The OTSun WebApp

-Tutorial 3-

-First edition-

Plot of Rays Traced Through 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, the OTSun web app is used to create a plot of rays traced through a Parabolic Trough Collector (PTC). For the correct utilization of this tutorial, the *OTSun WebApp Tutorial 1* should be completed first.

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.

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

The user can now proceed with the configurations of the simulation using the OTSun WebApp, which is located at the following link: http://otsun.uib.es/otsunwebapp (see Fig. 3).

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

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

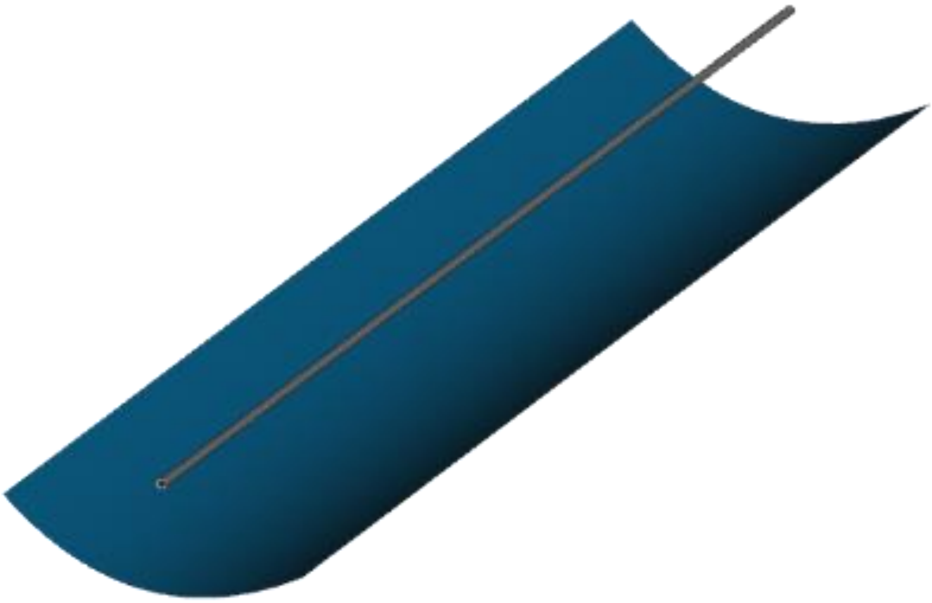

Fig. 1. Geometry of the PTC collector that is to be simulated.

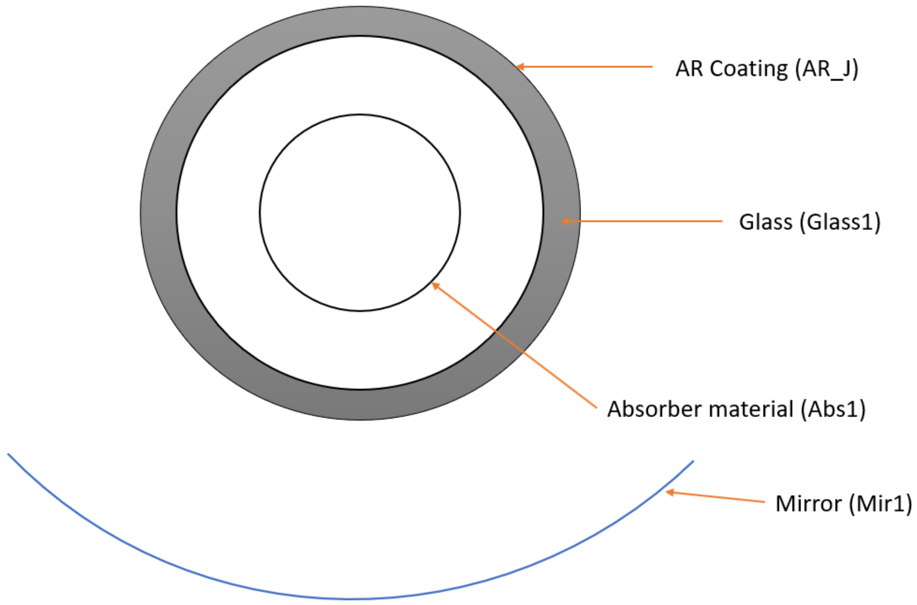

Fig. 2. Cross-sectional view of the collector's receiver tube. The names of the different objects appear with the corresponding names of the optical material assigned in parentheses. Not to scale.

