4th Construction Specialty Conference
4e Conférence spécialisée sur la construction

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

Evaluation of Energy Utilization Efficiency in Sanitation Systems using BIM

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Abstract: Having a reliable sanitation system is one of the aims of both developed and developing countries. This goal cannot be reached effectively without handling sanitation systems in a sustainable manner. This research presents a framework for planning sustainable sanitation systems using Building Information Modeling (BIM), Computer Simulation (CS) and Building Performance Modeling (BPM). Building Information Modeling (BIM) is introduced to ensure smooth implementation of sanitation plants by developing integrated management teams to avoid causing any disruptions in system operations. The paper describes the advantages of BIM-based models for sanitation system parts (i.e., sewer network and anaerobic wastewater treatment plant). Computer simulation is used to imitate the installation of flow measuring sensors in the sewer system to enable system operators to monitor the performance of the underground system consistently. The developed simulation tool detects any failure in the sewer network. Building performance model of an anaerobic sewage treatment plant is built to aid in the planning phase by analyzing the plant's performance environmentally. The outputs extracted from the performance model are studied to enforce the opportunities of using environment friendly systems in the operation stage of the plant. A case study of developing different scenarios and evaluating them is presented to show the how Building Information Modeling can help in energy saving in the design phase. A scenario of replacing a portion of the conventional electrical energy in sanitation plant during daylight with solar energy using photovoltaic systems is presented and evaluated in comparison with the conventional energy option to enforce the environmental aspect of sustainability in the system.

1 Introduction

Sanitation infrastructure is very critical in the development of any society. Consequences of a deteriorating sanitation system are structural damage in the network and local floods leading to inflow of water into basements, traffic disturbances, street and surface erosion, pollution of receiving waters and public discomfort (Sagrov et al, 2006). With 3.76 billion cubic meters produced annually, Egypt is the largest wastewater producer in the Middle East region. These large quantities should be met with equally dependable wastewater collection and treatment systems. Most of the cities in Egypt suffer from degenerating or inappropriate wastewater collection systems because they were mostly built in the first half of the previous century. Adding to that, the lack of adequate data for the wastewater production volumes projections and the past rehabilitation practices originate a lot of communication gaps between the planning and construction team and the operation and maintenance team. Therefore, handling the sanitation infrastructure in a sustainable manner can improve its condition and empower the collaboration within the whole system. With the emergence of the concept of sustainability, engineers started questioning its applicability in the construction sector through considering its economic, social and environmental dimensions not only at the construction stage, but also all through the whole project's lifecycle. It's not guaranteed that all three aspects of sustainability can always be fulfilled equally together. As a result, some researchers suggested ignoring the social side of sustainability in case of conflicts with the other dimensions due to its intangible nature (Parkin et al, 2003), while others argued that the economical side is the one to be ignored in case of conflicts with the others because the environmental and social aspects are more important to people (Hawkins and Shaw, 2004).

2 Building Information Modeling Workflow

Environmental matters should be put into consideration as early as possible. If they are not dealt with before or during the planning stage of a project, later alterations to the brief will cost money and cause annoyance. That is one reason why utilizing the building information modeling technology serves the environmental purposes efficiently. Building Information Modeling is an emerging tool which develops an informative model of a project that can be utilized in its planning, design, construction, documentation and operation. Observing the obvious impact Building Information Modeling had on construction and design, owners and facility managers started trying to extend its benefits by employing it in the facility management phase (Jordani, 2010). Normally, upon the completion of the construction stage of a project, the contractor hands over to the owner a great amount of project information including warranties, as-built drawings, equipment information and a lot other information (Sattenini et al, 2011). Some researchers suggested replacing all the information transferred to the owner on paper with the BIM's informative model. With the assistance of the BIM approach, facility-based maintenance management information enables information dissemination and information sharing in the three-dimensional environment (Su et al, 2011).

This process faced a massive coordination setback when it was initiated. Theoretically, a Building Information Model should be transferred to the owner after the construction stage is finished to be used in the facility management practices. However, the transferred models were not used by the facility managers due to their incomplete context from an operational point of view. The models were mainly fed by information and data related to the design and construction while being short of information related to operation and maintenance. This occurred due to the large communication gaps between the project designer, builder, owner and facility managers. Taking a single side to develop and assess a building's model will not satisfy all stakeholders. This problem can only be solved through the early involvement of facility managers in the model development stage to be sure that all the relevant information which are needed are transferred to the model (Sattenini et al, 2011). An ideal model development process should include all stakeholders from the design stage when early decisions are still effective and do not have a high impact on the project's cost. In addition, a clear scope of work for each project party should be set to avoid conflicts. Applying the Building Information Modeling approach in an early stage of the project has its advantages, however, it needs close monitoring to share the scope of work among of all project parties. The main problem that faces the implementation of the BIM approach is that users are not used to such collaborative work environment which led to many conflicts in responsibilities. Without an agreed scope and process, there are a multitude of problems that can arise in BIM execution, which will eventually defeat the purpose of BIM (Gong and Lee, 2011). So, it is agreed that successful executions of BIM projects often require good understanding of BIM processes.

