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Investigating solar envelope by making use of point clouds data

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Abstract. Dealing with solar envelope analysis in architectural design becomes crucial feature because it gives an impact to the building performance analysis in the real environment. Various simulation tools were used by architects play a significant role in determining the design process. However, these tools were not yet confirming the expected performance of the future building design. Manual modeling platform and actual information processing are delivering the main issue on the design operation. This analysis leads to the potential application of point cloud as design medium in architectural domain. This paper furthermore investigates a comparative analysis between point cloud data model-based and the conventional modeling. Some challenging tasks are discussed in related with the point cloud processing in the design framework. The main contribution of this paper is to propose a novel design method for exploring the solar envelope simulation as a part of conceptual design analysis.

1. Introduction

The rapid development of 3D laser technology inevitably has pushed the boundaries of design and engineering world. To date, however, practical implementation in the architectural area is predominantly remaining on heritage (DRAP et.al 2003; WHITE 2013) and landscape domain (LIN et.al 2016). Investigating point cloud as metadata processing in surveying data and digital reconstruction were assigned as the major subjects in these areas. Nevertheless, the provision and utilization of such information data have yet to be effective in most instances, and disconnections between point cloud processing and architectural design practice within design and analysis stage are obvious. However, the fundamental parts of enrichment of point clouds usability are as much as the hidden potential to the practical design implementations. Thus, by considering prospective applications in geosciences, computer graphics or photogrammetry are expected to wider architectural spectrum in data scan processing. As a data visualization, for instance, point cloud has been used in automation process for the planar 3D building interior modeling (SANCHEZ and ZAKHOR 2012), the automatic extraction of spatial arrangement (TAMKE et.al 2014) and visibility analysis techniques in the close range photogrammetry (ALSADIK et.al 2014). Regarding reverse engineering, it was found useful for surface road data management in the maintenance construction (FUJITA et.al 2014) and verification of as-built construction progress through photogrammetry techniques (SHIH and WU 2005). These existing literatures provide us the profound insight to step further into architectural design analysis. The utilization of point cloud as design medium particularly for solar analysis has offered a great potential to the exploration of solar envelope simulation.

Recently, the concept of solar envelope was firstly introduced by Knowles considering the amount of desirable sun access to the surrounding site based on a predefined time (Knowles 1974). This idea was then further elaborated by Capeluto & Shaviv (1997) using “solar rights envelope” and “solar collection envelope” to generate a final envelope that so-called “solar volume.” Furthermore, Ratti & Morello (2005) have investigated the concept of “iso-solar surface” through image processing method, DEMs (Digital Elevation Models) which corresponds to the number of solar energy in the urban area. These approaches, however, were not sufficient to represent the solar envelope simulation when it comes to the real environment as a fundamental context. Dissemination impact of solar radiation value and sunlight hours analysis will result differently for both the existing building and the generated envelope.

The utilization of 3D laser data scanning is not only introducing the real atmosphere of built environment but also covering the existing complex geometry such as building blocks, vegetation or other site properties. The simulation outcome is also simultaneously responded to the number of deviation result from the current solar analysis approaches. This paper mainly aims to investigate the potential of using point clouds data in generating solar envelope. In a broad spectrum, it is intended to improve design support means in architectural design analysis that corresponds to the passive design strategies for sustainable building design.

2. Design Procedure

This paper discusses the following procedures:

1. Selecting a geographical context in parallel with identifying the relevant attributes information from the point cloud data. This pre-processing step is included in the selection of solar envelope generation variables.
2. Developing a design framework through solar envelope generation technique by selecting the attribute information of point cloud data.
3. Demonstrating the generated design framework by considering several indicators to make a comparative analysis with conventional modeling platform. The conventional modeling means that we use the same context but manually generated in the computer program, usually called CAD-based drawing, by constituting the plain surface model. There are three design values which have been measured in the simulation result: the geometric envelope, total radiation value, and sunlight hour analysis.

3. Data Collection

The selected site is located in Kruisplein area, Rotterdam-Netherlands, nearby the Rotterdam central station. This area represents city center of Rotterdam which shows the dynamic urban forms such as high rise building, wide span building, large open space, and vegetation in between of the buildings (see Fig.1). We cover these urban properties through the point cloud data collection as a part of the relevant site elements. On top of that, this data collecting method illustrates the ability of point cloud data to capture complex information in the real environment.

