

## DATA EXTRACTION AS INPUT FOR THE ENERGY ANALYSIS OF AN URBAN DISTRICT WITH UMI

M. MARTIN, L. BANDE, P. MARPU, AND A. AFSHARI

*Institute Center for Smart and Sustainable Systems (iSmart), Masdar  
Institute of Science and Technology, Abu Dhabi, UAE*

*Email address: [mmartin@masdar.ac.ae](mailto:mmartin@masdar.ac.ae)*

*Email address: [lindita.bande@polimi.it](mailto:lindita.bande@polimi.it)*

*Email address: [pmarpu@masdar.ac.ae](mailto:pmarpu@masdar.ac.ae)*

*Email address: [aafshari@masdar.ac.ae](mailto:aafshari@masdar.ac.ae)*

AND

M. A. AL-MUSAWA AND G. R. KOLAN

*Spatial Data Division, Municipality of Abu Dhabi City, Abu Dhabi,  
UAE*

*Email address: [m.musawa@adm.abudhabi.ae](mailto:m.musawa@adm.abudhabi.ae)*

*Email address: [g.kolan@adm.abudhabi.ae](mailto:g.kolan@adm.abudhabi.ae)*

**Abstract.** The energy usage of an urban district has become a major subject of study and interest since we observed a significant expansion of cities caused by the movement of inhabitants. Sustainability of urban areas is mainly related to interactions between street patterns and building distances. Monitoring these connections in terms of energy flows creates possibilities of optimizing building construction and retrofitting. There are many tools used to make this possible. In this paper, we want to demonstrate how it is possible to import the 3D structure of an urban area recorded in an SHP file into the Urban Modeling Interface software. The data extraction protocol we developed to this aim principally consists in approximating clusters of XYZ coordinates into a set of boxes with minimum loss in geometry, orientation, and position of buildings. Estimations of energy consumption and CO<sub>2</sub> are among the outcomes we were able to obtain from imported data into UMI. Using the developed data extraction strategy, we can potentially analyze the energy usage of an entire city.

## 1. Introduction

Energy saving has become a priority in this growing city. During the society development energy has always been a key factor of the growth starting from the ancient work until today. Energy in a certain way defines how we live. Currently the demand for energy use is increasing while the resources are decreasing. The energy saving takes an extremely important place this times. Different studies have proved that by orienting the urban street pattern in accordance to the wind rose, having a dense urban texture, reducing the facade glazing, keeping an ideal proportion of building height increases the energy efficiency of the buildings.

Researches of Radhi and Sharples 2012 aimed at forecasting energy consumptions and CO<sub>2</sub> emissions in the residential sector of UAE..To develop their statistical model, they used indices related to the energy consumption in Abu Dhabi. According to them, buildings represent the sector that consume the biggest part of the total electric consumption in Abu Dhabi. This phenomenon is undoubtedly due to a strong usage of air-conditioning systems as per Afshari et al. 2014.

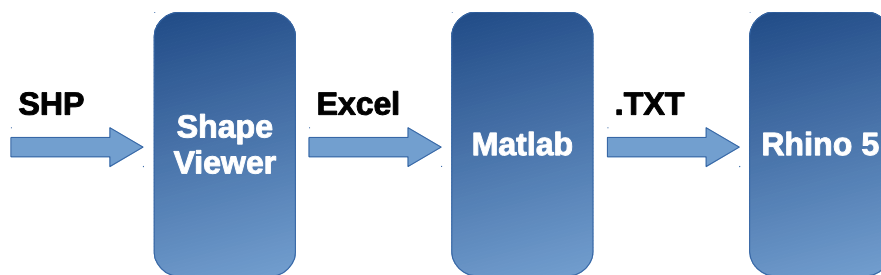
The Building Performance Simulation Tools such as, Energy Plus, Design Builder, IES, consider in the simulations only the single building taken into study. UMI has developed the urban scale of energy simulation, in this case the energy of one building is effected from the surrounding environment, building, bringing the model closer to the real conditions.

