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Publication date
2018

Document Version
Final published version

Published in
Proceeding of the Symposium for Architecture and Urban Design (SimAUD 2018)

Citation (APA)
Alkadri, M., Turrin, M., & Sariyildiz, S. (2018). Identifying the surface materials of the existing environment through point cloud data attributes. In *Proceeding of the Symposium for Architecture and Urban Design (SimAUD 2018)* (pp. 323-330). simAUD.

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Identifying the surface materials of the existing environment through point cloud data attributes

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ABSTRACT

The prospective application of 3D laser data scanning provides numerous possibilities for investigating environmental performances for architectural design. One of the possibilities includes the practical usability of point cloud data in examining the existing environment. Exploiting this potential would help to increase the information on properties of the real context, which currently often lack during the conceptual design process. As part of this general goal, this research particularly investigates the potentials of the surface attributes contained in the point cloud data such as color, position, and intensity information. The extraction of this information allows mapping the distribution of surface materials of the existing environment by considering the intensity and the albedo values. The outcome of the research constitutes a catalogue of surface materials that are useful for architects as a decision support environments. In parallel with computational design flow, this research ultimately aims at delivering a novel method for architects to perform site analysis comprehensively.

Author Keywords

Point cloud data; attribute information; intensity values; albedo; surface materials.

ACM Classification Keywords

I.6 SIMULATION AND MODELING; J.5 ARTS AND HUMANITIES - Architecture; J.6 COMPUTER-AIDED ENGINEERING – Computer-Aided Design (CAD).

1 INTRODUCTION

The practical implementation of 3D laser data scanning has been widely used in many fields especially related to data representation and data analysis such as civil engineering, computer science, photogrammetry, geoscience, and heritage. As a data structure, point cloud indicates a collection of multidimensional points [15]. It is characterized by spatial XYZ coordinates and is optionally be assigned by typical attributes such as intensity information, color information, and any additional abstract information. Richter et.al [17] illustrates further investigation of attribute information of point cloud data that contains six values: colour [11], object class information such as vegetation [8] and terrain [3], surface normal [14], horizontality [19], global height and local height [2]. These values can be employed to construct an accurate representation of point data such as size, orientation, and shape. However, not all of these attributes are practically relevant and feasible to construct design and analysis of architectural domain. In this case, architects need to identify the level of use of point cloud data attributes in the design practice. Some of those attributes need the pre-processing steps and particular knowledge to extract the full function of point properties.

Among the aforementioned attributes, this research focuses on the exploration of color, position and intensity information. In general, the use of these attributes is useful to fulfill the absence of information on the real environment during the site analysis process. In architectural design, often the current site modeling approach not only lacks in preserving a complex geometry but also information on materials and textures [1]. This may lead to the relevant discrepancies between the environmental analysis and the real context during the conceptual design process.

By making use of the intensity information, this research investigated further the surface reflectance of the existing context. The attribute of intensity potentially caters various practical tasks [10] such as detection of damaged concrete in the tunnel, identification of pavement lines and stripping, mapping seafloor, reflective detection signs, mapping different types of geologic layers in a cliff and identification of certain damages caused by natural disasters. In addition, the color and position information constructs a significant role in determining the artifact and structure of the image by converting RGB color to HSV values [11]. The potential application of these attributes then offers a great possibility to reveal the invisible information in the existing site. For example, the use of these attributes corresponds to surface characteristics [12] of the existing environment which may lead to the calculation of the Urban Heat Island (UHI) effects and other environmental assessments.

SimAUD 2018 June 05-07 Delft, the Netherlands
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Further, this research involves the visualization of correction intensity value in order to minimize the distortion factors of intensity value from the raw point cloud dataset. The ultimate objective of this study is to propose a method for analyzing the existing environment particularly related to the surface material properties of the existing site by considering the position, color and intensity information of point cloud data.

The paper is structured as following. In Section 2, a sample of case study is introduced and its data collection is presented. In Section 3, the workflow is presented. It focuses on the detail procedures of the research methodology including simulation and data processing of the point cloud data attributes. Last, the Section 4 constitutes a discussion of the simulation results.