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

2. Getting started

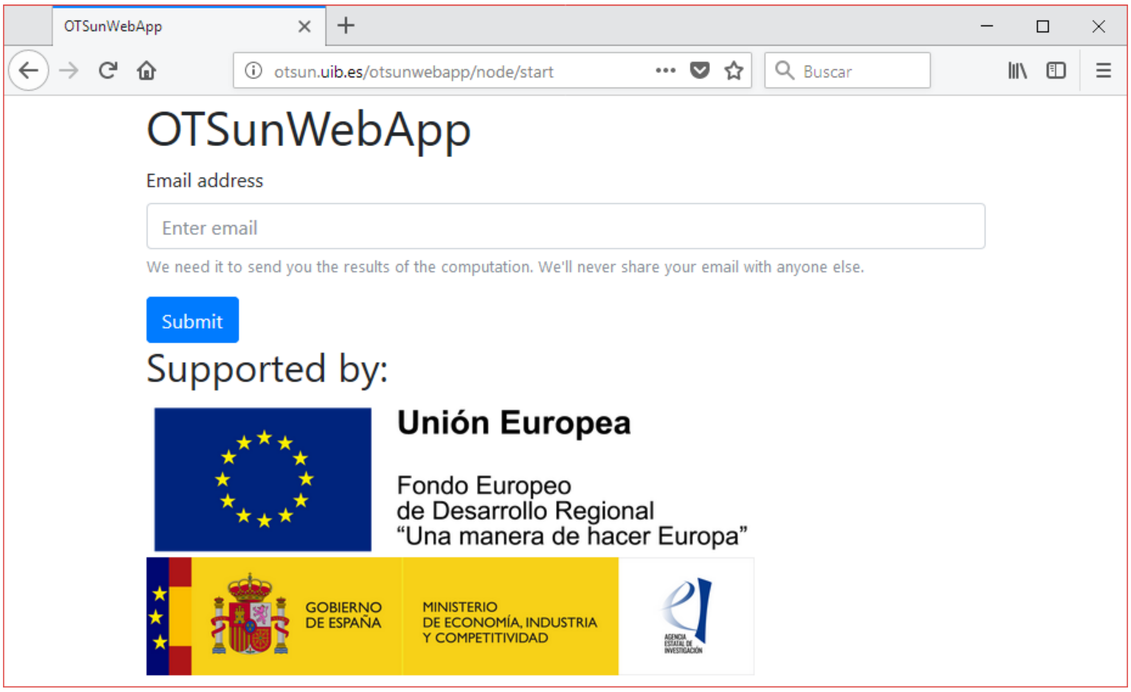

Fig. 3. Home page of the OTSun WebApp.

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

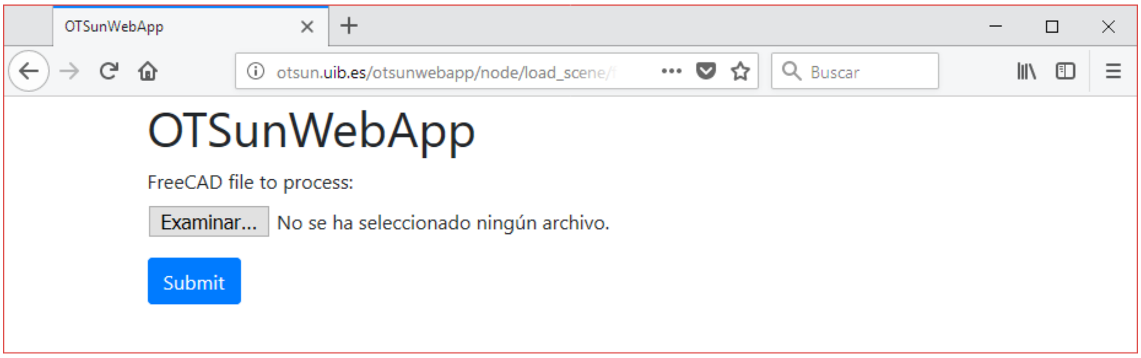

Fig. 4. Website to which the FreeCAD file (where the solar collector geometry is defined) should be uploaded.

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. 5). 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.