3 Building Performance Modeling Case Application

Building Performance Modeling is considered an early stage of Building Information Modeling. A building performance model is utilized during the planning and design stages of a project to evaluate many design options from an operational and environmental points of view. It gives an indication of how the project will perform if constructed under each design scenario. This aids the owner in estimating the operational costs of her/his facility in a very early stage. It can also be directed towards preliminary construction cost estimation, decision supporting strategies and environmental analysis of the project. The research presents a developed building performance model of an anaerobic wastewater treatment plant in Egypt which employs the lagoon system in treating the wastewater. Figure 1 displays the project's components. The project extends over an area of one million square meters, executed over two stages. The first stage is until 2015 with an expected daily capacity of 21,500 m^3 and the second stage is until 2040 with an expected daily capacity of 30,000 m^3 with a peak flow of 2,240 m^3/hr. After the project is modeled, the weather file of the project's site location is loaded. Each weather file carries the relevant weather data of its corresponding location. Outputs extracted from the performance model include the prevailing wind frequency diagram (see Figure 2). The diagram can be utilised to shows both the wind speeds and their relevant probabilities in the different directions over the whole year. The diagram shows that the prevailing wind direction is due south-east. Such information can be used in further urban design of the area surrounding the project. In the future planning of this area, developing a city in the south-east direction of the plant should be avoided over a certain distance to prevent gas emissions produced by the treatment process from being carried away to the residential area.