2 CASE STUDY

In this study, we collected and demonstrated a sample of 3D point cloud data. There are two main criteria for the dataset selection as follows:

- The attribute information contained in the point cloud data at least consists of position information (X,Y,Z), color information (R,G,B) and intensity (I). In the frame of exploratory techniques, this dataset is tested into the developed model. The location of dataset can be placed in any cities because the extraction of attribute information of point cloud becomes the focus of the research investigation. Thus, we gathered the dataset from the open data in order to let the other users test the similar available datasets (available at http://www.danielgm.net/cc, EDF R&D Telecom ParisTech). In this case, the dataset employed Terrestrial Laser Scanning (TLS) technique which provides possibilities for having more accurate data, texture and material representation of the real context compared with the Lidar (Light Detection and Ranging) dataset from the Airborne Laser Scanning (ALS). Given the availability of the dataset, we only employ the energy of the return pulse that refers to the intensity and the recorded RGB color. As by default, the return number is highly reliant on the type of scanner. Further, the use of TLS dataset in this study allows switching the viewport from the intensity format to the real color of texture during the working process. It also helps the users to visualize and analyze alteration of values in the 3D point cloud environment directly.
- The collected dataset contains multiple urban characteristics in order to perform complex analysis of existing urban context. As illustrated in Figure 1, the selected context consists of the housing façades with shops in the ground level, streets, trees and some parts of the building's roof. These urban elements become the important parts during the context analysis process to demonstrate the environmental relationship between elements according to the surface materials from the point cloud. Therefore, we can identify and analyse further the existing urban elements based on the certain material properties.

By having this criteria, the developed method in this study can be applied in the different urban context.

Figure 1. The 3D point cloud of the context.

3 METHOD

Starting from the raw dataset of the point cloud, the proposed procedure permits to identify and map the surface materials of the existing environment according to the albedo values. The procedure consists of three steps: (a) intensity correction, (b) data segmentation and (c) calculation of the albedo values. The overview of the process is illustrated in Figure 2.

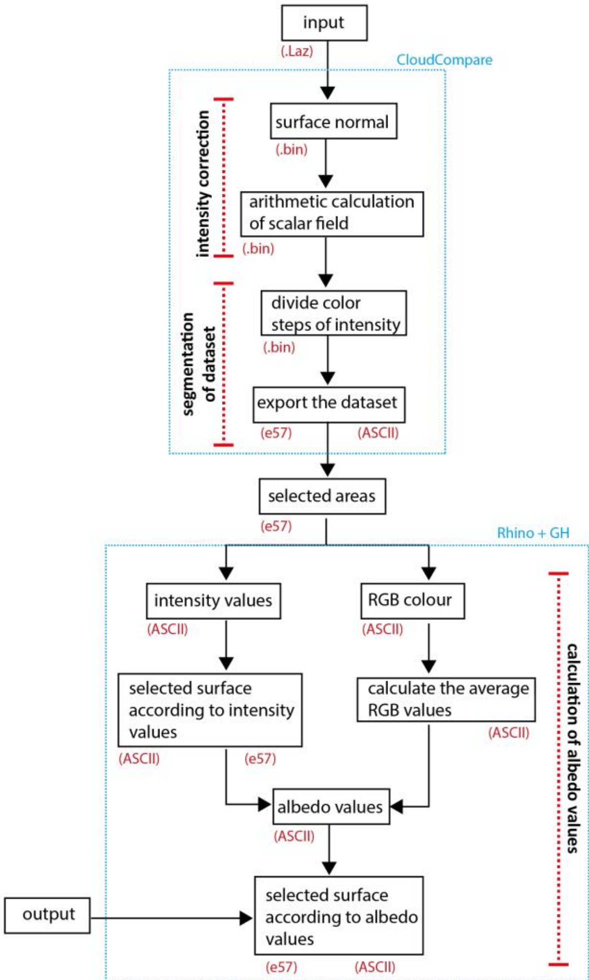

Figure 2. Overview of the proposed procedure

The computational workflow in this study generally uses two supporting tools. First, it consists of Cloud Compare (CC) for cleaning the outliers, segmenting the datasets according to the intensity values and exporting the datasets into the designated format. Besides, CC has a scalar field function that helps us to activate the metadata information (real values) of point cloud data such as distance, intensity, density, roughness, curvature and so forth [4]. Second, as 3D modeling tools, Rhino is coupled with Grasshopper components allowing the users to organize the 3D point cloud areas based on intensity and albedo values.

