https://github.com/bielcardona/OTSun/tree/master/OTSunWebApp

The OTSun WebApp

-Tutorial 1-

-First edition-

Simulation of a Parabolic Trough Collector

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On the OTSun project

The OTSun project is a research project whose main objective is to develop an open-source software to simulate the optical behavior of solar collectors. In this Monte Carlo ray tracing program, the trajectory of light rays is determined by the Fresnel equations of electromagnetic optics. The geometry of the solar collector is generated using the free software FreeCAD, allowing the user to visualize the scene. OTSun determines the optical efficiency of solar thermal collectors and photovoltaic solar cells. Its library is hosted on GitHub in the following link:

https://github.com/bielcardona/OTSun

In order to make it more user-friendly, a webtool has been developed which is located at the following link:

http://otsun.uib.es/otsunwebapp.

For more details, visit the OTSunWebApp folder documentation:

https://github.com/bielcardona/OTSun/tree/master/OTSunWebApp

1. Objective and first steps

In this tutorial, an example of a simulation with the OTSun web app is outlined step by step. The main goal of this tutorial is to demonstrate how to obtain the optical efficiency of a Parabolic Trough Collector (PTC).

The PTC, illustrated in Fig. 1, consists of a parabolic mirror, a glass envelope with an anti-reflective (AR) layer, and an absorber tube centered in the focal point of the parabola. Fig. 2 illustrates the cross-sectional view of the receiver and the shaped mirror, together with a description of each element.

Before conducting the simulation, it is recommended that the user visualizes the geometry. To do so, it is necessary to install FreeCAD 0.16[1]. The *FCStd file (FreeCAD format) where the PTC geometry is defined can be downloaded from the following link: test_PTC.FCStd. This PTC was also optically analyzed by Sallaberry et al. [1].

When the geometry is visualized in FreeCAD, the object labels contain words in parentheses (see Fig. 3). These are the objects that will interact with the rays during the optical simulation; the text in the parentheses is the name of the optical material of the object.

Furthermore, the following files, which can be downloaded at https://github.com/bielcardona/OTSun (tests folder), are necessary for the simulation:

- File for the complex refractive index of the glass: BK7_Schott.txt
- File for the optical response of the anti-reflective coating: AR-J.txt

Once the user is acquainted with the geometry and has downloaded the aforementioned files, he or she can proceed with the configuration of the simulation using the OTSun web app, which is located at the following link: http://otsun.uib.es/otsunwebapp (Fig. 4).

[1] At this point, OTSun is not compatible with FreeCAD version 0.17, which was released only recently.

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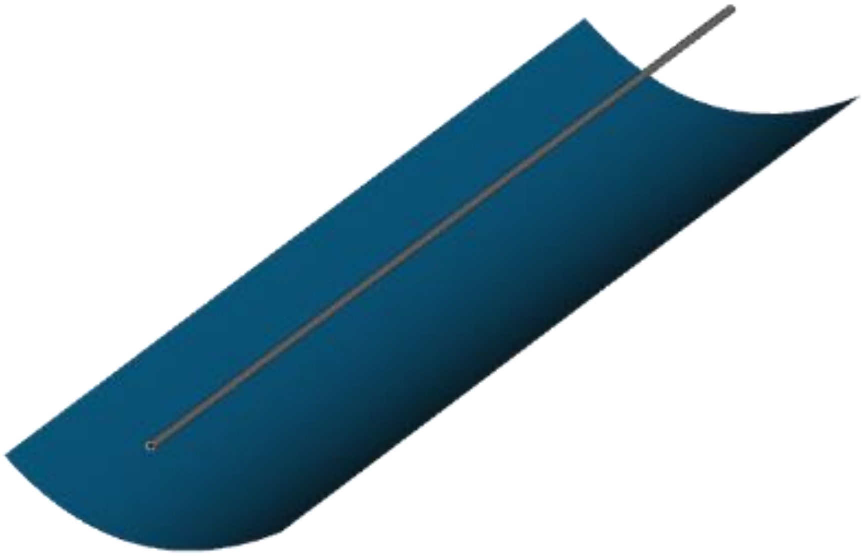

Fig. 1. Geometry of the PTC collector that is to be simulated.

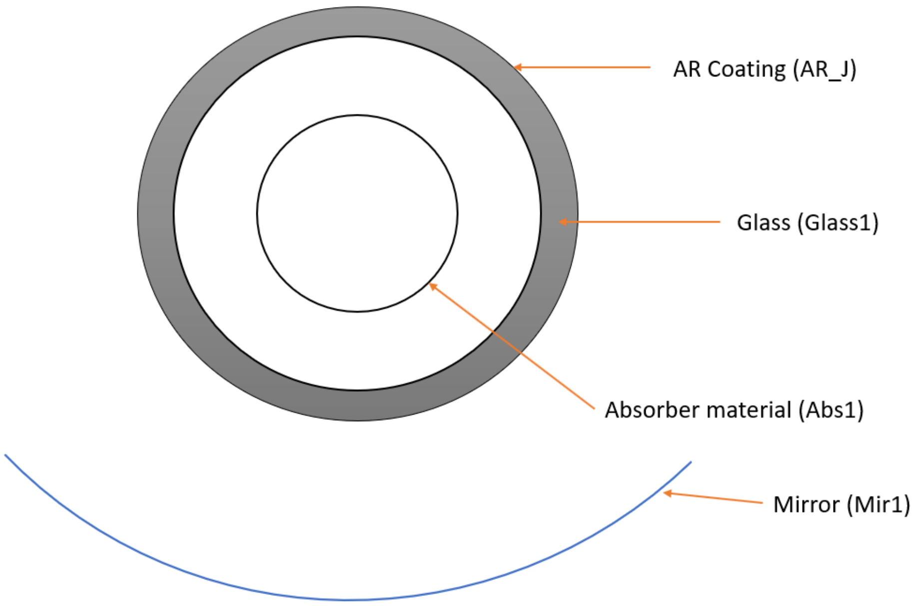

Fig. 2. Cross-sectional view of the collector's receiver tube. The names of the different objects appear with the corresponding names of the optical material assigned in parentheses. Not to scale.