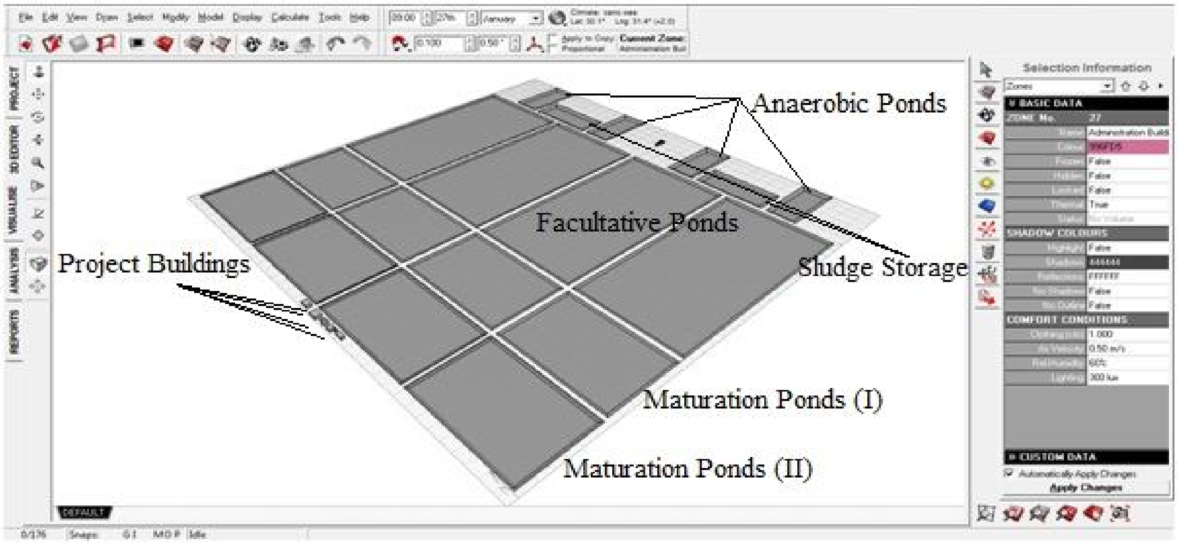


Figure 1: Sewage Treatment Plant Components on Autodesk Ecotect

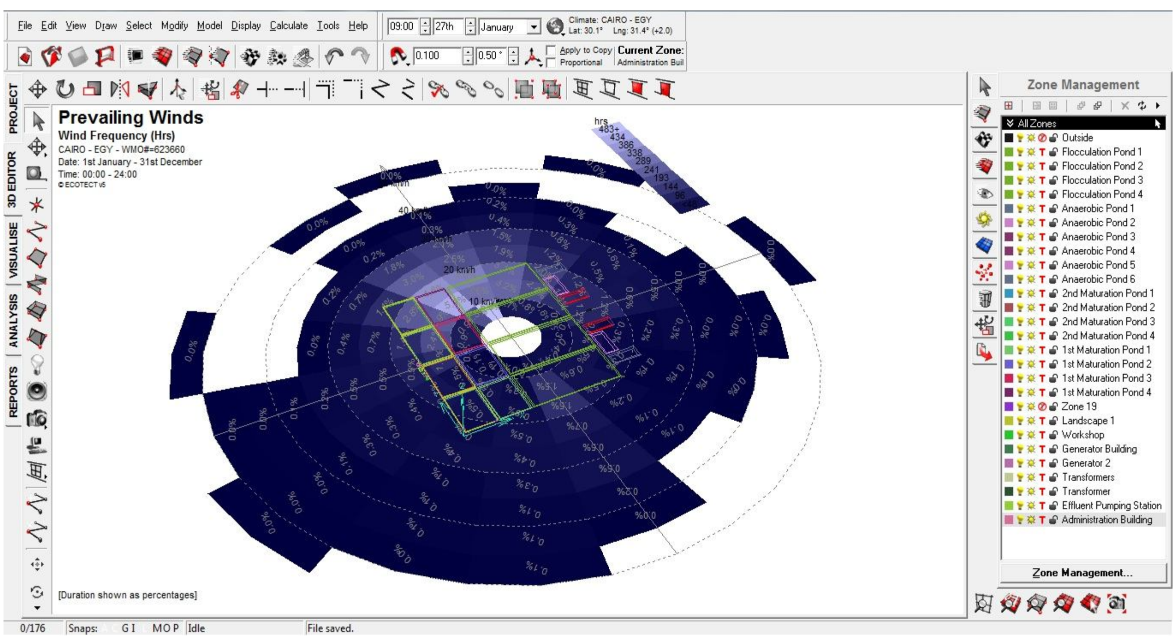


Figure 2: The Prevailing Wind Analysis in the Ecotect Model

Another output from the performance model are the solar properties of the project's location. Site solar analysis is carried out to simulate the project's solar exposure (see Figure 3). The figure shows a 100% solar exposure for more than five months lasting from 7 a.m. to 5 p.m. extending over 10 hours. On the other hand, the 100% solar exposure reaches a minimum of seven hours a day during December. The yellow part in the middle of the diagram shows that all through the whole year the project is subject to 100% solar exposure. This is due to the project's location in the middle of the desert. It gives a phenomenon called an unobstructed sky which allows the project maximum solar exposure because there are no buildings or obstacles around it that might block the sunlight.