Based on Rhino design environment, the Urban Modeling Interface (UMI) program was developed by MIT in order to propose an easy-to-use urban district analysis tool for architects and urban planners. From a simplified 3D structure of an urban area, information like energy use, walkability and daylighting can be assessed by UMI. Complex files imported from programs like ArcGIS, would simplify the design process of the architects and urban planners. Once they have the environment conditions and energy impacts in the area where a new building will be places or a new road will be added it will be more efficient and helpful in calculation the energetic behavior of the intervention in the early design phase.

In this paper, we defined a data extraction protocol which allows us to analyze an urban district stored in a SHP file with the UMI program. More than just consulting stored data, UMI can infer information related to energy consumption. While a dense urban area recorded in a SHP file can easily be imported into most of geographic information systems(GIS)like ArcGIS, UMI does not have any direct options that enables us to extract a complex urban structure and convert it into a simplified representation.

## 2. Data Extraction Process

To import a set of buildings recorded in a SHP file into UMI, we developed a data extraction protocol consisting of three basic steps. We first used the Shape Viewer software for generating an Excel file containing XYZ coordinates of each building. This Excel file was next imported into Matlab in order to proceed to a cubic approximation of each cluster of 3D points. The resulting cubic representation of the urban area was finally imported into the Rhino 5 environment using a Python script.



*Figure 1.* Data extraction process for importing a SHP file into Rhino 5 in order to be analyzed with UMI.

Shape Viewer is a free software that was developed for viewing SHP files. It exports the 3D structure stored inside the SHP file into an Excel file. Each row of the generated Excel file contains a building ID, a surface ID, a point ID, and XYZ coordinates. Consequently, it is possible to identify clusters of 3D points representing buildings of the urban area recorded in the SHP files.

This set of clusters can easily be imported and processed in Matlab. As we mentioned before, UMI only deals with simple shapes (i.e. cubes) for analyzing urban districts. Therefore, we had to find a strategy for estimating all these clouds of 3D points by cubes. Using a minimum bounding box algorithm (Freeman and Shapira, 1975), we were able to define eight XYZ coordinates for each cluster corresponding to the most representative cube. The reduced number of XYZ coordinates associated to one cube (i.e. the estimated 3D structure of one building) was finally stored into a .txt file to be easily read and manipulated by any programming language.

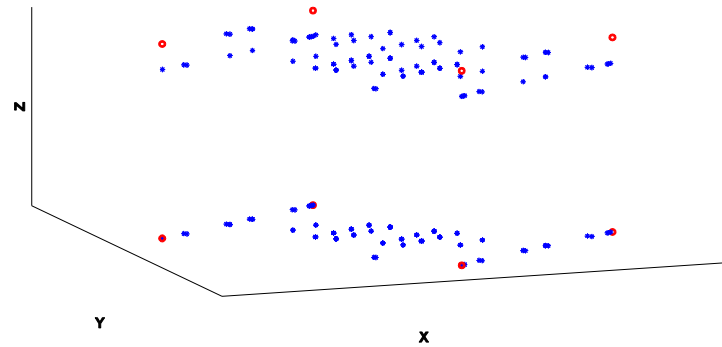


Figure 2. Cubic approximation of a cloud of 3D points (in blue) with height XYZ coordinates (in red).

The Python interpreter can be called from Rhino 5 for automatically generating 3D objects. Knowing this capability, we implemented a small Python script in the aim of importing cubes we created from Matlab. The resulting set of cubes can easily be processed with UMI in order to define properties of the urban area under study.

The above description is the input to UMI in order to provide the below output results. It basically analyses the electric consumption and CO<sub>2</sub> emissions among other functions not considered in this paper.