3.1 Intensity Correction

Given an understanding of dataset as the product of data scanning, several influencing factors should be taken into account in order to minimize the errors during the measurement [9] such as target surface characteristics, acquisition geometry, instrumental effects and environmental effects. These factors both directly and indirectly affect the intensity measurement of the acquired data scan. For example, the surface roughness of the building skin influences specular and diffuse reflection of the laser pulse; scanner location can affect the brightness level of the intensity, atmospheric variables like humidity and temperature pressures can also affect the intensity values. However, the listed factors are nearly impossible to reduce in a single algorithmic operation due to some local constraints. The original dataset, environmental condition and types of the scanner are some limitations that usually hard to control for the common users.

By considering the original dataset, this study applies intensity correction (I_c) through operation of angle of incidence (α). The equation of angle of incidence (α) uses multiplication between the current intensity (I) values and the cosine α [5-10].

$$I_c = I \times \frac{1}{\cos\alpha} \qquad (1)$$

Before that, however, the surface normal of point cloud dataset is computed firstly to identify the normal estimation of the existing point cloud. Although this process does not change the values, the surface normal is used for data visualization and further analysis of the surface orientation of dataset (see Figure 3).

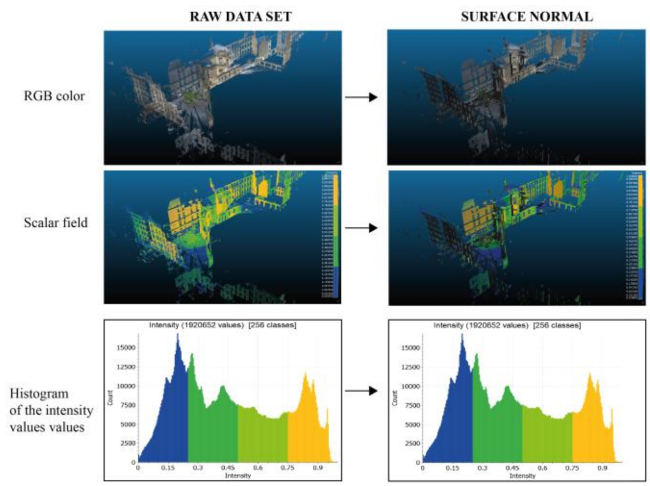

Figure 3. The 3D visualization of dataset between the raw point cloud data and the applied surface normal.

According to the result of intensity correction based on the angle of incidence (α) (see Figure 4), the following aspects illustrate the major changes from the initial intensity:

- The ground level (streets) of dataset demonstrates significant transformations. The initial intensity shows that the lowest intensity values (represented by the blue color) cover almost the ground level. In fact, the position of scanners (see Figure 4) only illustrates the green color which is referring to the second level of intensity values (0.25-0.5). The intensity correction ultimately applied the highest values on the ground level but still needs to consider some issues especially coming from the scanner effects like the brightness reducer [7], an amplifier for the low reflective surface [9] and so forth. In addition to that, the blue color in the initial intensity is detected in the area of the glass windows in the building facades. In reality, the glass material includes the reflective or glossy materials category which is supposed to have a high-intensity value. The different results are demonstrated by the intensity correction. The area of the glass windows nearly shows the yellow color which approximates the theoretical principles of reflectivity.

- There was an increasing color value of intensity by 0.5 shown in the histogram graph from the initial one (0 -1) to the correction phase (0 – 1.5). This result basically only affects the color step values because the real values of intensity remain the same amount. The similar mechanism applies to the normal surface operation. It only influences the 3D visual datasets. To confirm that, the statistic comparison is made by converting the color scale of intensity correction to the monochrome intensity color. Its results illustrate the same color scale values with the initial intensity which is back to the range between 0 – 1 (see the red boxes in Figure 4).

