and fill it. The edition of the database must not stop the software to work. Then, when the database is under maintenance, a copy of the last saved database is used by the software.

4) Function 4: Check the accuracy of data

If a mistake is made when filling the database, an error message must be shown.

7.3 Data stored in the Database

Costs are function of localization, time and inflation. Therefore, costs must be linked to these pieces of information and the database must be able to provide accurate information. Table 9 illustrates the different information stored in the database.

Table 9:Information stored in the Cost Database

<table>
<tr><th colspan="2">General information</th></tr>
<tr><td>Localisation/City
Localisation Index (compared to reference)
Inflation</td><td>Time of the Costs
Time Index (compared to reference)
Identification number</td></tr>
<tr><th colspan="2">Envelop costs</th></tr>
<tr><th>At the beginning</th><th>Future development</th></tr>
<tr><td>Cost of insulation
Cost of windows</td><td>Cost of the structure (concrete, steel)
Cost of finishing work
Cost of installation</td></tr>
<tr><th colspan="2">HVAC Costs</th></tr>
<tr><td>Equipment cost ($/power and efficacity) for:
• Fan
• Boiler
• Pump
• Heat pump</td><td>Equipment maintenance cost
Equipment useful life
Equipment salvage value</td></tr>
</table>

In RS-Means database, the cost of HVAC system depends on the power of each equipment. Therefore, the total cost for an equipment is easy computed. With inhouse data, the costs are provided per HVAC system. For example, the cost of a rooftop unit is not only the sum of each component that it is composed of. Thus, an algorithm must be developed in order to break down the total price of an entire unit. Given that the in-house database will not be used at the beginning, this problem will be addressed later. The salvage value is calculated with the CCA depreciation method.

Each cost may have multiple units, \$/m^2 for example, but the database must possess an internal algorithm, which converts one unit into an other. For example, if the entry of a pump power is in HP, the database will fill automatically the kW value. Simulead's software will then use the unity required.

The database also contains the fuel costs of the passed years and their predictions. Fuel escalation trends do not only rely on the inflation rate but also on the "generation capacity, local demand, import and export availability and a number of other economic indicators". Therefore, the fuel costs are provided by different governmental sources, like the National Energy Board (2007), which predicated the long term natural gas trends over the next 30 years. [4]

8 Case Study

8.1 General Information

The case studies will be based on a project currently conducted by Simulead. Due to the confidentiality of the project, some information will not be provided. However, the author chose this project due to its nature and its current development, which perfectly fit the software scope.

The project is located in Quebec province, Canada and is currently at the early stage of its development. It contains apartment buildings, offices and a retail area spread over more than 800,000 ft^2. Figure 17 illustrates a part of the project. The different geometries are not set and are susceptible to change. So far, no HVAC system has been considered nor the properties of the envelop. Therefore, Simulead's software can provide the best scenarios based on simulation analysis.

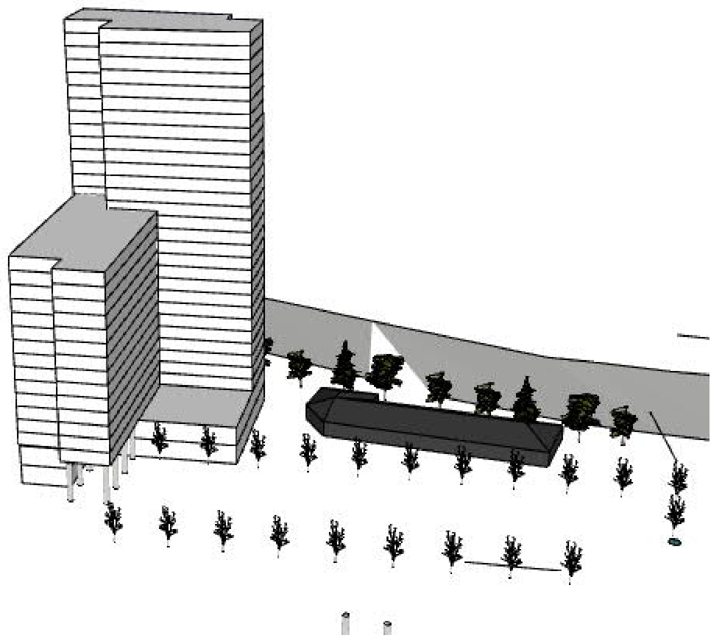


Figure 17: Part of the project

The paragraph below illustrates the workflow following by both the end user and the software. Given that the software is not developed yet, its intention is not to provide accurate data and is fictional.

The end user, assumed to be a male to facilitate the writing, has two geometries that he wants to test: A single 16 story building with flats, offices and retails area or 2 different 8 story structure, one for the apartments and the other for the offices and stores, respectively referred as first and second model. Besides, for each architectural design, he/she wants to know which HVAC system is more economical.