### 3. Case Study

The case study we considered for testing the data extraction process was taken from the main island of Abu Dhabi, framed from the streets of: Zayed the First Street, Sultan Bin Zayed the First Street, Fatima Bint Mubarak Street and 5th Street. It's a typical district with high rise residential, hotels and office buildings on the borders of the area and low rise residential buildings inside the area. There are also placed facilities such as small mall, a school, a mosque in the center of the district. The study of this zone was divided in three parts in order to facilitate the process of evaluating the glazing percentage on each building. The total number of buildings is 47, Fig. (3), divided as shown below in three tables. According to the data received from previous studies, a continuous verification on site for each building, a confrontation with the principles of construction in Abu Dhabi it was possible to reassume the calculations of the glazing as shown in Tab. (1), Tab. (2), and Tab. (3).



Figure 3. District division.

TABLE 1. District division 1.

| No. | Code | Building Type | No. Floors | Building Analysis |          |          |        |         |                  |
|-----|------|---------------|------------|-------------------|----------|----------|--------|---------|------------------|
|     |      |               |            | No. App           | South F. | North F. | Est F. | West F. | Tot % of Glazing |
|     | A1   | residential   | 24         |                   | 90.44    | 90.44    | 90.44  | 90.44   | <b>90.44</b>     |
|     | A2   | residential   | 14         |                   | 39.59    | 39.59    | 15.89  | 15.89   | <b>27.74</b>     |
|     | A3   | residential   | 14         |                   | 49.22    | 49.22    | 15.89  | 15.89   | <b>32.56</b>     |
|     | A4   | residential   | 14         |                   | 42.02    | 42.02    | 15.89  | 15.89   | <b>28.95</b>     |
|     | A5   | residential   | 14         |                   | 39.58    | 39.58    | 15.89  | 15.89   | <b>27.74</b>     |
|     | A6   | residential   | 14         |                   | 51.71    | 51.71    | 15.89  | 15.89   | <b>33.80</b>     |
|     | A7   | residential   | 14         |                   | 27.30    | 27.30    | 15.89  | 15.89   | <b>21.59</b>     |
|     | A8   | residential   | 15         |                   | 74.91    | 74.91    | 15.89  | 15.89   | <b>45.40</b>     |
|     | A9   | residential   | 14         |                   | 42.42    | 42.42    | 15.89  | 15.89   | <b>29.16</b>     |
|     | A10  | residential   | 14         |                   | 54.17    | 54.17    | 15.89  | 15.89   | <b>35.03</b>     |
|     | A11  | residential   | 14         |                   | 56.67    | 56.67    | 15.89  | 15.89   | <b>36.28</b>     |
|     | A12  | residential   | 14         |                   | 38.04    | 38.04    | 15.89  | 15.89   | <b>26.96</b>     |
|     | A13  | residential   | 14         |                   | 73.73    | 73.73    | 15.89  | 15.89   | <b>44.81</b>     |
|     | A14  | residential   | 14         |                   | 36.08    | 36.08    | 15.89  | 15.89   | <b>25.98</b>     |
|     | A15  | residential   | 14         |                   | 86.25    | 86.25    | 15.89  | 15.89   | <b>51.07</b>     |
|     | A16  | residential   | 15         |                   | 28.88    | 28.88    | 15.89  | 15.89   | <b>22.39</b>     |
|     | A17  | residential   | 14         |                   | 64.95    | 64.95    | 15.89  | 15.89   | <b>40.42</b>     |
|     | A18  | residential   | 15         |                   | 39.69    | 39.69    | 15.89  | 15.89   | <b>27.79</b>     |

TABLE 2. District division 2.

