DESIGN OPTIMIZATION USING GENOPT AND DAYSIM

Khaled Nassar & Mohamed Aly
THE AMERICAN UNIVERSITY IN CAIRO
DEPARTMENT OF CONSTRUCTION AND ARCHITECTURAL ENGINEERING

SEPTEMBER 2014

2014 INTERNATIONAL RADIANCE WORKSHOP
LONDON, UK, SEPTEMBER 1ST TO 3RD
Introduction

The main objective of this presentation is to show how to couple DAYSIM with GENOPT.

We demonstrate why this is important with some application examples.

Show the mechanics of how this can be done through an example application.

Discuss the results of this example using different optimization algorithms.

Present some further work that may need to be done.
What is GENOPT and DAYSIM

OPTIMIZATION

GenOpt® is an optimization program for the minimization of a cost function that is evaluated by an external simulation program. Also parametric Analysis

Michael Wetter
Lawrence Berkeley National Laboratory

SIMULATION

DAYSIM is a validated, RADIANCE-based daylighting analysis software that models the annual amount of daylight in and around buildings

Christoph Reinhart
Lawrence Berkeley National Laboratory
Why to do we need to couple simulation with optimization

DESIGN OF LIGHTWELL

Parametric variations – time consuming – especially if you have to consider different times of day
Example Application A: DESIGN OF LIGHTWELL

DESIGN VARIABLES

- Dimensions, i.e. Area
- Orientation
- Shape, i.e. wider at the bottom or top
- Reflective Material
Example Application B: DESIGN OF WINDOW FOR VIEWS AND DAYLIGHT

DESIGN VARIABLES

Window Dimensions
Aspect Ratio
Window Location
Other Geometry
Example Application C: DESIGN OF LIGHT POCKET

DESIGN VARIABLES

Pocket width and depth

Building

street
Why DAYSIM

GENOPT has been coupled with any other software

11th workshop we presented how to couple with RADIANCE

Instead of having to consider different times of day and different days around the year

Need Dynamic daylight measures from DAYSIM

Such as Daylight Autonomy, Useful Daylight Index (and in the future perhaps the New IES metrics)
Example Problem Considered here:
Increasing Light in Dense Urban Areas

Unpainted Surfaces, low reflectivity

Dark Conditions at street level

Narrow Sky view
Example Problem Considered here

Which Surface to Finish with Reflective Paint

Given a Limited Budget

Which surfaces can be painted and which should be painted

Variations by adding constraints, costs and types of paint, important areas, etc…
Example Problem Considered here

A Knapsack optimization problem

\[ TC = \sum_{i=1}^{m} \sum_{j=1}^{n} C_i^j \times A_i \times x_j, \quad x_j \in \{0,1\}, C_i^1 = 0 \]

Where \( C_i \) is the unit cost of painting building \( i \) with paint type \( j \) and \( A_i \) is the area of building \( i \).

\( x_i \) is a binary variable to represent whether building \( i \) will be painted with paint type \( j \).
Criteria for Daylighting

A Knapsack optimization problem

\[ \text{Obj} = \frac{TC}{D(x_1, x_2 \ldots x_{jn})} \]

Now \( D \) can be one of many daylight criteria in the street level:
- Daylight Autonomy (DA): percentage of working hours when a minimum work plane illuminance is maintained by daylight alone
- Useful Daylight Illuminances (UDI): divides working hours

Or we could even look at values in the inside of the rooms
Criteria for Daylighting

Goal Programming for Multi-Criteria

\[ Obj = w_1 \times \left[ \frac{TC - TC_{\text{target}}}{TC} \right] + \]
\[ w_2 \times \left[ \frac{D_{\text{target}} - D}{D_{\text{target}}} \right] \]

D is simply the annual average illuminance and \( D_{\text{target}} \) is the set value, i.e. 10,000lux
The Mechanics of how GENOPT works with DAYSIM (and other software)

Step 1
Daysim header
Rad Files
Sensors

Step 2
Header modifier
Batch file

Step 3
Genopt

Will be made available with this presentation
DAYSIM Files

DAYSIM Modeling and creating the required files

1. C:\~\material.rad,
2. C:\~\geometry.rad

Daysim_files
- Daysim_header_file.hea
- Daysim_material.rad
- Daysim_geometry.rad
- Daysim_sensor.pts
- Occupancy_file.csv
- Radiance Source Files
- Others
DAYSIM Files (what you have to change)

Specifying parameters

#Grasshopper Geometry
#Scene File written: 02/13/2013 11:45:30

facade_\%refl\%PercentReflectance\_polygon 000
0
0
9

-1.509174 15.22416 15
-1.509174 15.22416 0
-1.507891 20.35717 15

............
............

facade_\%refl\%PercentReflectance\_polygon 0002
What about changing the geometry of the model itself

Mood polygon wall_S1
0
0
12
%dimension1..
%dimension2..
%dimension3..