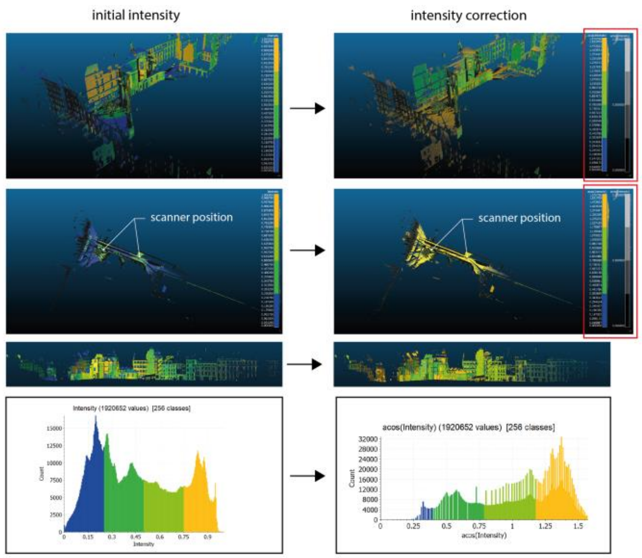

Figure 4. The comparison of 3D point cloud between the initial intensity and the correction intensity.

3.2 Segmentation of datasets

Furthermore, the new dataset is categorized into four color scales according to the intensity values. Its categorization starts from the lowest values up to the highest values such as A (0.0 – 0.39), B (0.39 – 0.78), C (0.78 – 1.17) and D (1.17 – 1.57) (see Figure 5). This step intends not only to visualize the identification of reflective surface but also to classify the surface materials of the existing context according to reflectance values, later called albedo values. Each of classified datasets is then exported into .E57 and ASCII format in order to be legible in Rhino as a 3D modelling tool.

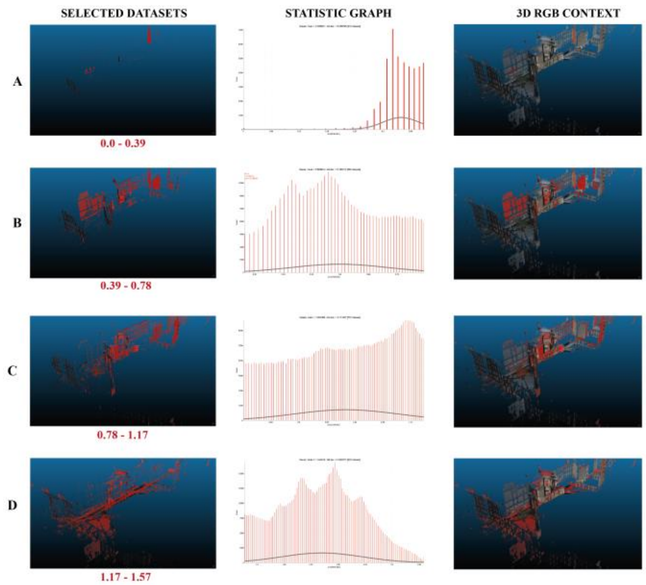

Figure 5. Segmentation of datasets according to the intensity values

3.3 Calculation of the albedo values

This part aims at calculating and analyzing the surface reflectance values of the materials dataset. Generally, the calculation process consists of two steps as follows:

- Synchronizing the intensity values between the metadata files in ASCII and the 3D geometry of point clouds in .E57 file. This process permits the selection of dataset according to the certain values and index of points. Besides, we can control the density of points that will be loaded into the workspace in order to manage the computational storage issues. In the process of dataset synchronization, several aspects are necessary to be noted such as the option of the attributes header, separator format between attributes and the order of the attributes. At a certain point, the order of attributes such as color attribute and scalar field (SF) function can easily change according to the format types of the order. Thus, the right attribute should be checked and picked during loading the datasets.
- Searching the average values of RGB color for each point in the selected dataset. Once the average RGB values are calculated, the albedo value for each point can also be computed. Thus, we can align the intensity and the albedo value of the selected surface. By doing that, the catalogue of the surface material of the existing context can be organized. Its catalogue becomes a reference for running the further environmental simulations such as UHI effects, radiation analysis, and thermal comfort.