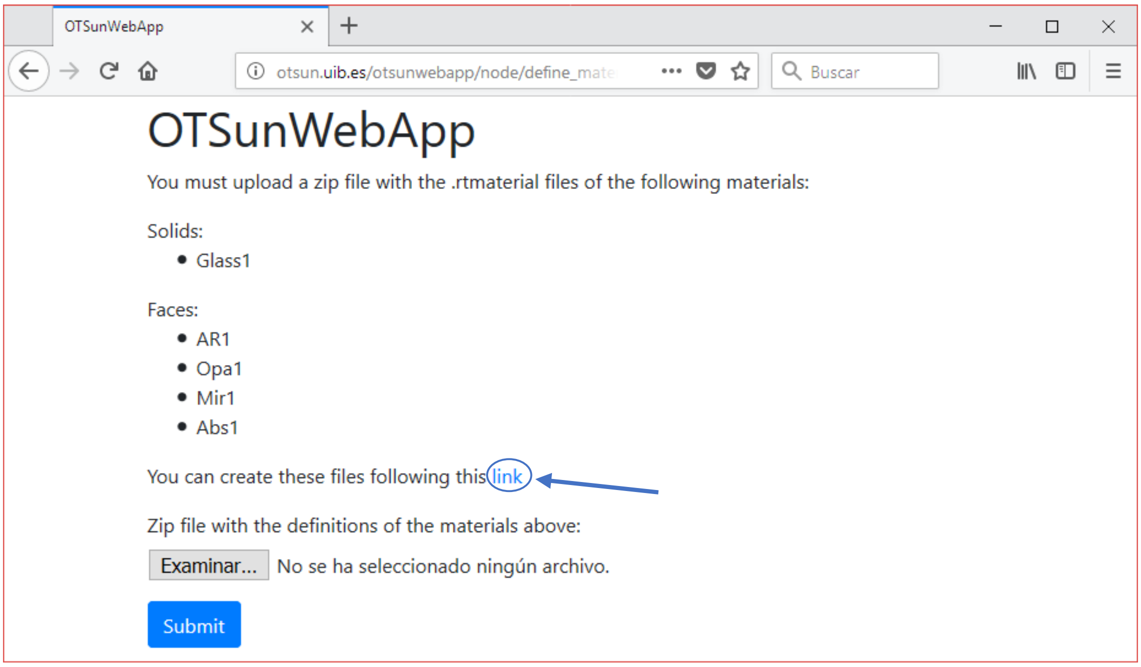

Fig. 5. Webpage for uploading material files present in the solar collector design.

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. 6 shows the label of each component in this particular case.