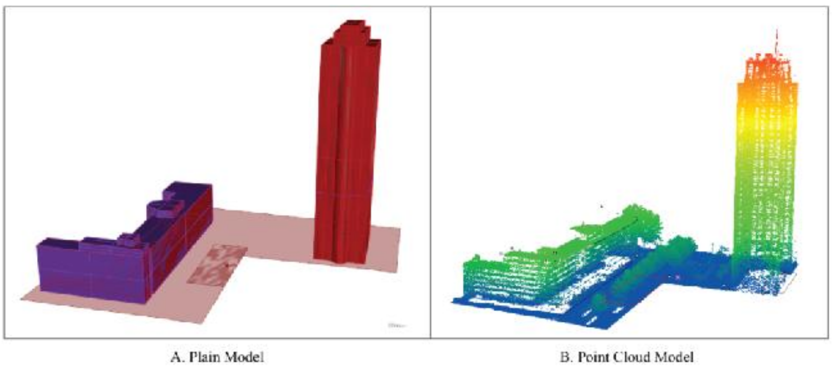


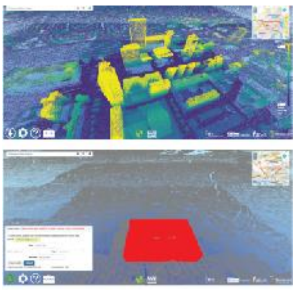
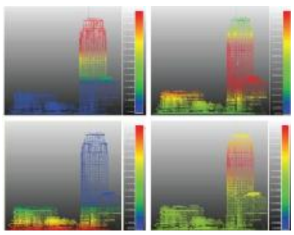
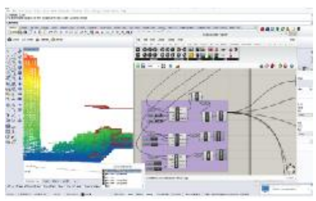
Figure 1: Selected site

The 3D point cloud data is obtained from the Digital Elevation Map (DEM) of Netherlands based on laser altimetry measurement (AHN Netherlands 2017), which is open source media and accessible for architects. Our primary concern is to extract this potential open information from the point cloud data to be used in architectural design analysis. It, however, still opens the possibility to obtain point cloud data in an accurate way by using such the Terrestrial Laser Scanning (TLS) device like Faro, Leica, Riegl and others.

Furthermore, we employed Cloud Compare (CC) for data preparation to be legible in Rhino and Grasshopper (GH) as parametric modeling platform. As a part of preliminary step of data processing, we converted the .laz format (original data format from DEM) to the .e57 file (designated format) and removed the outliers of point cloud in the selected site boundary. Then, we transformed the attribute information of point cloud data through the scalar field value. We used the height ramp feature in CC to obtain data colorization according the vertical unit. The scalar field value plays an important part in the development of design framework because it determines the type of variable input of point cloud data. For instance, by selecting the green (G) value for the color attributes, the point cloud data will show green color as the highest point geographically in the chosen area. We could also, by using CC, produce and calculate multiple values of scalar field for point cloud data such as R-G-B color, intensity, curvature, composite and so forth. However, calculation of this scalar field value depends on the type of extracted data which we selected from DEM, AHN. Each data format may correspond to the different scalar field value. The data preparation steps in CC enable us to identify and to extract such geometrical shape according to a certain level in the parametric modeling stage.

In the development of solar envelope design framework, we operated Ladybug component in Grasshopper (GH) and Volvox (Zwierzycki et.al 2016) for point cloud data processing. We also constructed the additional GH components to formulate a further analysis of point cloud data. Table 1 illustrates the workflow of data processing from the 3D raw point clouds data into the parametric modeling space.

Table 1: Workflow of 3D raw point cloud data processing

Step 1	**Step 2**	**Step 3**
		
DEM, AHN	**Cloud Compare (CC)**	**Rhino+Grasshopper**
Site selection: - set type of data. - specify density of points. - import the selected data. - the data format is .laz	Data conversion: - trim the boundary of site - filter the outlier of points - convert to scalar field value - the data format is .e57	Development of design framework: - import .e57 file - make a classification of objects included ground level and relevant facades - generate reference plan for each surrounding building

		- run the meshing process - set the solar envelope simulation based on selected objects and variables.