4 RESULT AND DISCUSSION

In order to construct an in-depth analysis of the results, this research examines the calculation of the surface material by dividing each of previous color steps into another four intensity ranges. In this case, we load all the points of the dataset (1.920.651 points) into the simulation so that each point property can be classified. For example, the group of A (0.0 – 0.39) is split again into four sub-datasets containing ranges between 0.0 – 0.1, 0.1 – 0.2, 0.2 – 0.3 and 0.3 – 0,4. These ranges become the selection criteria for the surface extraction. By having the detailed extraction of datasets, we can further identify the percentages of point density for each generated surface. The following table illustrates the distribution of point density according to the intensity values.

Intensity values	Point density	Percentages
A (0.0 – 0.39)	**44.641**	**2%**
0.0 – 0.1	125	2%
0.1 – 0.2	245	5%
0.2 – 0.3	4.481	10%
0.3 – 0.4	39.872	83%
B (0.39 – 0.78)	**426.374**	**22%**
0.4 – 0.5	80.130	19%
0.5 – 0.6	135.027	32%
0.6 – 0.7	110.272	26%
0.7 – 0.8	96.397	23%
C (0.78 – 1.17)	**589.637**	**31%**
0.8 – 0.9	128.632	22%
0.9 – 1.0	144.368	24%
1.0 – 1.1	168.186	28%
1.1 – 1.2	148.451	26%
D (1.17 – 1.57)	**859.999**	**45%**
1.2 – 1.3	280.346	33%
1.3 – 1.4	336.607	39%
1.4 – 1.5	204.439	24%
1.5 – 1.6	38.607	4%

Table 1. Distribution of point density according to the intensity values.

According to the Table 1, the general percentages between the intensity values and the density of points demonstrate an equal proportion. It means that the amount of points for each group is generally correlating with the level of intensity. The deviation values of sub-datasets illustrate a close range in average for each group. The only exceptions are the intensity value in Group A for the range between 0.3 – 0.4 and the range between 1.5 – 1.6 in the Group D. The percentages of these ranges show a massive discrepancy compared with the other ranges in their groups. The results statically illustrate that this existing environment averagely constitutes the reflective surface. It indicates that we can identify the surface characteristics of our existing context. For example, the high reflective surface most likely has the bright colors, smooth textures, the low surface temperature in the daytime and it has cool roofs. Thus, the selected surfaces can be used to run the further environmental analysis in the design process.

To complete the catalogue of the surface materials, the categorization of the 3D visual environment has organized according to the level of intensity and albedo values (see Figure 6). The statistics of albedo values are constructed by taking the total of identified intensity points and then, it is linked with the list of albedo values achieved from the calculation of RGB colors. Thus, we can put the graph comparisons between the albedo and the intensity values by using the same amount of points.

Figure 6 indicates that the intensity range between 1.3 – 1.4 in group D (the green box) constitutes the largest surface that can be covered with the high range of intensity values. By comparing with the albedo graph, however, the result is moderately low, it can only produce the albedo values in the range between 0.3 – 0.5. In the 3D point cloud data, the intensity range 1.3 – 1.4 can be found mostly spread in the entire context consisting of building facades, trees, streets and other site properties (see Figure 7a). This indicates that the connection between the surface properties of the areas and the environmental factors of the scanner seems work properly on this range. For example, the right incident angle of the scanner can determine which surface of the object producing the high-intensity values even though its surface consists of the same material and the same roughness. In this case, one object may consist of several intensity values and different objects can have the same albedo or intensity values. Thus, we can classify the surface of the built environment according to the intensity and albedo values attached to their point properties without any needs of geometrical separation between the objects like trees and buildings.

Besides, for a particular distance, the areas around the scanner positions are slightly cleaner from the red points. It designates that the correction intensity we applied into the datasets has worked for reducing the brightness level of the near distance.