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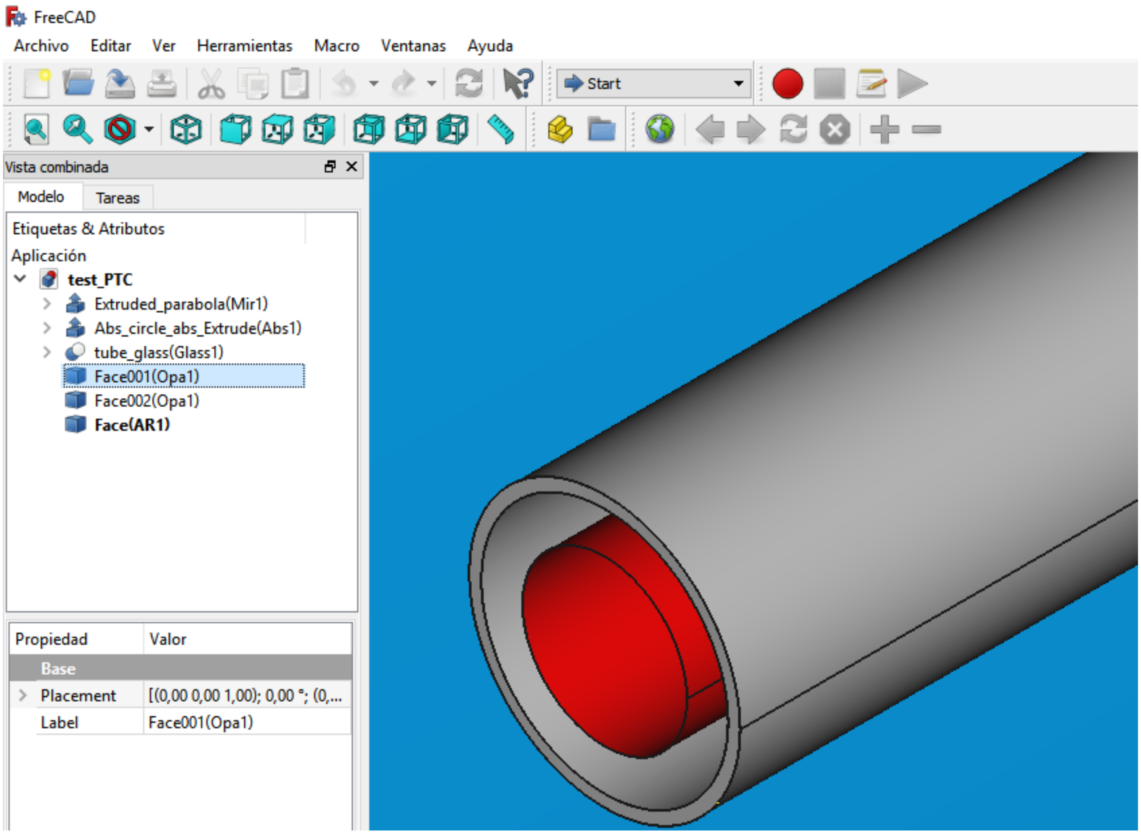

Fig. 3. Visualization of the collector geometry in FreeCAD. The different collector components are listed in the panel on the left. Each object is shown together with its respective label. The name of the optical material in parentheses must be included in the name of the ".otmaterial" file.*

2. Getting started

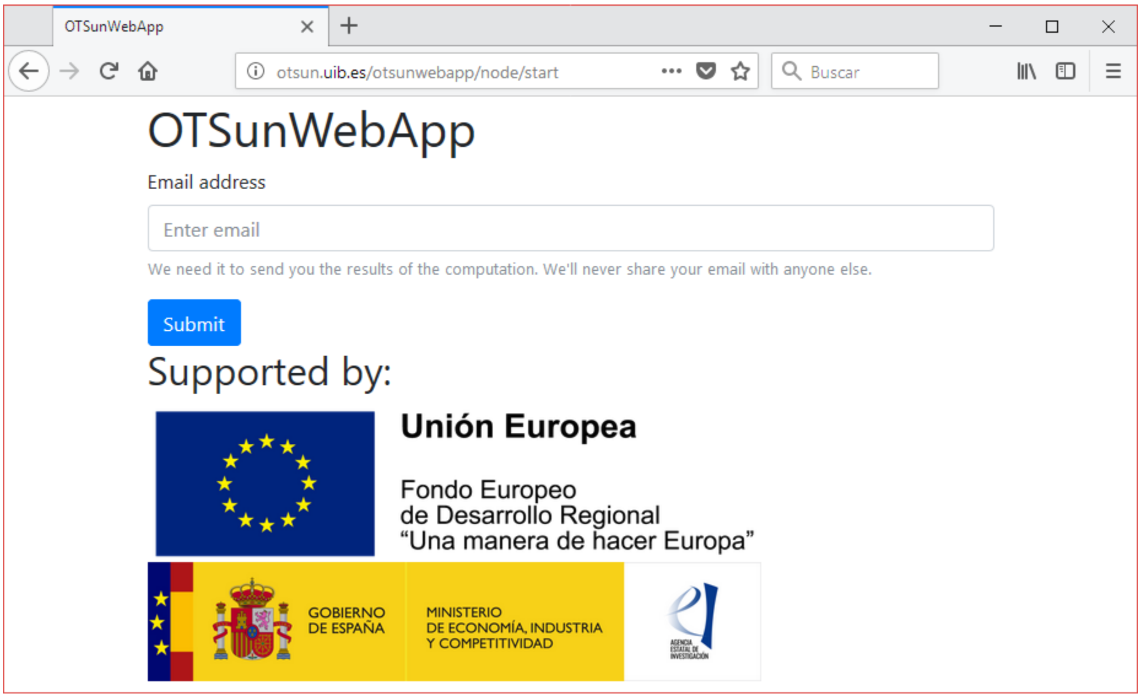

Fig. 4. Home page of the OTSun webApp.