4. Application of Case Studies

This paper constructs the solar envelope generation technique by making use of extension concepts from Capeluto & Shaviv (1997) considering two design principles "solar right envelope" and "solar collection envelope." The needs of obtaining sun access in our building (the proposed envelope) would be adjusted by following the floor level of surrounding buildings that we have set. This floor level will determine the maximum height of generated envelope in the design framework during a predefined period. It also simultaneously assigns the obtained envelope does not violate sun access for the neighboring buildings or the so-called "solar right envelope." As a result, the surrounding area where is located below the established floor level will get a shadow.

To some extent, the surrounding border can also be used to govern the lowest possible surface of our building (the proposed envelope) that could have sun access without being obstructed by the adjacent buildings. Afterwards, the defined surface could be used to determine position of the window and potential solar collector in our design or the so-called "solar collection envelope." However, the area located below the generated envelope surface will not get the sun access. As an architect, we should be able to explore and to maximize design possibilities of our designated envelope by constructing mutual dependency with the surrounding environment.

According to above-mentioned of the basic principle of solar envelope, we selected several parameters that could be relevant to our case study in this paper. Three considered parameters including in the design framework are climate, urban rules or zoning regulation, and surrounding environment (see Fig.2)

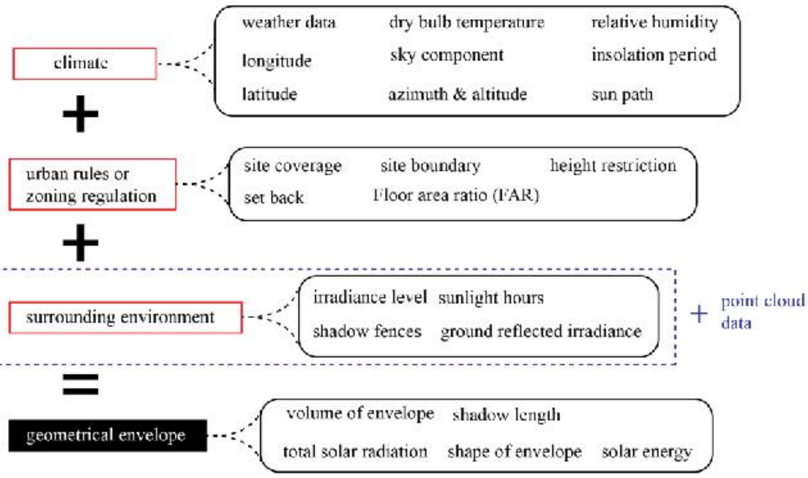


Figure 2: Parameters of Solar Envelope

In respect to these parameters, this paper extracted the climate data by using default formulation from Netherlands climate dataset. The selected site is 16,5 m x 42 m, which is located between the wide-span and high-rise building. The design simulation then sets the cut-off times during the period from June 1st to December 31st between 9 am and 10 pm. All connected variables in the design framework (see Fig.3) parametrically generate the solar envelope surface both solar rights and solar collection. According to this design framework, we enable to explore certain scenarios of design possibilities by making use of point cloud data.