8.2 Workflow

8.2.1 First Model

The user logs in the webserver of Simulead and has access to his previous projects. He created a new project and fill the general information: name, location, estimated year of occupation and a description of the project. Then, he clicks on “New Model” which at this stage is empty. In the geometry tab, the first model, a gbXml file, is uploaded in the webserver and a window appears and displays it in 3D. From this window, the user is able to evaluate if the model has been accurately transferred and can slightly modify the model if geometry issues have been noticed. A hole seems to have been created in the slab of the second floor. The user selects the nodes and drag them where they should be to erase the hole. The user closes the 3D display window and chooses the zoning per perimeter and core. The zoning pattern is displayed in 2D in order to be validated. Then the user orientates the model to South and defines the architectural properties he wants to test: window to wall (WWR) ratio 30%, 40% and 50%, envelop thermal resistance between R-15 and R-25 for the walls and R-20 to R-30 for the roof. Overhangs over the South facade windows are implemented with a length between 1 meter to 2 meters.

Once the geometry is set, the user goes to the energy tab to fill the required information. First, he selects the AHSRAE 2010 and assigns the type of space for each floor. Then default values for the loads are automatically created. The savings for the light power are design to be either 20%, 30% or 40%. The other loads stay identical. The second step is selecting the HVAC systems the user wants to test. Rooftop units with electric coils, or with hot water coils (2 different systems) and heat pumps on water loop are chosen, both having heat recovery. Given that the design is at the conceptual stage, the efficiency of the equipment are the default values of ASHRAE 2010. At this stage, the energy simulation can be performed. However, the user wants to see the impact of each scenario on the cost.

The user then goes on the economic analysis tab to provide the information. The study will be carried over 30 years, the level of maintenance is selected as Medium and the LOW and MEDIUM MARR are chosen. At last, the user clicks on the button Analyse.

The software imports all the information into OpenStudio with measures. For example, the window to wall ratio of 30% will be implemented with the measure "Add, remove or replace window ratio". Each scenario is simulated and the results are acquired by software to fill the Result Database. A scenario refers to a different combination of inputs. The equation below is a rough estimate of the number of scenarios.

$$10\, wall\ resistance * 10\, roof\ resistance * 3\, WWR * 2\, overhangs * 3\, light\ savings \\ * 3\, HVAC\ systems = 5{,}400\, scenarios$$

Once all the simulations have been performed, the software searches each cost associated with each element of the different scenarios and fills the Result database with them. Then, the software computes the economic tools like the NPW or the Discount payback period for each scenario with the 2 MARR provided. From all the information, the software draws the Sankey Diagram and the Result graph (Figure 6 & Figure 7)

In the result tab, the user has access to the Result graph. From the diagram, he can select the range of results he is interested by. For example, he selects the scenarios which have a NPW superior at – 10,000 $. Let's assume that it narrows the results to 10 scenarios. The user has then access to the Sankey diagrams of these scenarios and can analyse the energy repartition. In order to share the results with the client, the user export reports summarizing the 10 scenarios with the information the user selected.

8.2.2 Second Model

Given that most information is similar between the first and second models, the user duplicates the first file with the button Copy. In the second file he now imports the second model with the two different buildings. He follows the same steps than previously: control the geometry, select the zoning pattern, assign the space types, and fill all the energy and economic information required. The analysis is performed and the results are provided in the Result tab. As previously, he exports reports in order to decide, with the client, which scenario is the best for the project.

9 Limitations/Shortcomings of the Project and Next Steps

The main limitation of the project was the lack of knowledge of the author about software engineering. Indeed, this report is based on the assumption that every feature describes in it can be implemented. Interoperability between all the modules in the software must be evaluated by professionals and optimised in order to make the software as stable and efficient as possible.

Moreover, the project did not carry out a market research to evaluate the needs and expectations of the potential future clients and is totally based on Simulead experience. Therefore, some functions, use cases or features of the software may be modified in the future to consider the market analysis results.

10 Conclusion

Simulead wants to develop a software coupling energy simulations and cost analysis. This report identifies the main requirements for the software and enable further developments with computer engineers.

The main inputs and outputs have been highlighted, alongside with the functions that the software must possess. Use cases have been identified and explained, and a case study have been created so that software engineers perfectly understand Simulead's expectations.

The software is to be cloud based and uses OpenStudio to perform energy simulation, which will be fed by either a gbXml or a Sketchup model. The user will then enter the different scenarios he/she wants to test. The software will perform an economic analysis based on the energy results and on its cost database. At the beginning, the cost database will be fed with RS-means data and will then be replaced by an in-house database. Graphs are displayed to summarise the results and reports can be exported by the user.

The software will interact with several software/databases. Therefore, a compatibility analysis must be carry out by professionals to enable the interoperability. Besides, a market analysis must be performed to ensure that the software totally considers and answers the market needs and expectations.

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