1. Type in the email address where the user wants to receive the results of the simulation.
2. Click on “submit”.

3. Upload the geometry

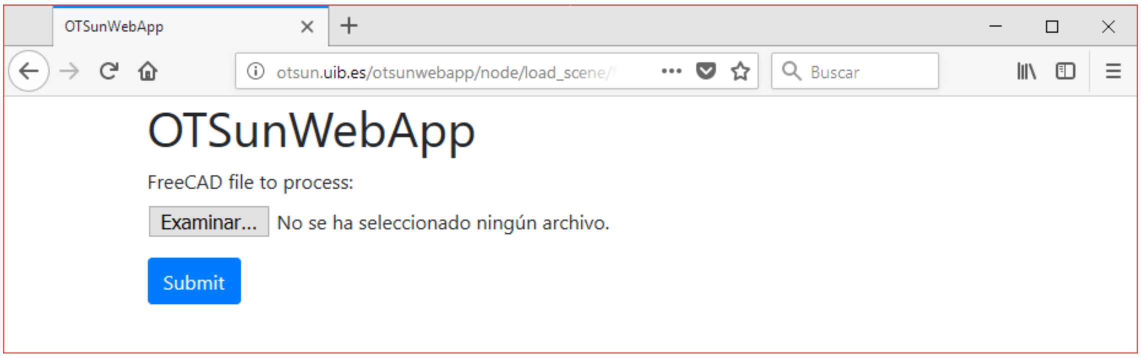

Fig. 5. Website to which the FreeCAD file (where the solar collector geometry is defined) should be uploaded.

1. Select the file test_PTC.FCStd, which contains the geometry of the solar thermal collector.
2. Click on “submit”.

4. Objects and materials

On the next webpage, the objects of the geometry of the uploaded solar collector appear (see Fig. 6). These objects are:

- Volume material: Glass1.
- Surface material: AR1, Opa1, Mir1, Abs1.

At this point, the optical properties of the objects of the geometry that interact with rays must be defined. For each object, a *.otmaterial file is needed. How to create such files is explained below.

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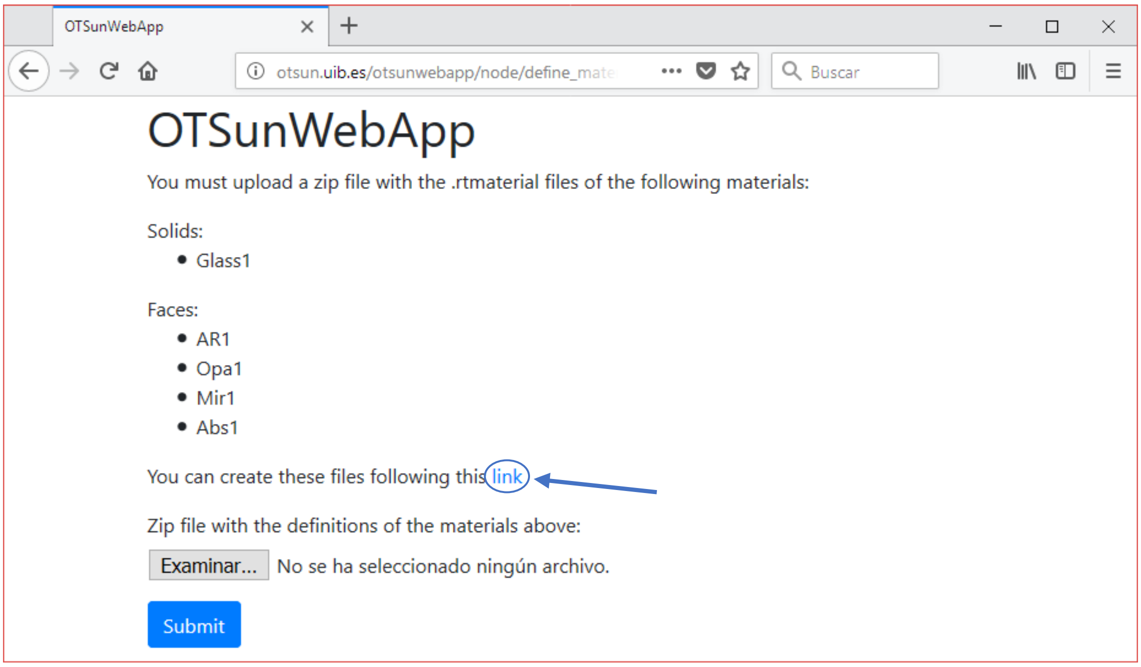

Fig. 6. Webpage for uploading material files present in the solar collector design.

It is important to note that the names of the material files must be identical to the text in parentheses in the label of each respective FreeCAD object. Fig. 3 shows the label of each component in this particular case.

If the user has already created a *.zip file containing all the optical property material files:

1. Select the *.zip file that contains all the material files.
2. Click on "submit".

Otherwise, the user must create the files for each material manually:

1. Click on the hyperlink shown in Fig.6, which will redirect the user to the "*Creator of Materials*" site (http://otsun.uib.es/otsunwebapp/material). This link leads to the tab shown in Fig. 7.
2. Identify each of the materials with the names that appear in Fig. 6 (Glass1, AR1, etc.). The following instructions describe how to create the material file called Glass1, which is the label for the glass of the collector.
3. Select "Volume" from the "Kind of material" drop-down list, since it is a volume material (Fig. 7).
4. Select "Variable refractive index" from the "Kind of volume material" drop-down list (Fig. 8), since it is a volume material with a variable refractive index as a function of wavelength.
5. Upload the text file which contains the refractive indices of the glass: BK7_Schott.txt.
6. Click on "submit". At this moment, the application has generated a file for this material called "Glass1.otmaterial".
7. For the rest of the materials, the same steps must be followed, choosing the characteristics described in Table 1 for each one of them.