| Building Analysis |      |               |            |         |          |          |        |         |                  |
|-------------------|------|---------------|------------|---------|----------|----------|--------|---------|------------------|
| No.               | Code | Building Type | No. Floors | No. App | South F. | North F. | Est F. | West F. | Tot % of Glazing |
|                   | B1   | residential   | 17         |         | 54.72    | 54.72    | 54.72  | 54.72   | <b>54.72</b>     |
|                   | B2   | residential   | 18         |         | 60.68    | 60.68    | 60.68  | 60.68   | <b>60.68</b>     |
|                   | B3   | residential   | 18         |         | 85.51    | 85.51    | 85.51  | 85.51   | <b>85.51</b>     |
|                   | B4   | residential   | 18         |         | 78.09    | 78.09    | 79.09  | 79.09   | <b>78.59</b>     |
|                   | B5   | residential   |            |         |          |          |        |         |                  |
|                   | B6   | residential   | 12         |         | 37.31    | 37.31    | 37.31  | 37.31   | <b>37.31</b>     |
|                   | B7   | residential   | 13         |         | 42.12    | 42.12    | 42.12  | 42.12   | <b>42.12</b>     |
|                   | B8   | residential   | 20         |         | 6.28     | 6.28     | 6.28   | 6.28    | <b>6.28</b>      |
|                   | C1   | residential   | 13         |         | 84.83    | 84.83    | 84.83  | 84.83   | <b>84.83</b>     |
|                   | C2   | residential   | 15         |         | 60.15    | 60.15    | 60.15  | 60.15   | <b>60.15</b>     |
|                   | C3   | residential   | 14         |         | 32.58    | 32.58    | 32.58  | 32.58   | <b>32.58</b>     |
|                   | C4   | residential   | 14         |         | 42.35    | 42.35    | 42.35  | 42.35   | <b>42.35</b>     |
|                   | D1   | residential   | 19         |         | 44.51    | 44.51    | 44.51  | 44.51   | <b>44.51</b>     |
|                   | D2   | residential   | 18         |         | 62.19    | 62.19    | 62.19  | 62.19   | <b>62.19</b>     |
|                   | D3   | residential   | 17         |         | 72.22    | 72.22    | 72.22  | 72.22   | <b>72.22</b>     |
|                   | D4   | residential   | 18         |         | 70.89    | 70.89    | 70.89  | 70.89   | <b>70.89</b>     |

TABLE 3. District division 3.

| Building Analysis |      |               |            |         |          |          |        |         |                  |
|-------------------|------|---------------|------------|---------|----------|----------|--------|---------|------------------|
| No.               | Code | Building Type | No. Floors | No. App | South F. | North F. | Est F. | West F. | Tot % of Glazing |
|                   | E1   | residential   | 5          |         | 43.60    | 43.60465 | 38.8   | 38.8    | <b>41.20</b>     |
|                   | E2   | residential   | 5          |         | 36.36    | 36.36364 | 38.8   | 38.8    | <b>37.58</b>     |
|                   | E3   | residential   | 5          |         | 29.49    | 29.48905 | 38.8   | 38.8    | <b>34.14</b>     |
|                   | E4   | residential   | 5          |         | 42.54    | 42.54144 | 38.8   | 38.8    | <b>40.67</b>     |
|                   | E5   | residential   | 5          |         | 37.02    | 37.01657 | 38.8   | 38.8    | <b>37.91</b>     |
|                   | E6   | residential   | 5          |         |          |          |        |         |                  |
|                   | E7   | residential   | 5          |         |          |          |        |         |                  |
|                   | E8   | residential   | 5          |         | 24.23    | 24.22611 | 38.8   | 38.8    | <b>31.51</b>     |
|                   | E9   | residential   | 5          |         | 35.59    | 35.59322 | 38.8   | 38.8    | <b>37.20</b>     |
|                   | E10  | residential   | 5          |         | 43.46    | 43.45679 | 38.8   | 38.8    | <b>41.13</b>     |
|                   | E11  | residential   | 5          |         | 61.87    | 61.86557 | 38.8   | 38.8    | <b>50.33</b>     |
|                   | E12  | residential   | 5          |         | 39.40    | 39.40182 | 38.8   | 38.8    | <b>39.10</b>     |