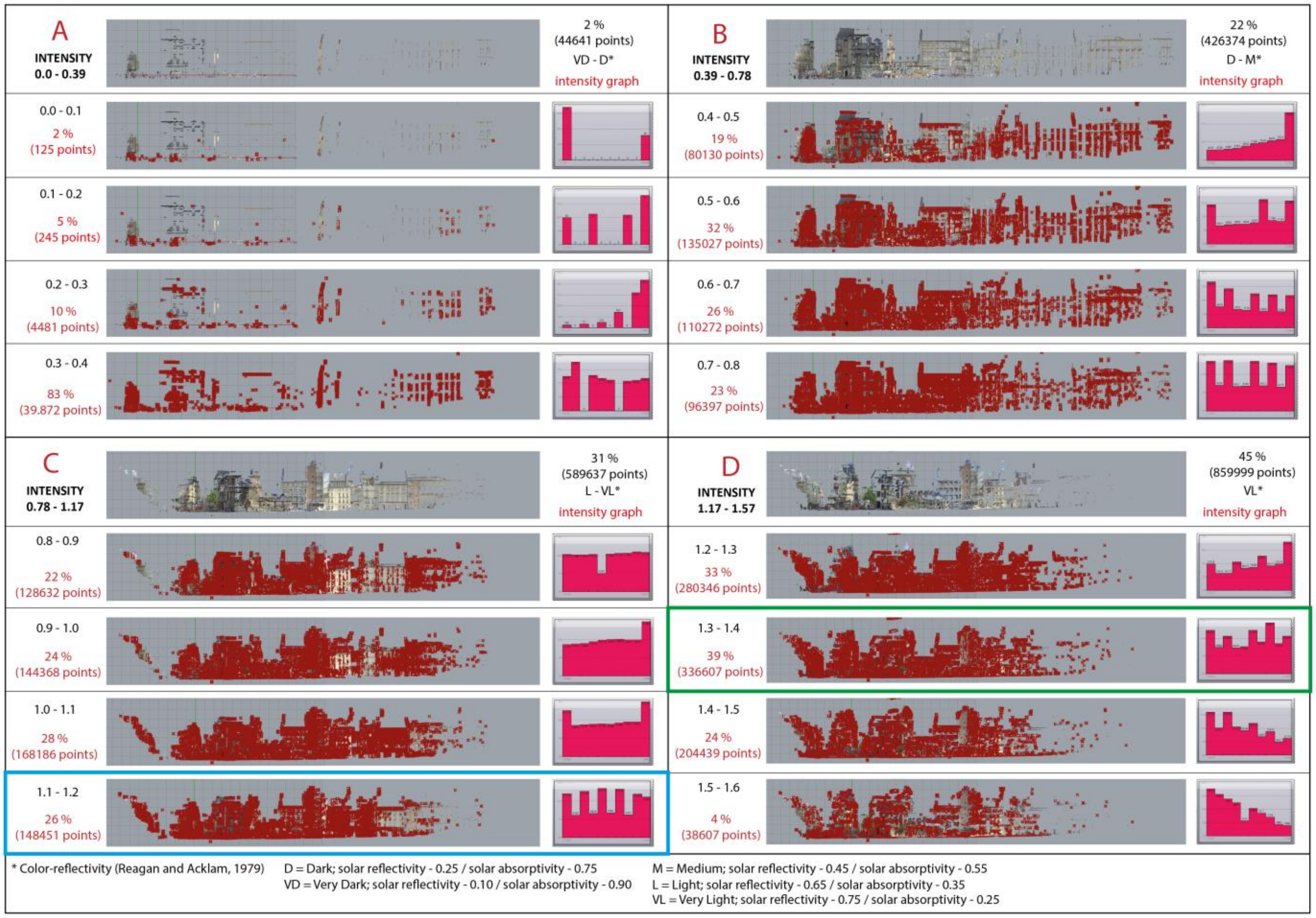

Figure 6. Classification of the datasets according to the intensity values

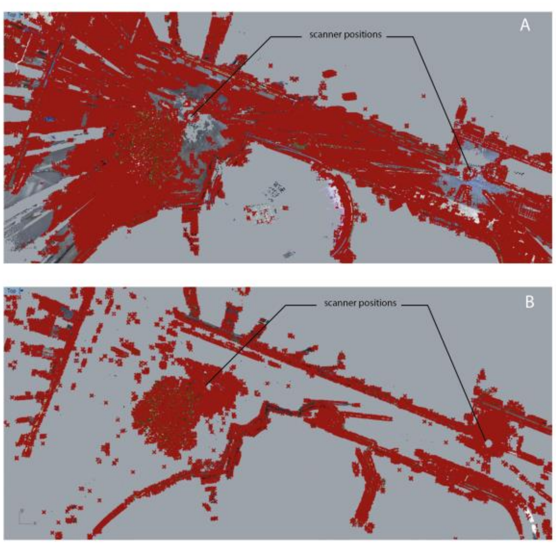

Figure 7. (a) The intensity range between 1.3 – 1.4 Group D (b) The intensity range between 1.1- 1.2 Group C

Furthermore, the Figure 6 shows that the highest albedo value is located in the intensity range between 1.1 – 1.2 in Group C (the blue box). Although the density of points only detects 26% from the total density in Group C, the statistic results show that 5.208 points are occupying the highest albedo values in the range of 0.9 – 1.0 and 15.951 points stand for the range` between 0.8 – 0.9. As illustrated in Figure 7b, the coverage areas for this range mainly consist of building facades and the trees. The significant distinction compared to the Figure 7a is shown in the ground areas. The result simultaneously indicates that material of asphalt produces a low albedo which has a dark color, rough textures, and high-daytime surface temperatures. Another contrast results comparing with the Figure 7a are the areas around the scanner positions which collects much more points.