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8. Once all the material files have been created, they should be stored in the same local folder and compressed into a single *.zip file, as illustrated in Fig. 9.
9. Go back to the previous tab and upload the *.zip file (see Fig. 10).
10. Click on “submit”.

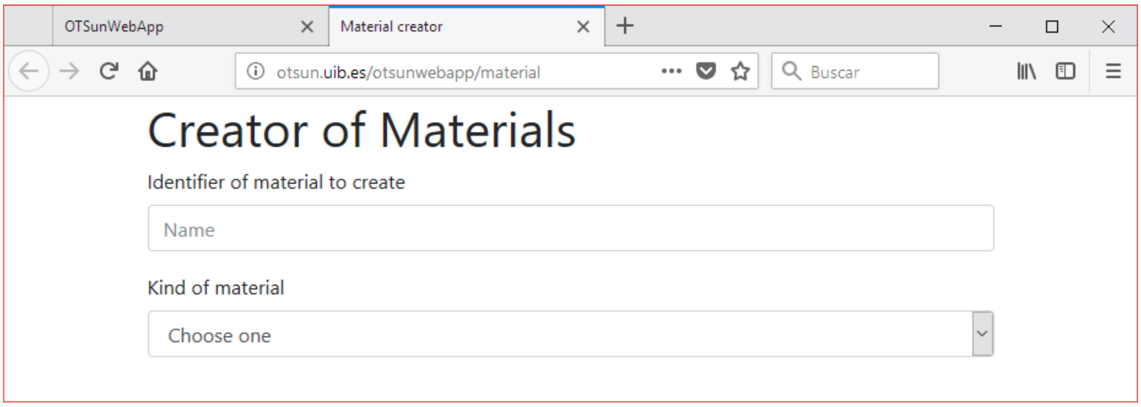

Fig. 7. Webpage for the creation of OTSun material files.

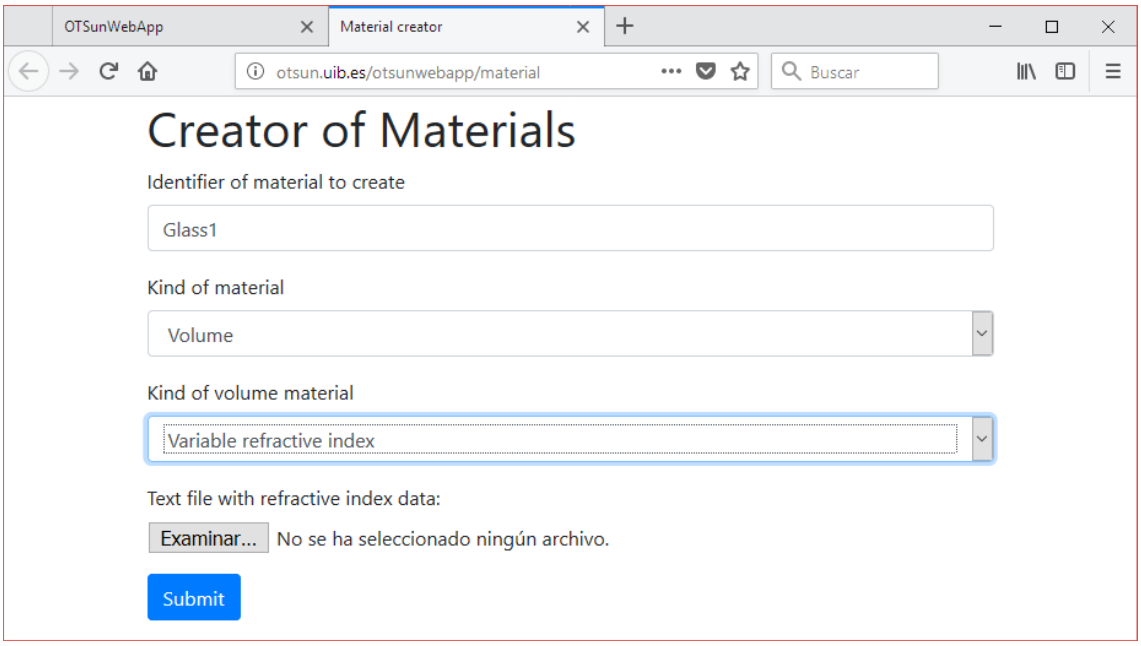

Fig. 8. Webpage for the creation of OTSun material files.

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Table 1. Characteristics of the materials.

Material	Name	Type – subtype of material	Optical properties
Glass	Glass1	*Volume – Variable Refractive Index*	BK7_Schott.txt
Anti-reflective Coating	AR1	*Surface – Transparent Polarized Coating Layer*	AR-J.txt: MgF_2[2]
Mirror	Mir1	*Surface – Reflector Specular Layer*	$R = 0.94$
Absorber Material	Abs1	*Surface – Absorber Simple Layer*	$\alpha = 0.95$
Opaque Material	Opa1	*Surface – Opaque Simple Layer*	

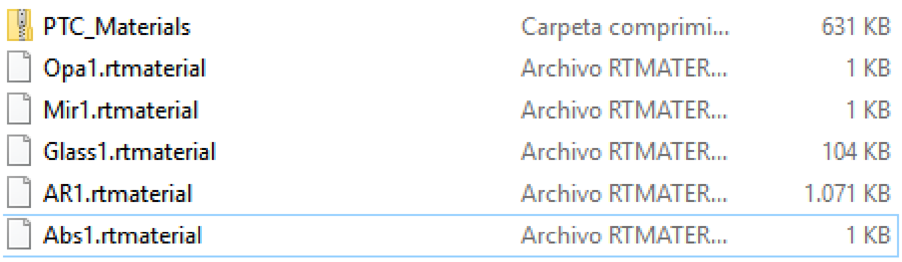

*Fig. 9. Directory containing the OTSun material files of each component, and the collective *.zip folder.*