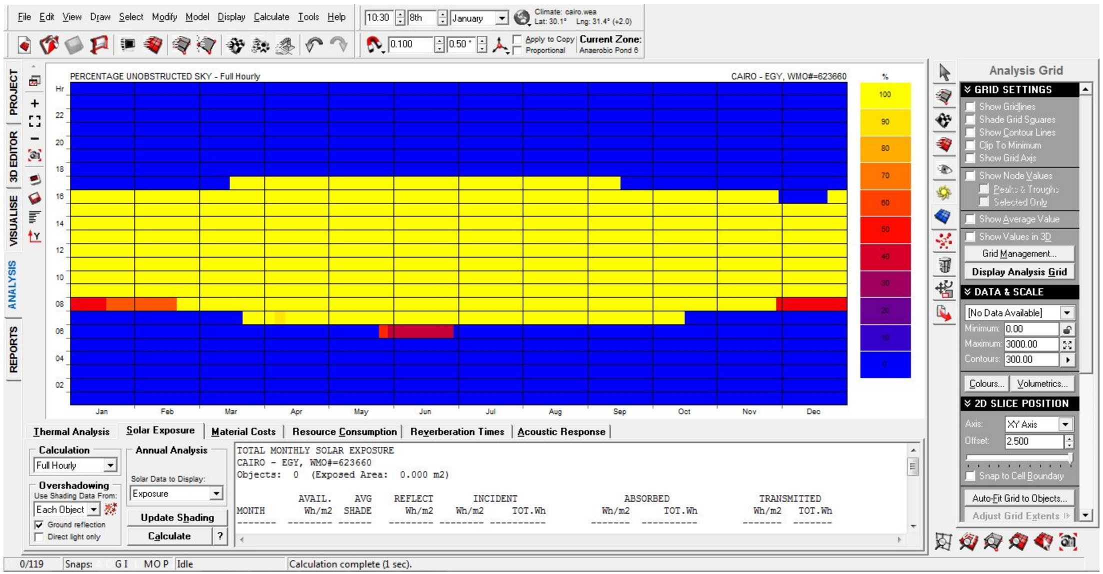


Figure 3: Project Solar Exposure Analysis

4 Building Information Modeling in the Sanitation Sector

4.1 Modeling Sewer Network

Before its construction, an information model of the sewer network is developed to show the pipeline's properties, levels and locations. The first step to develop the sewer information model is setting up the sewer network pipe diameters and materials. Materials vary from PVC to Reinforced Concrete. Once the materials are assigned, the operator can start modeling the sewer network. Polylines of the network's alignment are drawn and then the corresponding pipe properties are set to every part in the line. The gradient of the pipe, the start and finish pipe levels are also set. The "S" in Figure 4 stands for the manholes. Once the model is built, it can be displayed in 3-Dimensional view to make it easier for the contractor, subcontractors or workers at the construction site. The most important benefit of using the building information modeling approach is to develop a sewer network model that has all the needed information in one model.

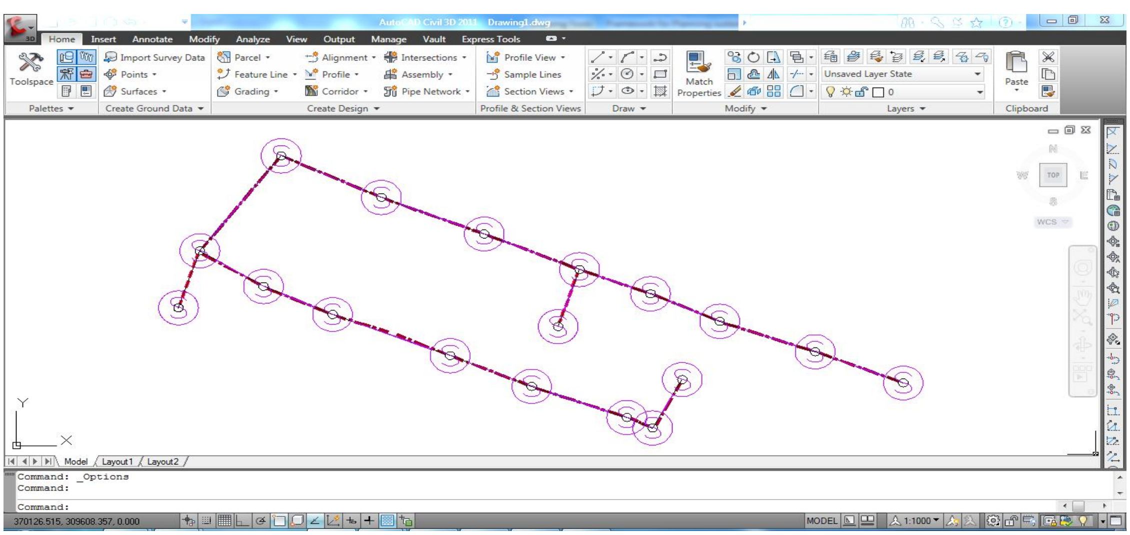


Figure 4: A Plan of the Developed Sewer Sample on AutoCAD Civil3D

4.2 Modeling the Treatment Plant

What differentiates building information models from other 3D models is that they are intelligent models. This means that the modeling software does not recognise the model as lines and curves only. When a wall is drawn in a building information model, the software understands that this is a wall that is made of a specific material and has definite area and volume. A basic advantage for that model development technique is that it calculates the quantities of materials and elements needed in the project during the model development stage. These quantities are updated automatically when the design is changed giving the designer an idea about the amount of materials that are needed for every design alternative.

Basic project information is initially inserted. This information is divided into two categories, project status and energy settings data. Project status information includes client name, project name, project address, project status and number. This data is not used for technical purposes, however, it is needed for project managing and coordination functions. Energy settings data helps in the building energy analysis when the model is exported to energy analysis software. Then, project location is accurately specified using a Google Maps link in the software (see Figure 5). This is utilized later in calculating project's site solar exposure, incident solar rays intensity, prevailing winds speed and direction. Finally, the file export complexity should be decided. Export complexity is corresponding to the amount of details that are needed to be attached to the model when it is exported to energy analysis software packages. Once the project information entry stage is finished, the model is developed. Figure 6 shows the developed information model of the treatment plant located on the project's corresponding 3D topographic map. This gives an indication of the depth that needs to be excavated and provides a vision of how the project will match with the surrounding environment after it is finished. It can also help in site coordination during different project phases.