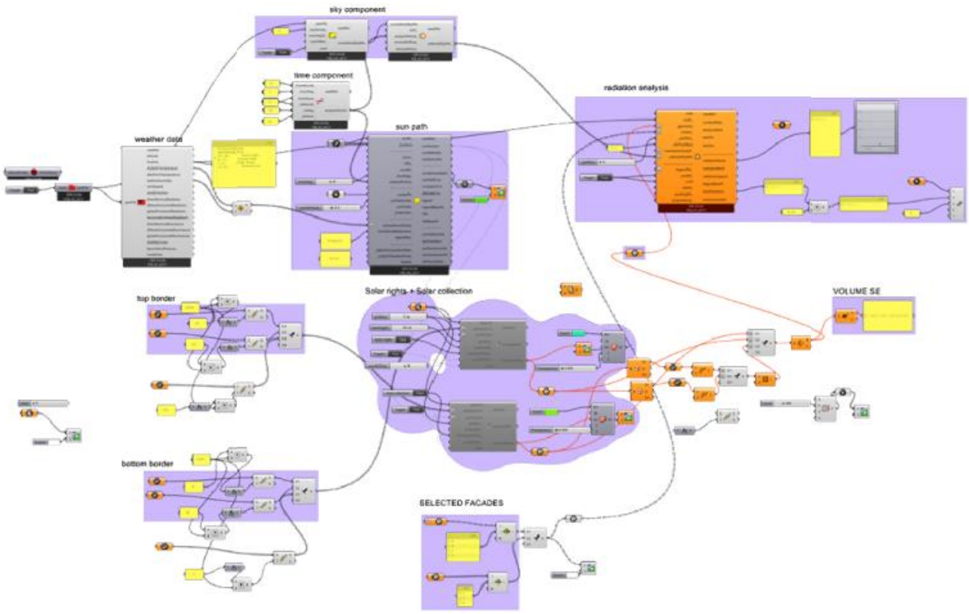


Figure 3: Design framework

As a set of data structure, point clouds is assigned as the detached of three-dimensional location (XYZ coordinates) that can have auxiliary metadata (WHITE 2013). Typically, it represents each record of point data such as color information, intensity, and position information. In this case, the 3D point cloud contributes to enhance the value of surrounding environment parameters by giving several impacts to the geometric envelope as follows:

- Consideration of vegetation as part of surrounding site variables is able to affect the shape and volume of the designated envelope. Plants could also be counted into the protected variable to have sun rights access (DEKAY 1997) like a solar community garden. The relevant vegetation in this case study has contributed to slightly increasing the volume and the radiation value of the generated solar envelope.

- Calculation of the total solar radiation value to the generated envelope produced a different result when considering only surrounding building facades which are facing to the site rather than measuring the whole surrounding building surface.

- Utilization of sunlight hour analysis on the surrounding building facade is useful to detect the most accessible area of solar access radiation. It further helps us to extract the possibility of locating solar collector and placing windows in the building façade. Moreover, we could discover disparity of generated total radiation value between point cloud surface-based and plain modeling surface by looking at the reflected radiation vector to those surfaces. The sunlight hour analysis is also potential to define the boundary of sun access area on the ground level of the site.

- The point cloud data opens further possibilities to figure out the complex building geometry of surrounding environment such as the roof shape, ground properties, building facades and so forth. Capturing the existing building blocks through the conventional way may end with the difficulty of geometric identification because building shape could overlap each other on a particular perspective. Thus, implementation of point cloud data offers more extensive analysis platform concerning the deeply understanding of relationship between our site and the surrounding environment in the real context.

The exported point clouds from CC consists the colored scalar field based on height ramp indicator. It however still represents the unclassified cloud of points. For example, the ground level, building shape, and vegetation remained in the same entity of points. Thus, we need to make a selection and classification for the object variables. The ground points are selected first based on the vertical unit to illustrate a different geographical level. This selection will help us to classify other objects above the ground level such as trees and buildings. Once classification is completed, we employed the extracted outline from the building's boundary as a threshold to set up the maximum height of the designated solar envelope. The threshold line acts as a floor limit representing both the bottom and top border of surrounding buildings. The aims of this threshold line are to manage the area that receives shading from the surrounding buildings and to control the maximum height of the generated solar envelope.

5. Result and Discussion

According to the simulation process, we compared two modeling platform approaches between point cloud and plain modeling. Three assigned indicators are used as a benchmark to investigate the simulation result as follows: the geometrical envelope that consists of volume and shape of the envelope, the produced total radiation value by the generated solar envelope, and the calculation of sunlight hours on the surrounding building facades.