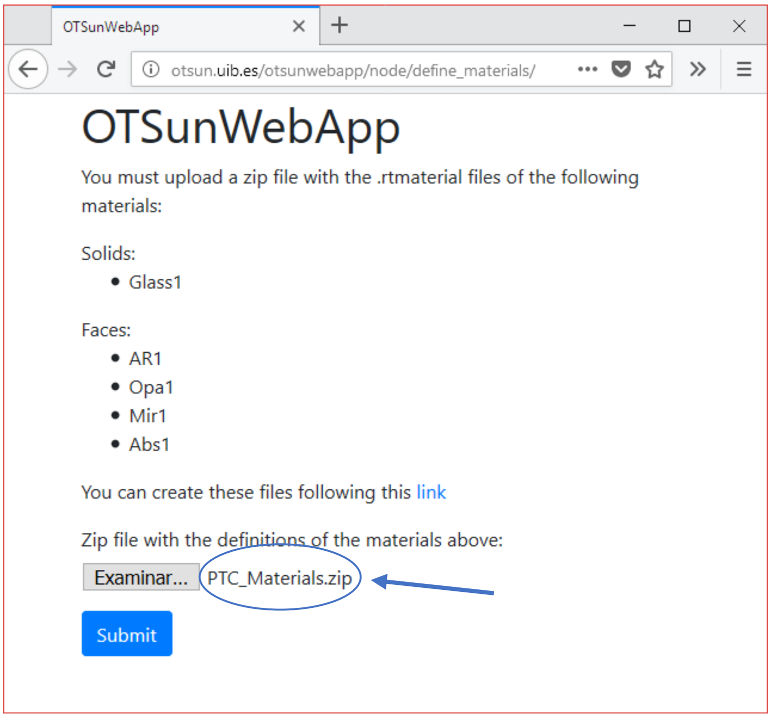

*Fig.10. Webpage for uploading the material files. The *.zip folder containing all material properties has been selected.*

5. Inputs for the simulation (experiment)

In the drop-down list shown in Fig. 11, there are three types of analysis to perform in the simulation. In this case, the user will select "*Total analysis*", the purpose of which is to obtain the optical efficiency for different positions of the sun, based on the Reference Air Mass 1.5 Spectra for direct solar radiation: ASTMG173. The results are presented in *.txt files.

In this example, the simulation is at normal incidence. The number of rays is 1000. This number has been chosen so that the calculation is quick. To obtain a more reliable result, the use of at least 10000 rays is recommended for this PTC. The aperture area of the PTC is 19090215 mm^2. Note that the PTC is a solar thermal collector, hence this is the aperture area for optical thermal efficiency, while the aperture area for photovoltaic is null since there is no photovoltaic material. Finally, a Circum Solar Ratio (CSR) value of 0.05 is chosen for the Buie model of the Sun [3].

The parameters are summarized below:

1. Select "Total analysis" and click on "submit". The simulation parameters will then be defined (see Fig. 12).
2. Sun position: $\phi_i = \phi_f = 0^o$, and $\theta_i = \theta_f = 0^o$.
3. Number of rays: 1000.
4. Collector aperture area for thermal: 19090215 mm^2. This is the aperture area of the PTC.
5. CSR value: 0.05.
6. Click on "submit".

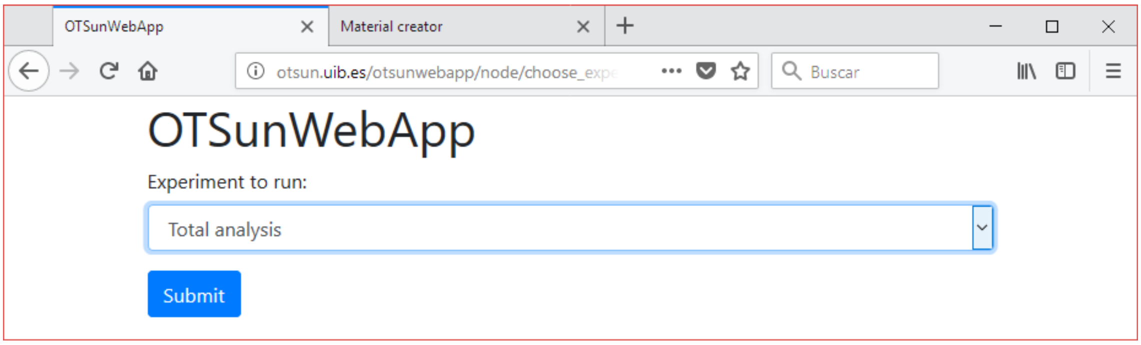

Fig. 11. On this webpage, the simulation type can be selected. In this case, a "Total analysis" will be conducted.