|     |             |   |       |          |      |      |              |
|-----|-------------|---|-------|----------|------|------|--------------|
| F1  | residential | 5 | 39.64 | 39.63964 | 38.8 | 38.8 | <b>39.22</b> |
| F2  | residential | 5 | 41.58 | 41.58004 | 38.8 | 38.8 | <b>40.19</b> |
| F3  | residential | 5 | 41.51 | 41.50943 | 38.8 | 38.8 | <b>40.15</b> |
| F4  | residential | 5 | 42.61 | 42.61438 | 38.8 | 38.8 | <b>40.71</b> |
| F5  | residential | 5 |       |          |      |      |              |
| F6  | residential | 5 | 38.84 | 38.84409 | 38.8 | 38.8 | <b>38.82</b> |
| F7  | residential | 5 | 40.68 | 40.68396 | 38.8 | 38.8 | <b>39.74</b> |
| F8  | residential | 5 | 57.11 | 57.10956 | 38.8 | 38.8 | <b>47.95</b> |
| F9  | residential | 5 | 39.29 | 39.29059 | 38.8 | 38.8 | <b>39.05</b> |
| F10 | residential | 5 | 41.84 | 41.83536 | 38.8 | 38.8 | <b>40.32</b> |
| F11 | residential | 5 | 51.37 | 51.36986 | 38.8 | 38.8 | <b>45.08</b> |
| F12 | residential | 5 | 60.86 | 60.8642  | 38.8 | 38.8 | <b>49.83</b> |
| F13 | residential | 5 | 40.83 | 40.83225 | 38.8 | 38.8 | <b>39.82</b> |
| F14 | residential | 5 | 34.80 | 34.79769 | 38.8 | 38.8 | <b>36.80</b> |
| F15 | residential | 5 | 24.30 | 24.29668 | 38.8 | 38.8 | <b>31.55</b> |
| F16 | residential | 5 | 45.93 | 45.9279  | 38.8 | 38.8 | <b>42.36</b> |
| F17 | residential | 5 | 42.90 | 42.89617 | 38.8 | 38.8 | <b>40.85</b> |
| F18 | residential | 5 |       |          |      |      |              |
| F19 | residential | 5 | 44.94 | 44.94238 | 38.8 | 38.8 | <b>41.87</b> |
| F20 | residential | 5 | 33.82 | 33.82022 | 38.8 | 38.8 | <b>36.31</b> |
| F21 | residential | 5 | 42.63 | 42.63473 | 38.8 | 38.8 | <b>40.72</b> |
| F22 | residential | 5 |       |          |      |      |              |
| F23 | residential | 5 |       |          |      |      |              |
| F24 | residential | 5 | 54.66 | 54.65839 | 38.8 | 38.8 | <b>46.73</b> |

#### 4. Energy Consumption and CO<sub>2</sub> Emissions

Based on a SHP file received from the Municipality of Abu Dhabi, we imported all buildings of the case study into the UMI interface using the developed data extraction process. Then, we defined each building according to the number of floors and the glazing ratio specified in Tab. (1), Tab. (2), and Tab. (3). Finally, we run a UMI simulation in order to estimate energy consumption and CO<sub>2</sub> emissions.

Fig. (4) represents the electric energy consumption approximation of each building in the urban district under study. According to this result, all buildings consume between 503 and 640 kWh/m<sup>2</sup> of electricity on average over the year. While buildings with higher electric consumption are located in

areas A, E, and F, urban areas B, C, and D is characterized by lower electric consumption.