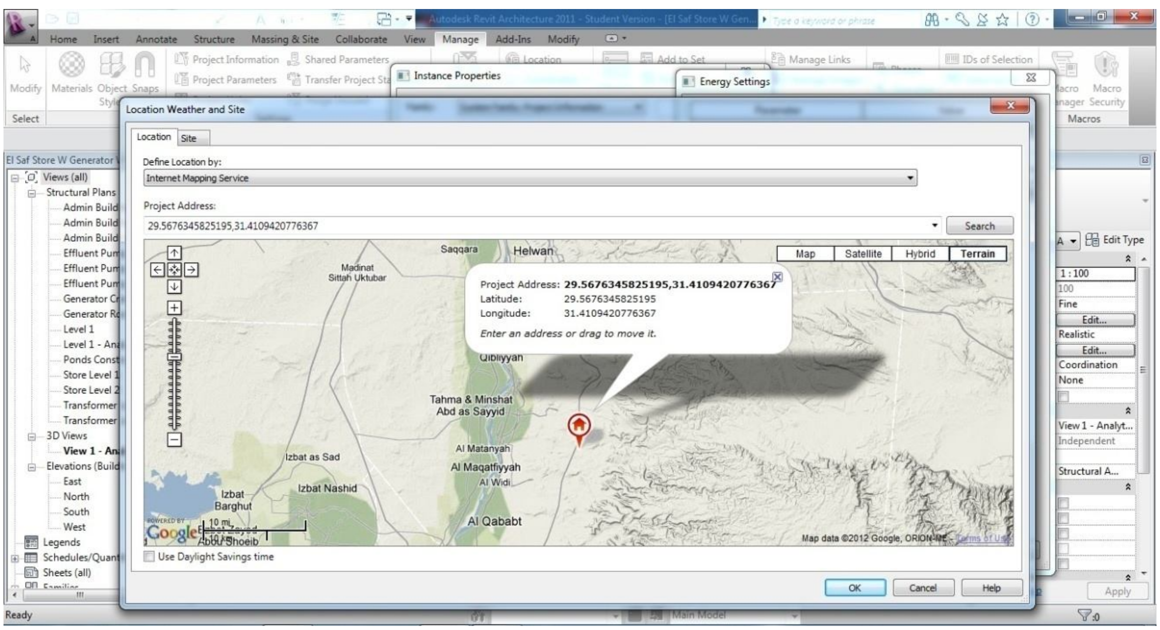


Figure 5: Specifying Project Location on Revit using Google Maps Link

Building information modeling outputs can be divided into three different types; clear project understanding, design alternatives and construction execution outputs. Some of the outputs can be used to ensure that all project parties clearly understand how the project will look like when it is finished. This serves in giving the contractor a clear vision of every part in the project and how it can be executed. Features like the sectioning tool, the viewpoints and the walkthrough tour help in visualizing the project to all project parties. The sectioning tool can be used by contractors in the construction site to show a certain part that is not fully understood by the construction team. Also, the walkthrough tour is a very effective output for the building information model. This feature resembles a realistic tour through the project. It is used to study the circulation in the project and proposes the study to the building users. In addition, it is utilized to study different design scenarios and their suitability. Instantaneous measurements can be made during the tour to ensure the accuracy of certain dimensions. This helps in developing an integrated understanding the project which aids in originating ideas of different design changes which can be proposed.