Mood polygon wall_S1
0
0
12
5 ${val1 *2+1} 0
0 ${val1 *2+1} 0
0 ${val1 *2+1} 1
5 ${val1 *2+1} 1

VARY DIMENSIONS

PARAMETRIC VARIATION
A. The Header Modifier

@echo off
setlocal enabledelayedexpansion
set INTEXTFILE=Daysim_header_file.hea
set OUTTEXTFILE=Daysim_header_file1.hea
set SEARCHTEXT=Mfile1
set REPLACETEXT=project_directory %~dp0
set OUTPUTLINE=

for /f "tokens=1,* delims=¶" %%A in ('"type %INTEXTFILE%"') do (
    SET string=%%A
    SET modified=!string:%SEARCHTEXT%=%REPLACETEXT%!
    echo !modified! >> %OUTTEXTFILE%
)

del %INTEXTFILE%
rename %OUTTEXTFILE% %INTEXTFILE%

Mfile1 = marker for one of the header files
A. The Header Modifier

@echo off
setlocal enabledelayedexpansion
set INTEXTFILE=Daysim_header_file.hea
set OUTTEXTFILE=Daysim_header_file1.hea
set SEARCHTEXT=Mfile2
set REPLACETEXT=tmp_directory %~dp0
set OUTPUTLINE=

Remainder of the Header Modifier
Could be written for any system (linux, mac etc...)

Mfile2 = marker for one of the header files
B. The Batch File

@ echo off
SET RAYPATH=.;C:\Radiance\lib;C:\Radiance\bin;C:\DaysimBinaries;$RAYPATH
SET PATH=.;C:\Radiance\lib;C:\Radiance\bin;C:\DaysimBinaries;$PATH
C:
CD C:\DIVA\DaysimBinaries
epw2wea  %~dp0EGY_Cairo.623660_IWEC.epw %~dp0EGY_Cairo.623660_IWEC.wea
:: 1. Import Radiance File
radfiles2daysim %~dp0Daysim_header_file.hea -m -g
:: 2. Calculation Daylight Coefficients File (*.dc)
gen_dc %~dp0Daysim_header_file.hea –dif –dir -paste
CD C:\~\DaysimBinaries
:: 3. Generate Illuminance File (*.ill)
ds_illumin %~dp0Daysim_header_file.hea
:: 4. Generate Dynamic Controls and Daylighting Outputs
gen_directsunlight %~dp0Daysim_header_file.hea
ds_el_lighting.exe %~dp0Daysim_header_file.hea
exit
GENOPT FILES

- OptWinXP.ini
  Initialization File

- RadianceWin XP.cfg
  Configuration File

- Command.txt
  Command File
GenOpt Files

1. OptWinXP.ini

   This is the main file that tells GenOpt where to find the actual project files, the location of the objective function in the results.

2. RadianceWinXP.cfg

   This file is the file that tells GenOpt how to call the program from the command line and the correct syntax for that.

3. Command.txt

   This file has two main functions:
   1. to tell GenOpt which parameters to change and how to change them (i.e. ranges, steps).
   2. To specify the optimization algorithm to be used and its parameters
A. Initialization File

Simulation {
Files {
    Template {
        File1 = direct_radiance_file.tmp_template.rad;
        File2 = skyPatches_template.rad;
        File3 = Daysim_geometry_template.rad;
        File4 = Daysim_material_template.rad;
        File5 = material_template.rad;
        File6 = Daysim_sensor.pts;
        File7 = Daysim_template.vf;
        File8 = Daysim_template.bat;
        File9 = Daysim_template.hea;
        File10 = Daysim_template.rad;
        File11 = 8to6with_occ_template.csv;
        File12 = error_template.dat;
        File13 = EGY_Cairo.623660_IWEC_template.epw;
    }
}

These are the template files given to the program
A. Initialization File

Input {
    File1 = direct_radiance_file.tmp.rad;
    SavePath1 = Save;
    File2 = skyPatches.rad;
    SavePath2 = Save;
    File3 = Daysim_geometry.rad;
    SavePath3 = Save;
    File4 = Daysim_material.rad;
    SavePath4 = Save;
    File5 = material.rad;
    SavePath5 = Save;
    File6 = Daysim_sensor.pts;
    SavePath6 = Save;
    ........
}
Log {
    File1 = error.dat;
}

These are the file edited and saved for the simulation
A. Initialization File

Output {
    File1 = Daysim_autonomy.DA;
}

Configuration {
    File1 = "RadianceWinXP.cfg";
}

........