Table 2: Comparison of total sunlight hours and radiation value between two model approaches

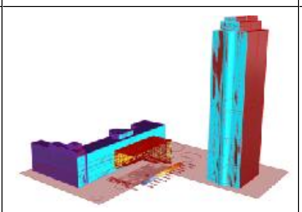
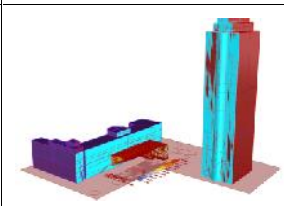
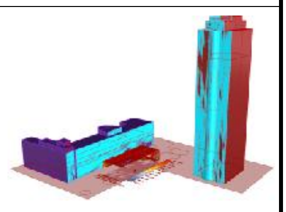
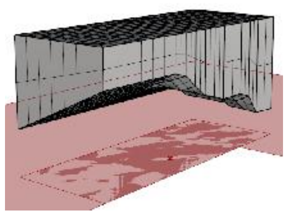
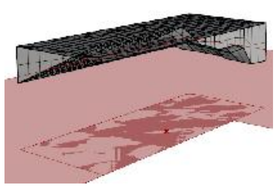
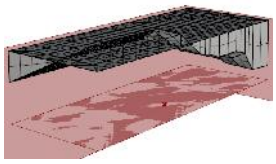
Plain model-based	**Total sunlight hours (n hours)**	**Deviation area* (m²)**	**Total radiation (kWh)**
Building facade A (wide span)	27.476,68	161,888	248.328
Building facade B (high rise)	129.187,77	12,627	207.756
Selected site (ground level)	29.324,46	5,879	72.274,11
Point cloud-based	**Total sunlight hours (n hours)**	**Deviation area* (m²)**	**Total radiation (kWh)**
Building facade A (wide span)	18.236,16	0,00785	51.822,194
Building facade B (high rise)	47.040,23	4,45021	114.613,314
Selected site (ground level)	17.387,45	0,9853	45.552,12
*deviation area represents the total area that receives sunlight hours and then divided by the calculated area that collects sun access smaller than 8.5 hours (desirable hours).			

The simulation result in the Table 2 demonstrates significant disparities of radiation value between two different modeling platforms. There are two aspects taken into account in the existing area: the building facades and the selected site at the ground level. The plain modeling illustrates that the total sunlight hours and the received total radiation are inclined to produce the excessive value compared to the point cloud modeling-based. This is because the point vectors reflect in a perpendicular direction to the designated surface. Thus, the plain surface could collect a large number of total solar reflections which may affect the further design analysis.

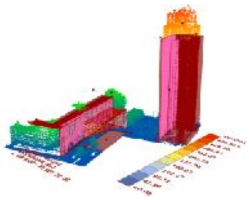
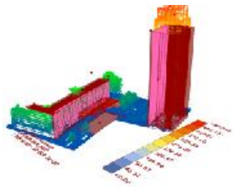
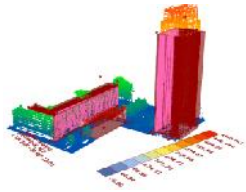
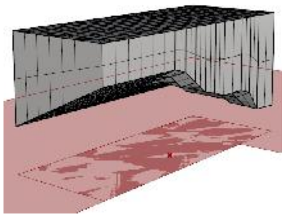
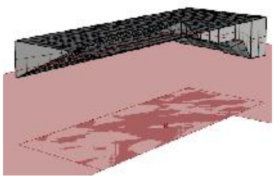
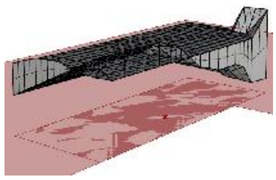
On the other hand, the generated triangular irregular networks (TIN) surface from point clouds data illustrates the uneven surface morphology. The TIN surface basically constructs topographic depth referring to dissemination and the density of original point data. As such, the point vectors spread in a random direction by following the surface morphology. The projection of this mechanism navigates to more accountable results in terms of radiation analysis. The result in particular deals with the surface modeling platform that becomes crucial variable in the envelope generation process.

This paper moreover examines comparative analysis between the plain modeling and the point cloud data-based. We measured two simulation indicators: the total volume of generated envelope and the total radiation value. Each modeling platform is assigned by three scenarios based on the different level of threshold. These thresholds basically correspond to up and bottom level of the selected surrounding objects. The up level indicates the solar collection boundary and the bottom level refers to the solar rights boundary. In this case, the thresholds of the plain modeling are set only to account the surrounding building forms that include wide span and high rise building. By exploiting the point cloud data however we could set vegetation in the site as additional border variable. This means that we consider sun access to our building (the proposed envelope) without being blocked from the selected vegetation.