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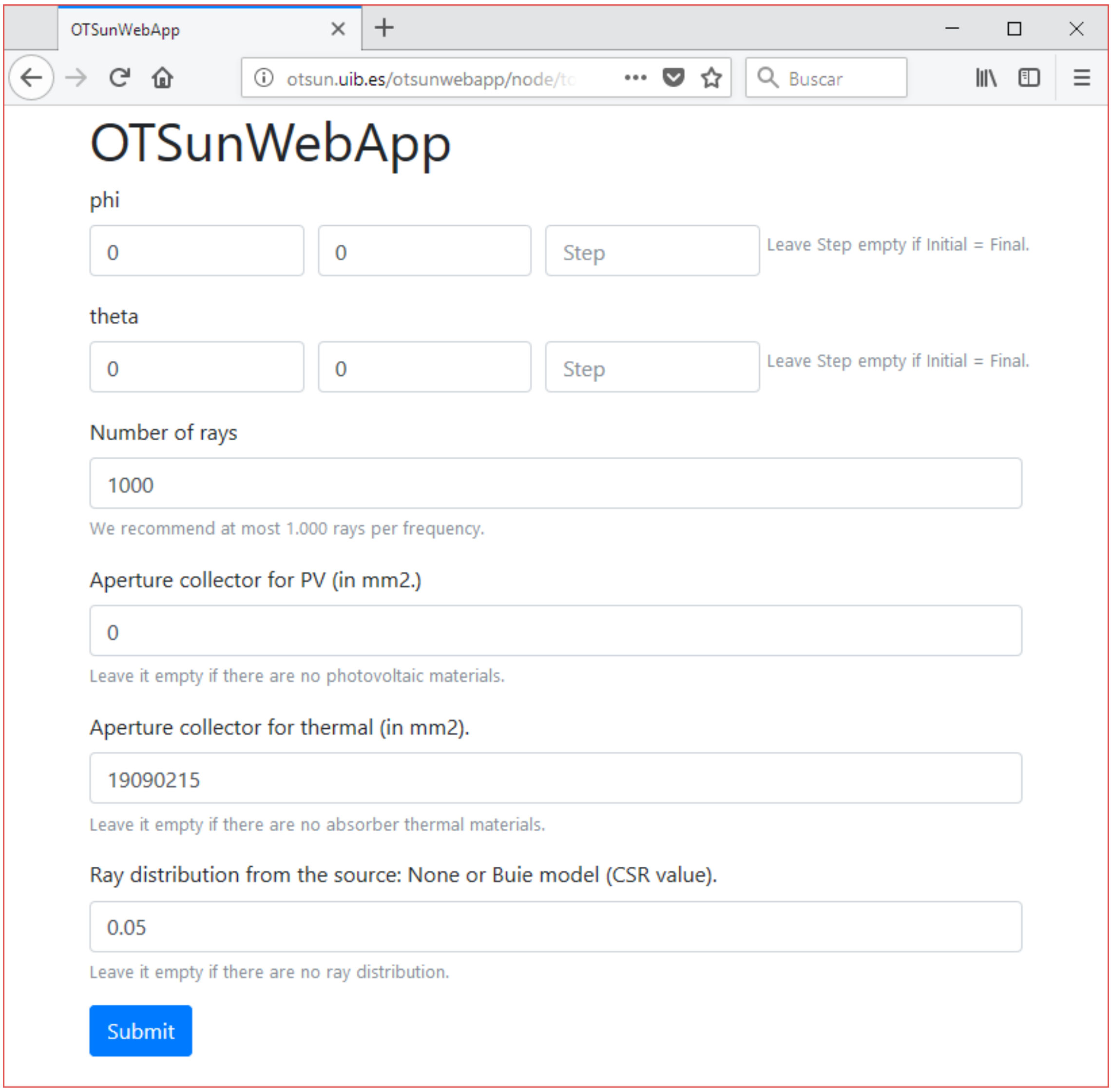

Fig. 12. Webpage with the ray tracing configurations.

6. Run simulation

At this point, the application displays the webpage illustrated in Fig. 13. The instructions presented on this webpage must be followed to start the simulation process. By clicking on “OK”, the user will reach the webpage illustrated in Fig. 14, which will show whether there is an error. An error indicates that the simulation could not be executed. If there are no errors, a link appears from which the simulation status can be accessed (see Fig. 15). On this webpage, if the user refreshes the webpage, the simulation progress is displayed.

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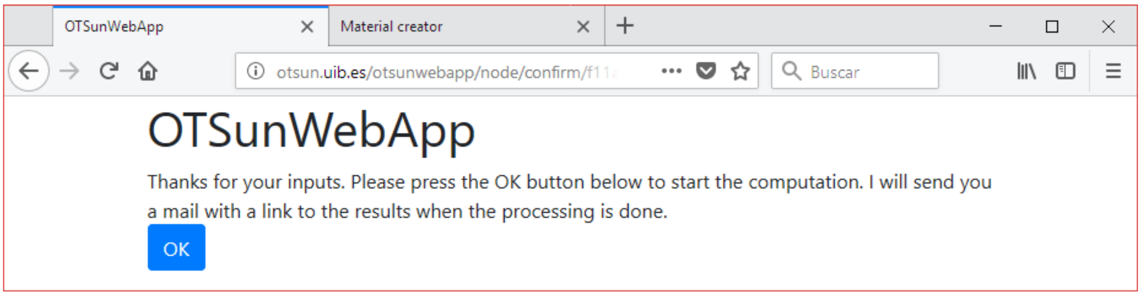

Fig.13. Confirmation message after all ray tracing settings have been uploaded successfully.

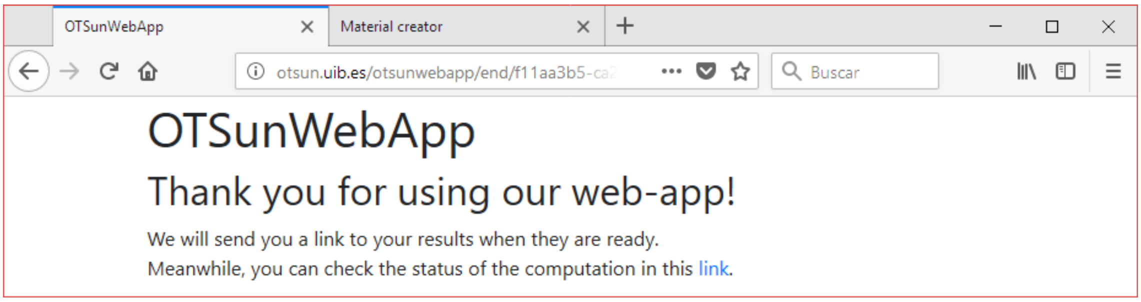

Fig.14. "Thank you" message. The link that appears leads the user to the webpage with the computation status.