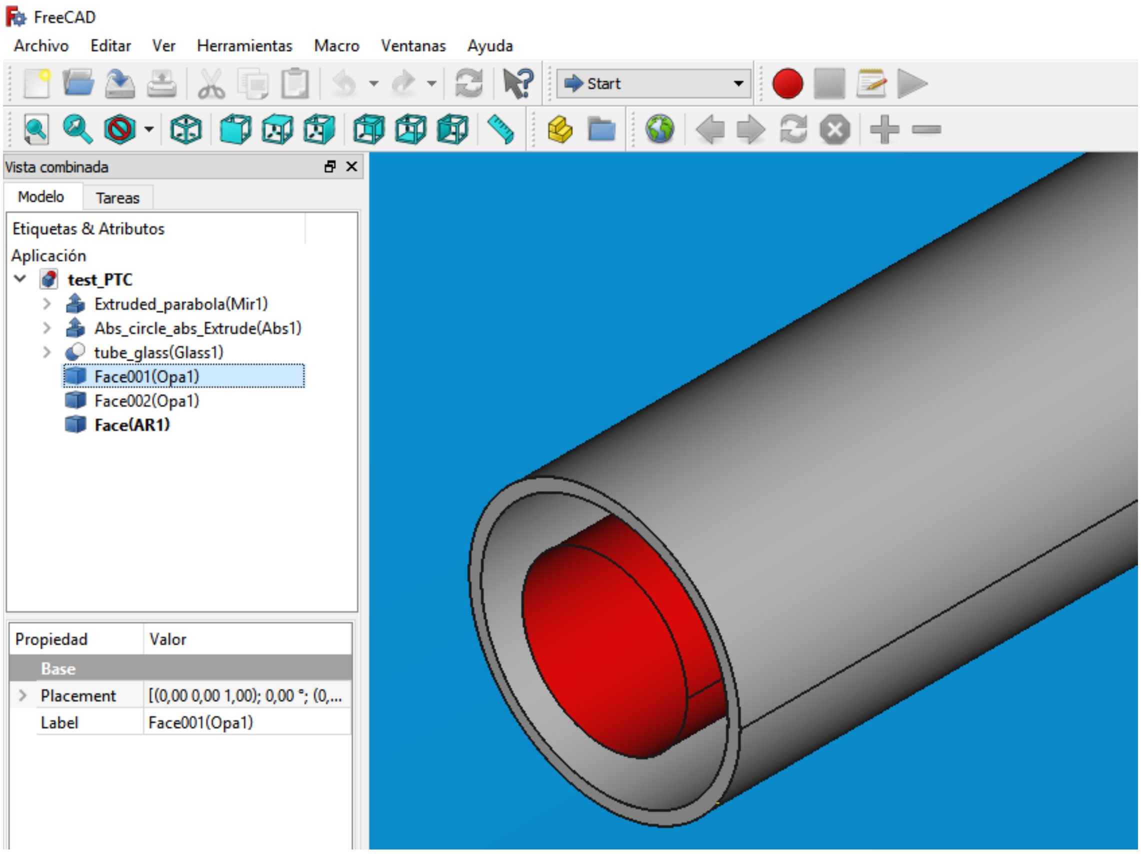

Fig. 6. Visualization of the collector geometry in FreeCAD. The different collector components are listed in the panel on the left. Each object is shown together with its respective label. The name of the optical material in parentheses must be included in the name of the ".otmaterial" file.*

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.5, 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. 5 (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.

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

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.
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".

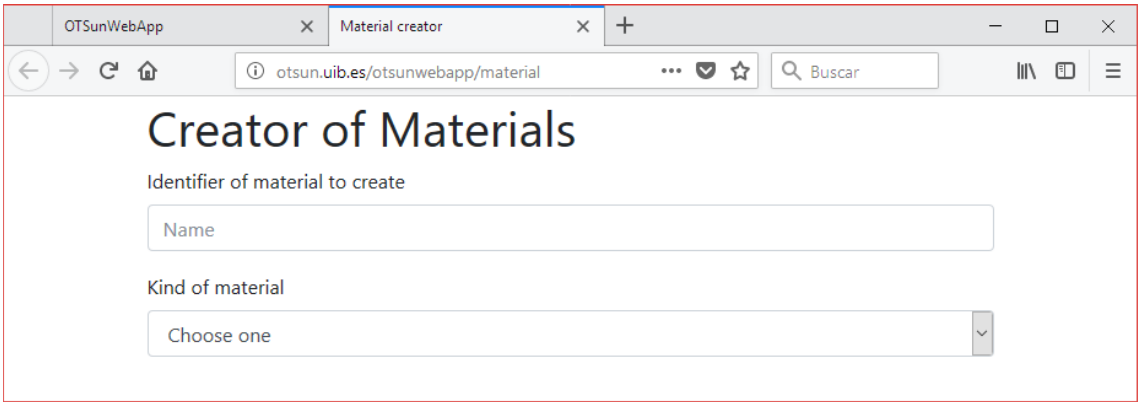

Fig. 7. Webpage for the creation of OTSun material files.

