The basic geometric entity in my ray tracing program is *plate* which is a planar polygon. A plate is represented by the primitive geometric objects *triangles*. A plate can be used to simulate a wall, a rooftop, or a piece of terrain. In my program, the concept of *building* is not used. But a restriction for the plate is forced which is based on a building, i.e., the *normal direction* of a plate is defined as the unit vector normal to the plate and pointed *outwardly* from the building. For terrain plates, the normal directions are pointed toward air from the earth. Many of my algorithms are dependent on this restriction.

**I. Input File Protocol**

The input file to the ray tracing engine is a description of the 3D geometrical model, the electric parameters, and the antennas. Here is an explanation of the input protocol.

1. The file contains four top level groups:
   a. RefGroup/endRefGroup
   b. TxGroup/endTxGroup
   c. RxGroup/endRxGroup
   d. FreqGroup/endFreqGroup.

   These top level groups can have sub-groups. For example, the RefGroup is a collection of plates which reflect the EM waves (no transmission is considered). So all the buildings in an urban environment can be collected in the group. A sub-group in RefGroup can be the plates representing a particular building with the same electrical parameters.

   A sub-group can be repeated in the x, y, and z directions defined in Repeat. This function is very useful in defining periodic structures such as several lined-up buildings with the same geometry.

2. RefGroup: Description of reflection-only objects (e.g., for walls in urban propagation).
   a. The group starts with the token ‘RefGroup’ on a single line.
   b. The next line is the number of subgroups, $ng$. A distinction of a subgroup is that the plates therein have the same relative permittivity, conductivity, and thickness.
   c. Then each subgroup will have the following format:
      i. The subgroup starts with ‘Group’ on one single line.
      ii. The next line is ‘Epsilonr, sigma, thickness’ which indicates the following line gives $\varepsilon_r$, $\sigma$ (S/m), and thickness (m) of the plates in this subgroup.
      iii. The values of $\varepsilon_r$, $\sigma$, and thickness of the plates are given in a single line. Note that for PEC, set sigma $= -1$; for half space material (e.g., a ground) interface, set thick $= -1$ (Currently, it is assumed thick $= -1$).
iv. The next line is the number of plates in this subgroup, \( ne \). Note that each plate is a set of triangles. For example, a polygon with 4 vertices should be decomposed into 2 triangles. For more general cases, the polygon should be decomposed into several triangles.

v. In each of the following \( ne \) lines, one or more triangle is defined using their vertices. Each vertex is represented by its \( x \), \( y \), \( z \) coordinates. These coordinates are delimited by a space. Vertices are delimited by a semicolon (\( ; \)). Note that each line can only have one polygon.

vi. The elements in the subgroup can be repeated to generate more elements. For example when one building is constructed, we can repeat it in \( x \), \( y \), \( z \) direction several times to obtain many copies of it. The next ‘Repeat’ line achieves this capability.

vii. The subsequent two lines give the repetition times and the repetition step, in \( x \), \( y \), and \( z \) directions. (If no repetition, set these two lines to ‘1 1 1’ and ‘0 0 0’.)

viii. The subgroup is ended with ‘endGroup’

ix. Two restrictive rules are used for listing the vertices of a planar polygon, i.e., the vertices should be listed either clockwise or counterclockwise and the vertex sequence should define the outward normal of the plate.

3. TxGroup: Description of transmit antennas
   a. Starts with \texttt{TxGroup} on one single line.
   b. The number of groups in the next line.
   c. ‘Group’ on a new single line.
   d. The next line is always a token ‘relative2Terrain’.
   e. The next line takes 0 or 1 indicating the height of antenna is absolute or relative to the terrain.
   f. If \texttt{relative2Terrain} == 1, a new line is needed to input the antenna height above the ground. If \texttt{relative2Terrain} == 0, no need for this line.
   g. The next line is the number of antennas, \( nt \).
   h. One line lists the 3D coordinates of all \( nt \) antennas.
   i. ‘endGroup’.
   j. ‘endTxGroup’.

4. RxGroup: Description of receive antennas; the same format as \texttt{TxGroup}.

5. FreqGroup: Description of frequency; self explainable.

6. \texttt{maxRefLevel}: Maximum number of reflections.

7. Other rules:
   a. No blank lines inside each (sub)group is allowed.
   b. Only ‘\#’ on a single line is used to separate groups.
   c. All the tag names and delimiter symbols should be followed exactly as stated in the above.