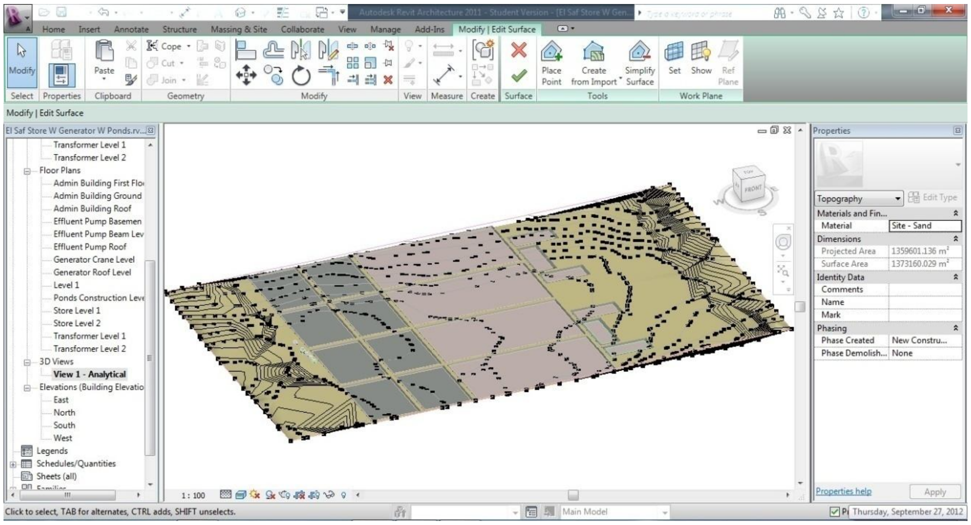


Figure 6: Placing the BIM Model on its 3D Topographic

Another crucial output of the building information model is the clash detection property. This property assists both the project designer and constructor to detect any clash between different project elements to avoid site rework during construction. As a result, the design can be refined to avoid that conflict before it is faced in the construction site. To utilize this feature, the different building elements are selected and a test is started. The test run shows all the clashes between the selected items and whether that clash is new or has been discovered before but not resolved yet. The selected clash is then highlighted as per Figure 7.

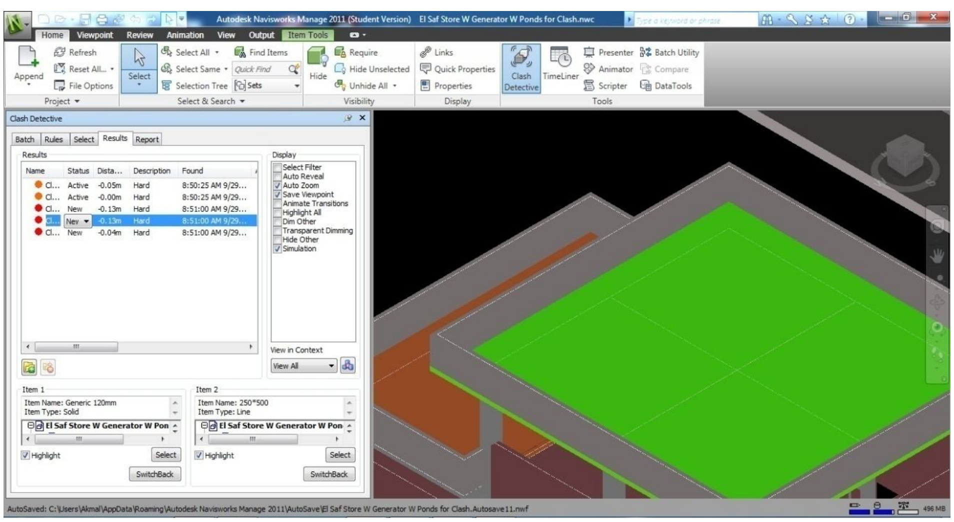


Figure 7: Clash Detection Test Run

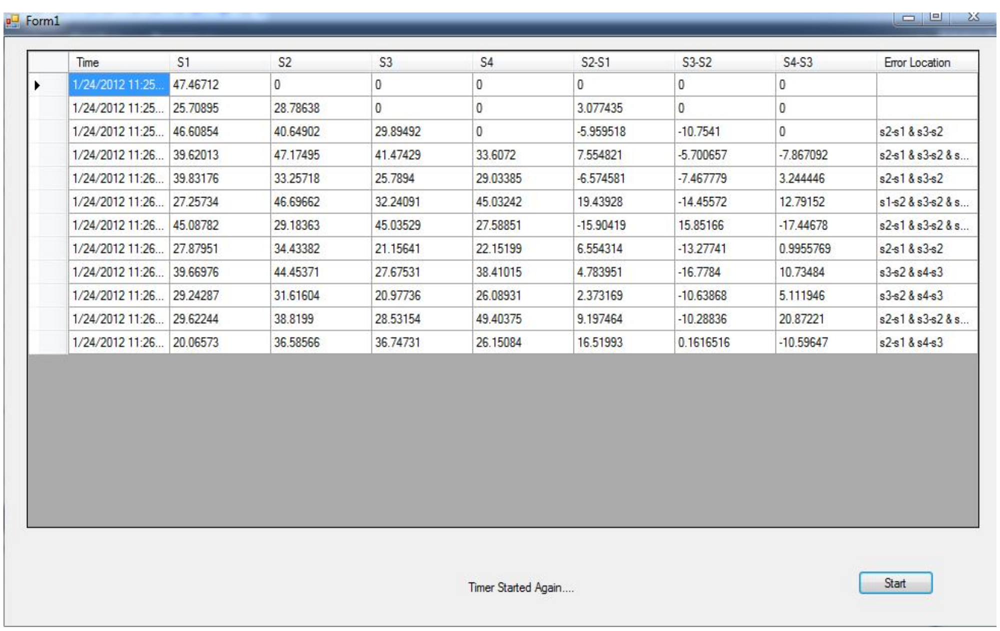
Building information modeling can also be used as an effective quantity surveying and cost control tool. One of the properties of the developed intelligent models is that it automatically calculates the materials' quantities as the model is built. These quantities are updated according to changes in the model. As a result, once the model is completed, the designer can gain an insight of the amount of materials needed and this can help in value engineering studies. As the quantities are calculated, inserting the cost of materials provides the user with the corresponding total cost estimate of the design. Originating design alternatives and calculating their cost can be helpful to fit the project design into a certain predefined budget.