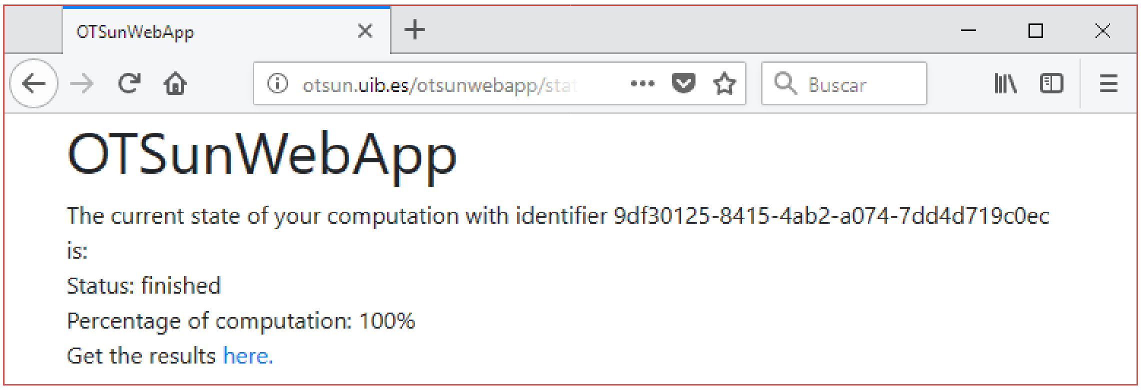

Fig. 15. Webpage with the computation status.

7. Results

Shortly after the simulation has finished, the user will receive an email at the address that he or she previously specified. The email contains a hyperlink ("Get your results at: *link*"), which will trigger an automatic download of an "output.zip" file that contains the results. This compressed file contains the "efficiency_results.txt" file.

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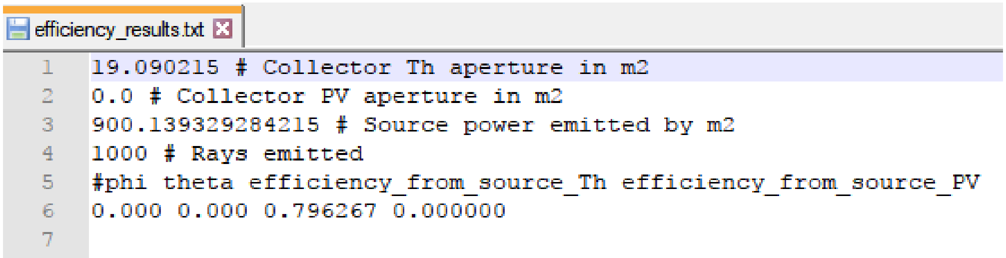
In addition to a short summary of the main configuration parameters, the file also contains the simulated optical efficiency at normal incidence (see Fig. 16). In this example, the optical efficiency at normal incidence is 79.6%. This value is only indicative; the result can oscillate around this value because a greater number of rays is needed for the convergence of the optical efficiency.




```
19.090215 # Collector Th aperture in m2
0.0 # Collector PV aperture in m2
900.139329284215 # Source power emitted by m2
1000 # Rays emitted
#phi theta efficiency_from_source_Th efficiency_from_source_PV
0.000 0.000 0.796267 0.000000
```

Fig.16. Text file with the results of the simulation.

8. Practical examples

In the following examples, the parameters to be introduced are shown in order to obtain the optical efficiency in the longitudinal plane and in the transversal plane of the PTC. This kind of simulation has also been performed by Sallaberry et al. (2015) [1].

8.1. Longitudinal plane

The purpose of this example is to obtain the optical efficiency in the longitudinal plane. The simulation of the PTC is carried out in the same way as in the previous sections, but now introduces the following values for the parameters described in Section 5:

1. Sun position: $\phi_i = \phi_f = 90^{\mathrm{o}}$, and $\theta_i = 0^o, \theta_f = 90^{\mathrm{o}}$ and $\Delta\theta = 2^{\mathrm{o}}$.
2. Number of rays: 10000.
3. Aperture collector for thermal: 19090215 mm^2.
4. CSR value: 0.05.

Please note that due to the high number of rays emitted and the number of sun positions now considered, the calculation will take longer. The email with the results may therefore take several hours to arrive, depending on the availability of the server. The results are illustrated in Fig. 17 and in Table 2.

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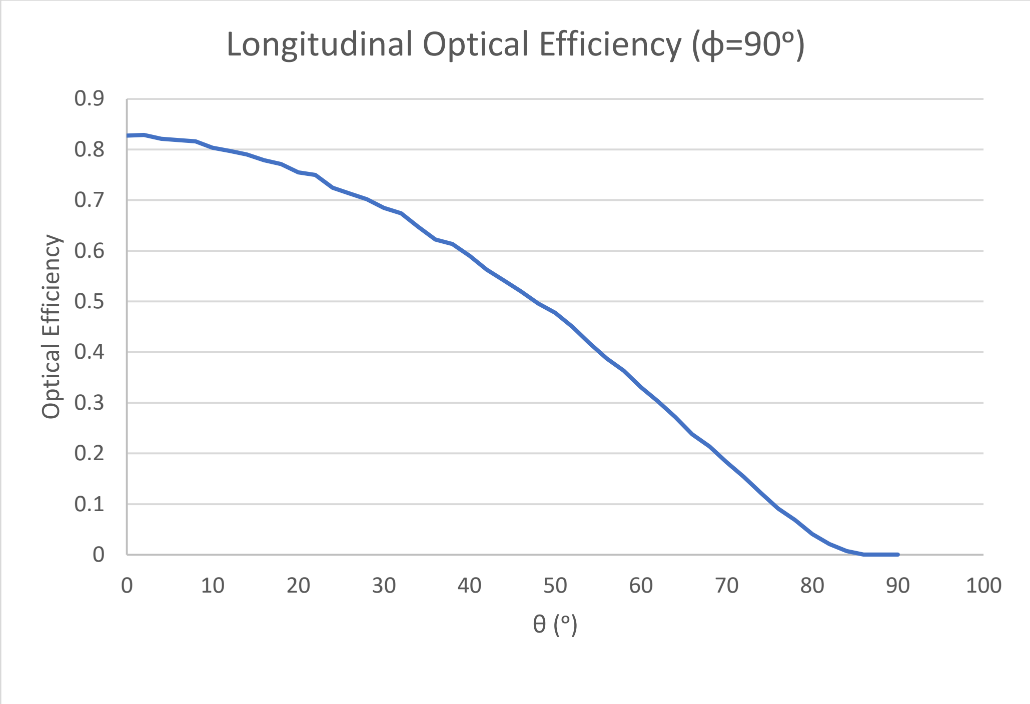

Fig. 17. Optical efficiency depending on the incidence angle in the longitudinal plane.