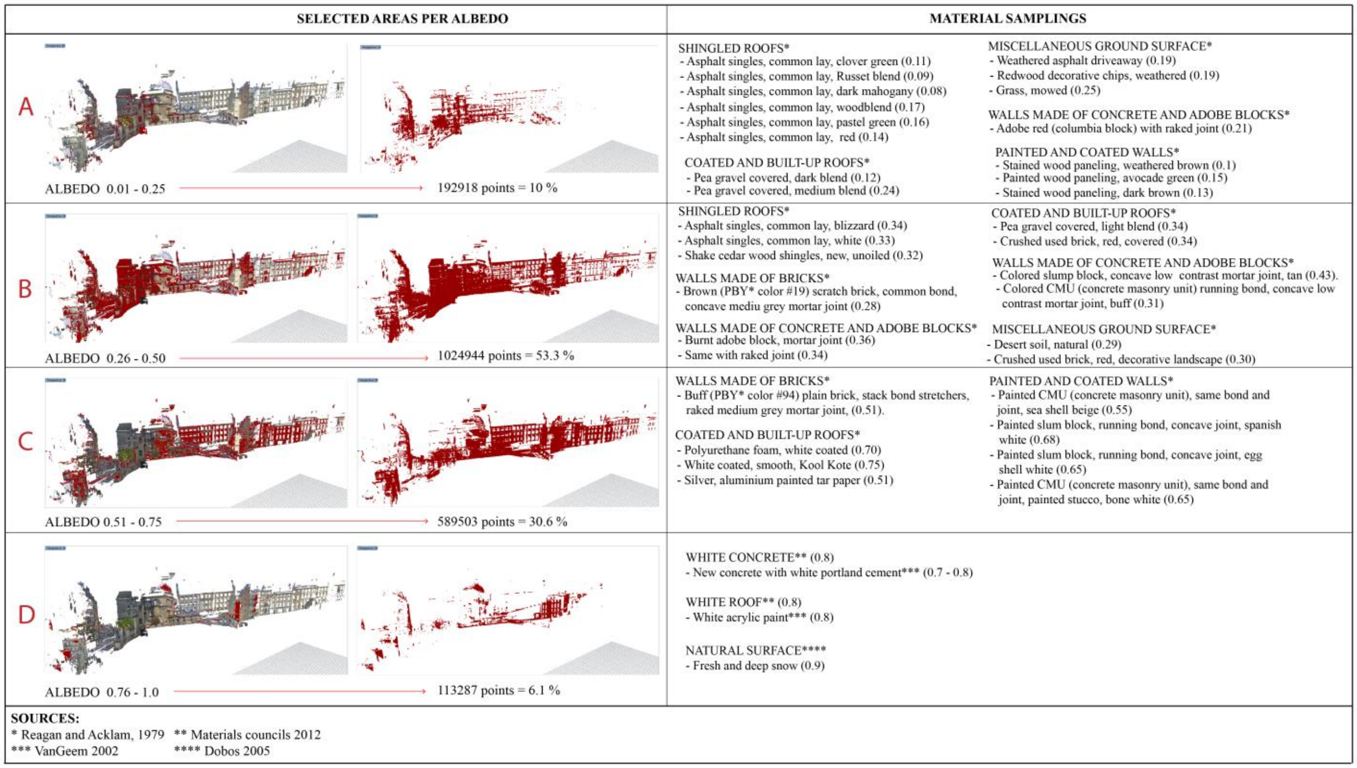

Figure 8. Identification of the type of materials according to the albedo values

Having set the classification of the datasets according to the intensity and albedo values, the study then attempts to map the albedo values of the datasets with the existing database of the materials (see Fig.8). We collect the existing database of material sampling from the various sources [16-13-18-6]. The goal is to identify the type of material properties that match with the range of albedo values yielded by the 3D scan of the surface of the existing environment.

According to the Fig.8, the albedo range B (0.26-0.50) covers the largest percentage of existing areas around 53,3 % from the total points. In the material sampling, we can find that the amount of materials identified in the B range also shows a great variety compared to other ranges. The indication of this result navigates us to consider further the sustainable approach in terms of material properties when proposing the new building in these areas. Also, the needs of maintaining the microclimate condition to lower the UHI effects in the existing context.

In contrast, not much of the material samplings is found in the albedo range D although it basically approximates the ideal materials for the urban environment. The albedo range between 0.76 - 1.0 usually refers to the material with a lighter surface. The area percentage of this albedo range only shows 6.1 % of the total points. Its coverage areas consist of the glass roof and some parts of the building facades that have a brighter color on the surface.

5 CONCLUSION AND FUTURE RESEARCH

This study focuses on the exploration of attribute information contained in the point cloud data to identify the surface materials of the existing environment, taking into account the intensity and the albedo values. The general aim is to build an environmental catalogue of surface materials from the existing local context. Thus, architects can have a comprehensive information related to the site analysis that useful for design exploration afterward. According to the detailed process of surface material exploration illustrated above, several concluding remarks can be drawn as follows:

- The attribute information in the point cloud data is not only useful for the real 3D visualization but can also be used for the performance simulation and environmental analysis.