5 Modeling Sewer Flow

Underground pipelines are one of the most critical components of municipal infrastructure in terms of asset value and impacts on a regional or national economic development (Sinha, 2004). Aging sewer networks can lead to a decrease in the level of service due to leakages or, in case of serious failures, can cause accidents leading to heavy social and economic consequences. A challenge to solving infrastructure deficiencies is the poorly met need to optimize spending in a sustainable manner that meets budget constraints, customers' expectations of a certain level of service and regularity requirements (Abdul Moteleb, 2010). Adding to that, investments made in the rehabilitation process of the network should be based on optical observation and assessment of the pipeline's condition to make sure that the relevant funds are allocated according to reliable condition assessment reports. However, in the current management practice, due to the limited budget and the massive size of the pipe network, only a fraction of drainage pipe networks is subjected to the condition assessment program.

To deal with that problem, a simulation tool is developed to model the flow inside the sewer network. It simulates the implementation of flow measuring sensors inside the network to measure in each corresponding spot. Figure 8 represents the user interface of the developed simulation tool. It includes a column that contains the timings at which the readings were taken, four columns representing a sample of four sensors, and a column showing the area at which the errors were detected. In addition, there are three columns which calculate the difference in the values of flow between each two consecutive spots. If the calculated number is above or below two predefined values, an error message is sent indicating a leakage in the specified section. The two predefined values were set to give an error in case of infiltration or exfiltration.

When the error message is sent, a built-in expert system tool is automatically initiated. This tool helps the operator in deciding the most suitable rehabilitation or replacement method to deal with the detected problem. Sewer network failures are divided into two main types; structural and functional (Berardi et al, 2008). The expert system tool uses this classification according to the value of error detected. Afterwards, the operator is asked some yes/no questions which leads him to the best method to treat the damage.



Time	S1	S2	S3	S4	S2-S1	S3-S2	S4-S3	Error Location
1/24/2012 11:25...	47.46712	0	0	0	0	0	0	
1/24/2012 11:25...	25.70895	28.78638	0	0	3.077435	0	0	
1/24/2012 11:25...	46.60854	40.64902	29.89492	0	-5.959518	-10.7541	0	s2-s1 & s3-s2
1/24/2012 11:26...	39.62013	47.17495	41.47429	33.6072	7.554821	-5.700657	-7.867092	s2-s1 & s3-s2 & s...
1/24/2012 11:26...	39.83176	33.25718	25.7894	29.03385	-6.574581	-7.467779	3.244446	s2-s1 & s3-s2
1/24/2012 11:26...	27.25734	46.69662	32.24091	45.03242	19.43928	-14.45572	12.79152	s1-s2 & s3-s2 & s...
1/24/2012 11:26...	45.08782	29.18363	45.03529	27.58851	-15.90419	15.85166	-17.44678	s2-s1 & s3-s2 & s...
1/24/2012 11:26...	27.87951	34.43382	21.15641	22.15199	6.554314	-13.27741	0.9955769	s2-s1 & s3-s2
1/24/2012 11:26...	39.66976	44.45371	27.67531	38.41015	4.783951	-16.7784	10.73484	s3-s2 & s4-s3
1/24/2012 11:26...	29.24287	31.61604	20.97736	26.08931	2.373169	-10.63868	5.111946	s3-s2 & s4-s3
1/24/2012 11:26...	29.62244	38.8199	28.53154	49.40375	9.197464	-10.28836	20.87221	s2-s1 & s3-s2 & s...
1/24/2012 11:26...	20.06573	36.58566	36.74731	26.15084	16.51993	0.1616516	-10.59647	s2-s1 & s4-s3

Figure 8: Simulating Sewer Flow Model

6 Solar Energy Case Study

Finally, a case study is presented to verify the feasibility of using solar energy to replace the conventional auxiliary electrical loads in the buildings of the previously modeled wastewater treatment plant. Electrical energy used in sewage treatment plants is divided into two types, low energy power and high energy power (Melaine et al, 2008). Low energy power is the electrical power used in both the instrumentation and control of the plant while high energy power is used for pumping the produced effluent. Solar energy systems can only replace the low energy power because trying to substitute the high energy power with renewable energy is not a practical approach. A workflow is prepared to coordinate the analysis process and test the feasibility of the proposed system (see Figure 9).Then, the developed BIM model is transferred to Green Building Studio cloud service.