Table 3: Comparison of envelope's volume and total radiation value between two model approaches based on three different scenarios

Plain model-based	**Scenario A (m)** **Up : 50/20** **Bottom : 3/2**	**Scenario B (m)** **Up : 60/15** **Bottom : 7/5**	**Scenario C (m)** **Up: 80/10** **Bottom : 1/1**
Envelope's volume (m^3)	7.598,45	1.728,35	1.718,25
Radiation Value (kwh)	71.773,52	40.659,40	42.867,55
Simulation			
Geometrical envelope			
*up = highrise building / widespan building (meter)			

down = highrise building / widespan building (meter)

Point cloud model-based	**Scenario A (m)** **Up : 50/20/14** **Bottom : 3/2**	**Scenario B (m)** **Up : 60/15/14** **Bottom : 7/5**	**Scenario C (m)** **Up: 80/10/14** **Bottom : 1/1**
Envelope's volume (m^3)	7.658,44	1.858,60	1.779,23
Radiation Value (kWh)	94.124,96	59.469,86	49.202,94
Simulation			
Geometrical envelope			
*up = highrise building / widespan building / vegetation (meter) down = highrise building / widespan building (meter)			

According to the simulation result in Table 3, both models are nearly demonstrated the same envelope shape for the all scenarios. The largest envelope volume is illustrated by the scenario A, whereas the least dimension is obtained by the scenario C. The differentiation of these scenarios validates that the closest distance between up and bottom border will generate the greater volume. As a result, the plain modeling gains the smaller envelope volume compared to the point cloud-based. Another remarkable result is that vegetation which is considered as the up border confirms the volume alteration of the solar envelope.

Furthermore, the simulation measures radiation value for both model platforms. In this context, we account the relevant surrounding building facades in the site to obtain the more accurate result. The radiation value of point cloud model-based shows the significant upgrading. This means that the TIN surface from point cloud data has succeeded to enhance the radiation value of the generated envelope thoroughly. The result of this radiation value furthermore could encourage architects to explore more the potential information of surrounding context. In addition, architects can map the solar potential surface on the generated envelope to position the window and the interior building layout based on desirable sun access. Lastly, the simulation result is also useful to figure out the pre-determined material properties in the building surface in the conceptual design stage.

6. Conclusion

This paper generally proposes the idea of using point cloud as a context data in generating and analyzing solar envelope. The utilization of point cloud data has offered the architectural possibilities to step further into the design analysis. The important role for architects is the ability to manage the relevant site information properly in the real environment which simultaneously could enhance the accuracy of modeling simulation analysis in the conceptual design stage. Therefore, the point cloud data through color information and position information enables architect to select a certain area precisely among many objects. By using parametric design space, we could control the point cloud data more flexible that correspond to the geometrical shape of the developed design framework.

Furthermore, point cloud data has confirmed the positive contribution to the solar envelope analysis through three selected indicators: the enhancement of solar envelope volume, the total radiation value for generated envelope, and the sunlight hour analysis for the surrounding building facades. The TIN surface of point cloud data represents the extraction of surface morphology from the real building context which is assigned by the irregular surface pattern and the scattered point vectors. As a result, the total radiation and the sunlight hour value from the point cloud data shows a decreasing number compared to the plain modeling.

During the design simulation process, some acknowledged limitations of this study are addressed. For instance, the material properties from the point cloud data could not be displayed through meshing process because of extraction of the original data from DEM, AHN. Thus, design investigation of the point cloud data focuses on the utilization of point attributes such as color information and position information. Another considerable factor is the density of point that corresponds to the geometrical aspect, the accuracy of the TIN surface, and the robust information that could we extract from the data. However, the execution of the high resolution point cloud data still consumes expensive time due to a great number of hardware computer memories.

The potential fruitful areas for further research from this study are the possibilities in constructing solar energy distribution by adding multiple performance indicators such as shadow analysis, material properties, daylight factor, and other microclimate variables. This design method is expected to open a novel design framework for the future building performance analysis in the conceptual design phase. As it also responds the concept of "metabolism" Knowles by having a broad impact quality on the built environment.

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