ObjectiveFunctionLocation
{
    Name1 = fitness;
    Function1 = "divide( %fitness2% , %fitness1%)";
    //Name2 = fitness1;
    //Function2 = "add( %fitness13% , %fitness4% , %fitness3% , %fitness6% , %fitness7% , %fitness8% , %fitness9%)";
    Name2 = fitness1;
    Function2 = "add( %fitness16% , %fitness15%)";
    Name3 = fitness2;
    Function3 = "add( %Da1% , %Da2% , %Da3% , %Da4% , %Da5% , %Da6%)";
    Name4 = Da6;
    Delimiter4 = "3.006000";
    Name5 = Da5;
    Delimiter5 = "3.005000";
    Name6 = Da4;
    Delimiter6 = "3.004000";
    Name7 = Da3;
    Delimiter7 = "3.003000";
    Name8 = Da2;
    Delimiter8 = "3.002000";
    Name9 = Da1;
    Delimiter9 = "3.001000";
    Name10 = fitness3;
    Function10 = "multiply( %refl% , 20)";
    Name11 = fitness4;
    Function11 = "multiply( %refl2% , 30)";
    Name12 = fitness5;
    Function12 = "multiply( %refl3% , 20)";
    Name13 = fitness6;
    Function13 = "multiply( %refl4% , 20)";
    Name14 = fitness7;
    Function14 = "multiply( %refl5% , 25)";
    Name15 = fitness8;
    Function15 = "multiply( %refl6% , 35)";
    Name16 = fitness9;
    Function16 = "multiply( %refl7% , 35)";
    Name17 = fitness10;
    Function17 = "multiply( %refl8% , 15)";
    Name18 = fitness11;
    Function18 = "multiply( %refl9% , 15)";
    Name19 = fitness12;
    Function19 = "multiply( %refl10% , 20)";
    Name20 = fitness13;
    Function20 = "add( %fitness5% , %fitness4% , %fitness3%)";
    Name21 = fitness14;
    Function21 = "add( %fitness6% , %fitness7% , %fitness8%)";
    Name22 = fitness15;
    Function22 = "add( %fitness9% , %fitness10% , %fitness11%)";
    Name23 = fitness16;
    Function23 = "add( %fitness13% , %fitness14% , %fitness12%)";
}
Initialization File

Name2 = fitness1;
Function2 = "add( %fitness16% , %fitness15%)";

Name3 = fitness2;
Function3 = "add( %Da1% , %Da2% , %Da3% , %Da4% , %Da5% , %Da6%)";

Name4 = Da6;
Delimiter4 = "delimiterofyourchoice";

Function10 = "multiply( %refl% , 20)";

............
Name22 = fitness15;
Function22 = "add( %fitness9% , %fitness10% , %fitness11%)";
.............
B. RandianceWin Config

SimulationStart
{
    Command = "@Simulation.Files.Log.Path1%/Run_Batch-file.bat";
    WriteInputFileExtension = true;
}

If you wanted to access any of the files you defined in the initialization file you can access them here
C. Command File

```plaintext
Vary{
  Parameter
  {
    Name = refl;
    Min  = 0;
    Ini  = 40;
    Max  = 80;
    Step = 20;
  }
  Parameter{
    ...........
    OptimizationSettings
    {
      MaxIte = 2000;
      MaxEqualResults = 100;
    }.............

  Algorithm{
    Main = GPSHookeJeeves;
    MeshSizeDivider = 2;
    InitialMeshSizeExponent = 0;
    MeshSizeExponentIncrement = 1;
    NumberOfStepReduction = 4;
  }
```

Solve the Problem Using Particle Swarm Algorithms

For each particle
  Initialize particle
END

Do
  For each particle
    Calculate fitness value
    If the fitness value is better than its personal best
      set current value as the new pBest
    End
  Choose the particle with the best fitness value of all as gBest
  For each particle
    Calculate particle velocity according equation (a)
    Update particle position according equation (b)
  End
While maximum iterations or minimum error criteria is not attained
Results using Particle Swarm Algorithms

Particle Swarm Algorithm parameters:

- Number of particles (swarm size) = 50
- C1 (importance of personal best) = 1
- C2 (importance of neighborhood best) = 3

Blue = Normalized Daylight
Red = Normalized Cost
Results

Before

After
Possible change in the Objective Function

Area of Importance

Add internal areas in Objective function

Can not be painted
## Results using Different Optimization Algorithms

<table>
<thead>
<tr>
<th>N, number of surfaces</th>
<th>Generalized Pattern Search</th>
<th>Particle Swarm</th>
<th>Hybrid Global Optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>100</td>
<td>0.88</td>
<td>0.91</td>
<td>0.91</td>
</tr>
<tr>
<td>1000</td>
<td>0.75</td>
<td>0.83</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Normalized Value of Daylight Component of the objective function after convergence
Future: What about BSDF material and geometry

Simulation and Optimization can be a very powerful tool

Benefits of annual simulation metrics from DAYSIM

Next step: Can you use GENOPT to optimize the geometry of BSDF material for CFS?

We could vary the shape of the BSDF material and observe the results for an annual simulation

Also tie in GENOPT with a three or five-phase method to optimize the shape of a BSDF material
Questions