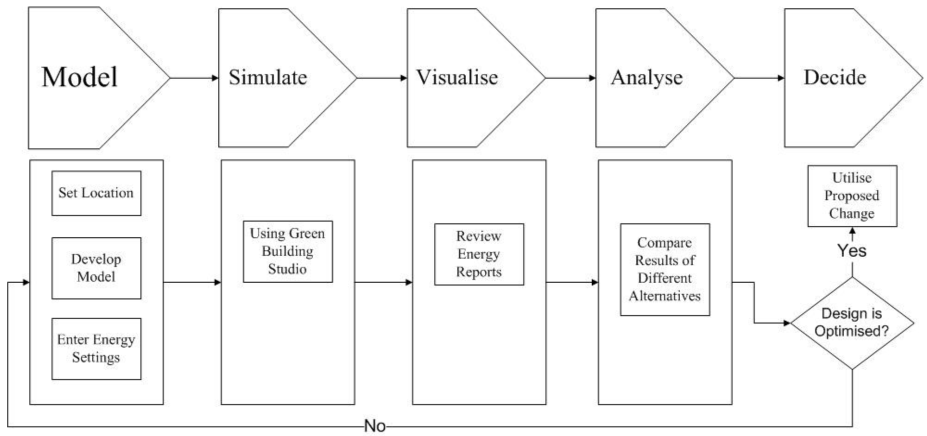


Figure 9: Solar Energy Implementation Study Workflow

When the building energy performance is simulated on the energy analysis tool, full reports about the building's energy consumption are generated. The average equipment and lighting power consumption intensity is calculated with respect to the building area. Moreover, the required heating and cooling capacity is calculated to guarantee keeping the building's interior temperature within the comfort zone. Figure 10 shows the summary of the solar study for the transformers building as a sample. It indicates that the maximum payback period of the solar system is 11 years which leaves the project with more than 15 years of revenue. It also shows that the needed area to accommodate the solar cells of the transformers building is 235 square meters assuming an efficiency of 13.8% for the solar panels system.

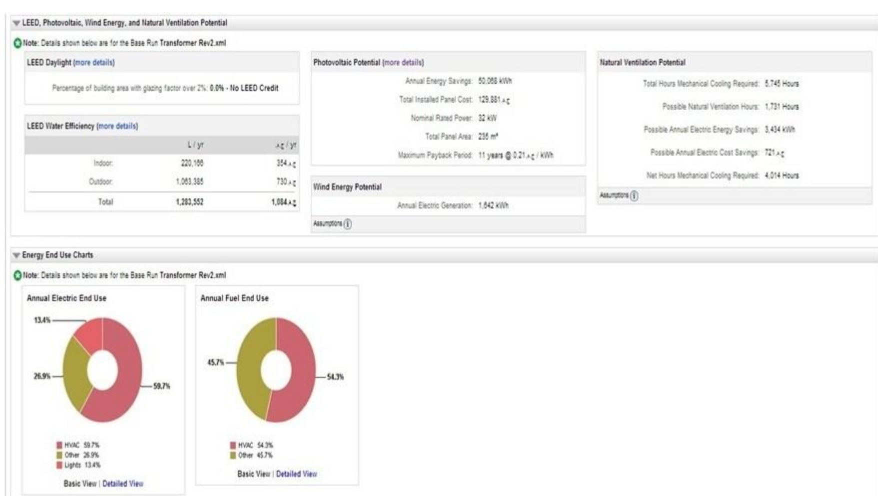


Figure 10: Transformers Building Energy Distribution Charts and Solar Study Summary

7 Conclusion

The research presented a framework of planning sustainable sanitation using a variety of methods and tools. The considered sustainable sanitation systems includes both sewer networks and treatment plants. It showed how building information modeling, building performance modeling and computer simulation can be utilized to enforce the sustainability of the sanitation system and improve its reliability. Using such tools can empower the system's energy efficiency, reduce the waste due to rework and help in dealing with the system is a proactive mode. Adding to that, the research demonstrated a solar energy study which proved the practicality of using solar energy instead of conventional electrical energy used in for auxiliary loads in the treatment plant buildings. This can impose the environmental aspect of sustainability while considering the economical side as well.

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