Table 2. Simulation results for the longitudinal plane of the PTC.

ϕ(°)	***θ*(°)**	**Efficiency from source Th**	**Efficiency from source PV**
90	0	0.82733	0
90	2	0.828357	0
90	4	0.821202	0
90	6	0.818588	0
90	8	0.815876	0
90	10	0.803389	0
90	12	0.797297	0
90	14	0.789847	0
90	16	0.778545	0
90	18	0.771446	0
90	20	0.7548	0
90	22	0.749698	0
90	24	0.724777	0
90	26	0.713033	0
90	28	0.70159	0
90	30	0.684643	0
90	32	0.673817	0
90	34	0.647656	0
90	36	0.622217	0
90	38	0.613547	0
90	40	0.590091	0
90	42	0.562815	0
90	44	0.541145	0

ϕ(°)	***θ*(°)**	**Efficiency from source Th**	**Efficiency from source PV**
90	46	0.519783	0
90	48	0.496112	0
90	50	0.477522	0
90	52	0.449903	0
90	54	0.417678	0
90	56	0.387502	0
90	58	0.363387	0
90	60	0.330226	0
90	62	0.302751	0
90	64	0.27155	0
90	66	0.237689	0
90	68	0.213852	0
90	70	0.182791	0
90	72	0.153743	0
90	74	0.122033	0
90	76	0.091293	0
90	78	0.068218	0
90	80	0.040679	0
90	82	0.021094	0
90	84	0.007045	0
90	86	0.000564	0
90	88	0.000097	0
90	90	0.000091	0

https://github.com/bielcardona/OTSun/tree/master/OTSunWebApp

8.2. Transversal plane

The purpose of this next example is to obtain the optical efficiency in the transversal plane. The simulation of the PTC is carried out in the same way as in the previous sections, but now introduces the following values for the parameters described in Section 4:

1. Sun position: $\phi_i = \phi_f = 0^o$ and $\theta_i = 0^o, \theta_f = 3^o$ and $\Delta\theta = 0.2^o$.
2. Number of rays: 10000.
3. Aperture collector for thermal: 19090215 mm^2.
4. CSR value: 0.05.

Please note that due to the high number of rays emitted and the number of sun positions now considered, the calculation will take longer. The email with the results may therefore take several hours to arrive depending on the availability of the server. The results are illustrated in Fig. 18 and in Table 3.

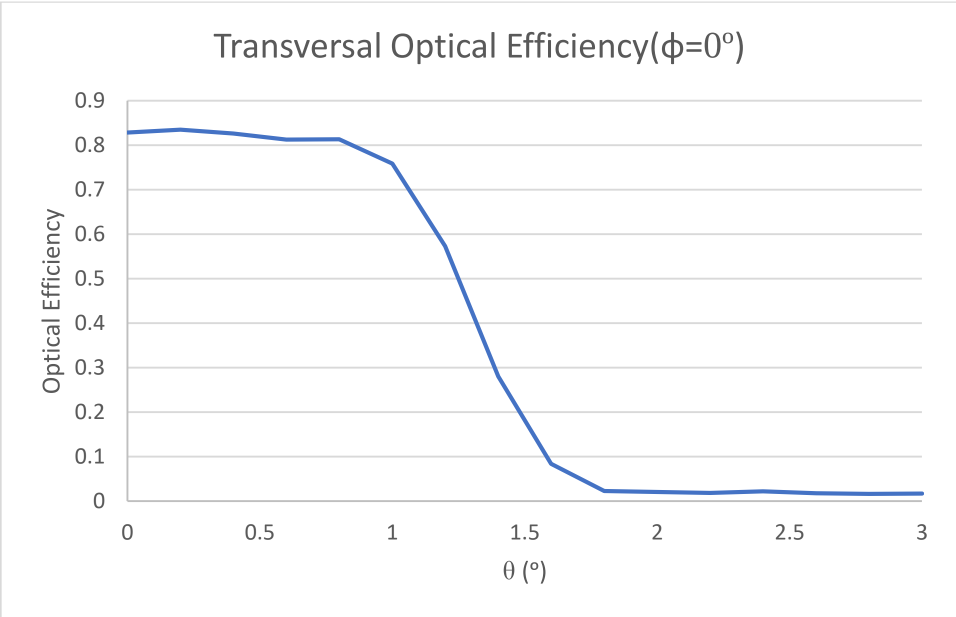

Fig. 18. Transversal efficiency curve of the collector.

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Table 3. Simulation results for the transversal plane of the PTC.

ϕ(º)	***θ***(º)	**Efficiency from source Th**	**Efficiency from source PV**
0	0	0.828332	0
0	0.2	0.835345	0
0	0.4	0.826552	0
0	0.6	0.812869	0
0	0.8	0.813435	0
0	1	0.758479	0
0	1.2	0.573214	0
0	1.4	0.28019	0
0	1.6	0.083837	0
0	1.8	0.022991	0
0	2	0.020704	0
0	2.2	0.018563	0
0	2.4	0.021774	0
0	2.6	0.017639	0
0	2.8	0.016231	0
0	3	0.017005	0

References

1. F. Sallaberry, R. Pujol-Nadal, M. Larcher, and M. H. Rittmann-Frank, "Direct tracking error characterization on a single-axis solar tracker," Energy Convers. Manag. **105**, 1281–1290 (2015).

2. J. D. Hertel, F. Bonnín-Ripoll, V. Martínez-Moll, and R. Pujol-Nadal, "Incidence-Angle- and Wavelength-Resolved Ray-Tracing Simulations of a Linear Fresnel Collector Using the In-House Software otsun," J. Sol. Energy Eng. **140**(3), 034502 (2018).

3. D. Buie, C. J. Dey, and S. Bosi, "The effective size of the solar cone for solar concentrating systems," Sol. Energy **74**(5), 417–427 (2003).