- The intensity correction as part of post-processing datasets allows checking and identifying the approximation of true intensity values from the data scan. In addition, this procedure intends to consider some aspects that can affect the measurement values of datasets such as environmental condition, acquisition process, and the instrumental factors. In the pre-processing steps, the use of reflectometers during the scanning process will improve the accuracy of the dataset model through the alignment of the individual scans.
- Identification and classification of the surface materials help us to detect the number of areas in the context that performs high reflective surface. By controlling the certain values of intensity and albedo values, that is in parallel

provide a high possibility of focusing the exploration on the particular areas.

Besides, some current limitations and future research development are addressed. For example, the range correction may also need to be considered for the verification of the intensity values of the datasets. However, the current data sets do not allow for this procedure because it has already consisted of multiple scanning. In this case, the range correction is suitable to use for a single data scan. The fitting process of datasets can proceed afterwards.

Another aspect is the calculation of albedo values in this study which only focuses on the RGB color from the 3D point cloud data scan. Various environmental parameters should be considered further to acquire the true albedo values. Also, the existing albedo standards are necessary to include in the calibration process.

The potential areas for further research are the possibility of constructing environmental simulation processes such as UHI effect, thermal comfort, and radiation analysis. The integration of performance simulation in the future study will enhance the complexity of site analysis and also, to maintain the quality of built environment between the new design and the local context during the conceptual design stage.

ACKNOWLEDGMENTS

The research described in this paper was part of Ph.D. research which financially supported by Indonesian Endowment Fund for Education (LPDP).

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