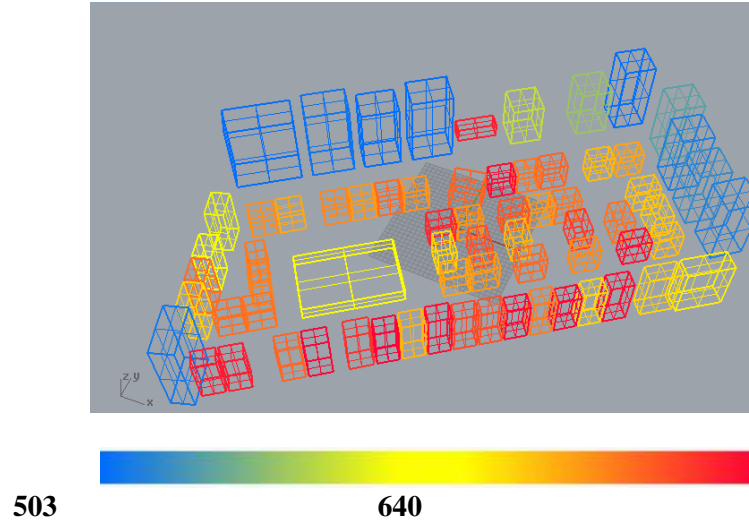
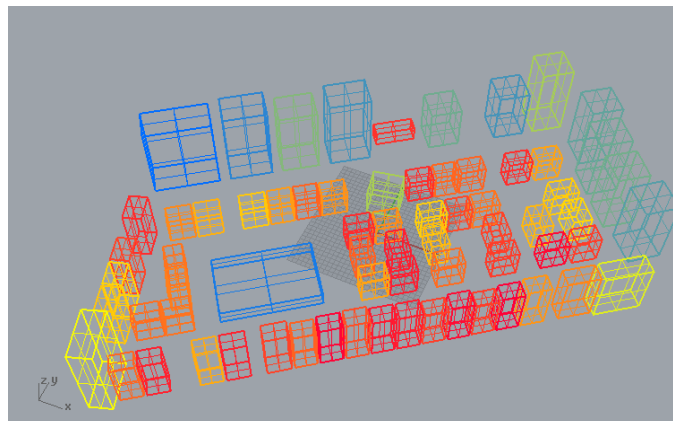


Figure 4. Electric energy consumption estimation (in kWh/m<sup>2</sup>) for each building.

CO<sub>2</sub> emissions in the urban area under study are introduced in Fig. (5). The range of emitted CO<sub>2</sub> on average over the year in each building is approximated between 68 and 86 kg/m<sup>2</sup>. Conforming to this observation, urban areas B and D are the ones with the lowest CO<sub>2</sub>cost. These results are calculated based on the type of construction of the studied buildings, wall package and type of glazing defined the Abu Dhabi Municipality report (ref). The study is referred to Abu Dhabi weather data.





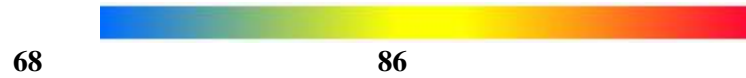


Figure 5. CO<sub>2</sub> estimation (in kg/m<sup>2</sup>) for each building.

## 5. Conclusion

In this paper, we introduced a methodology for extracting an urban district stored in a SHP file in order to make its energy analysis possible with UMI. Based on a case study, we estimated the average electric consumption and CO<sub>2</sub> emissions over the year of an urban area imported into UMI employing the developed data extraction protocol.

The verification of the results with the real data is shown in Tab. (4). together with an estimated error percentage. As it can be seen, the error value is quite low that brings us to the conclusion of the efficiency of the estimation made in UMI.

TABLE 4. Comparison Table.

| Comparison Table |          |            |          |        |
|------------------|----------|------------|----------|--------|
| No               | Category | Estimation | Measured | Error% |
| 1                | Blue     | 503.00     | 0        |        |
| 2                | Green    | 548.67     |          |        |
| 3                | Yellow   | 571.50     |          |        |
| 4                | Orange   | 594.33     |          |        |
| 5                | Red      | 640.00     |          |        |

The capabilities of UMI in inferring information related to the energy consumption of the urban area under study are still limited. The implementation and analysis of the urban heat island effect in UMI would be an interesting challenge for a future study.

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