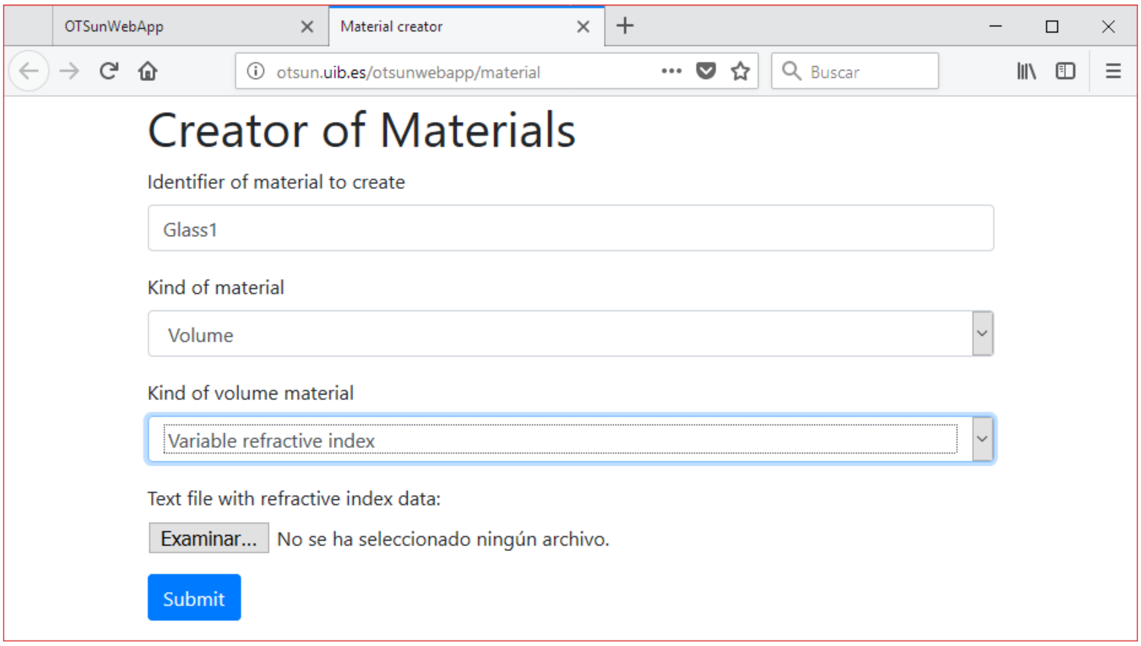

Fig. 8. Webpage for the creation of OTSun material files.

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

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 [1]
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*	

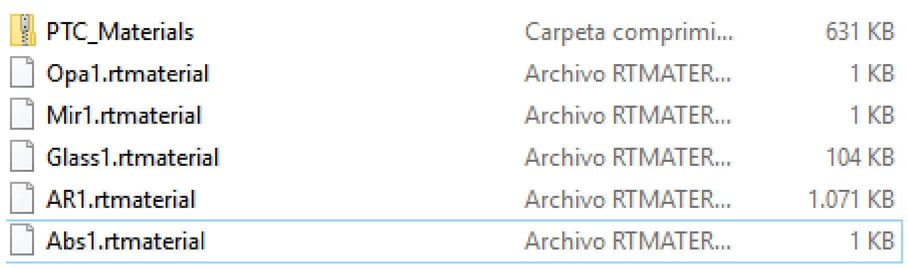

*Fig. 9. Directory containing the OTSun material files of each component, and the collective *.zip folder.*

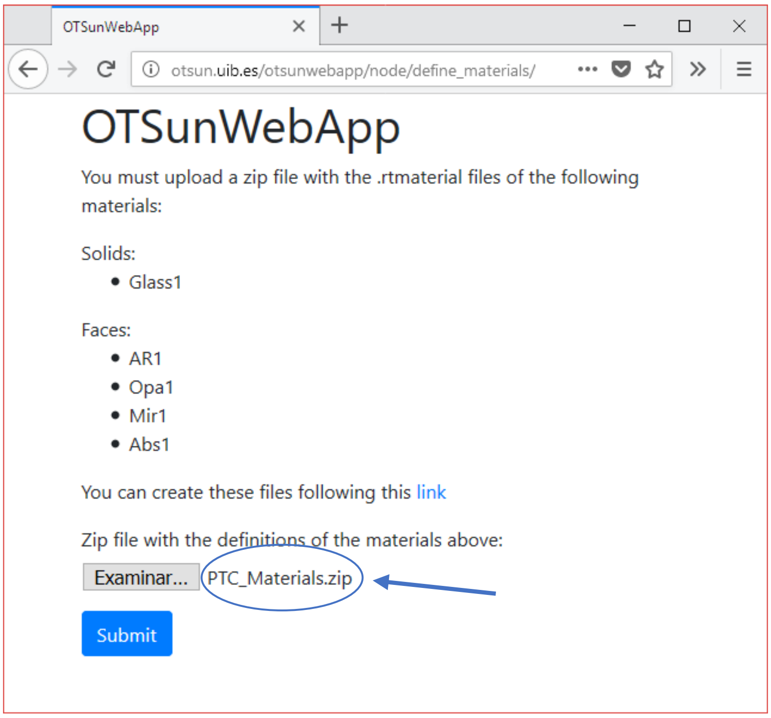

*Fig. 10. Webpage for uploading the material files. The *.zip folder containing all material properties has been selected.*

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

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 "*Single experiment with plot of rays*", the purpose of which is to obtain a plot of the rays traced through the PTC (Fig. 11). The result is presented in a *.FCStd file.

In this example, the plot of rays is at normal incidence. In order to avoid a high density of rays in the image, the number of rays for drawing is 50. The wavelength of the rays is 500 nm. The aperture area for thermal is 19090215 mm^2, while the aperture area for photovoltaic is null, since no photovoltaic material is present. Finally, a Circum Solar Ratio (CSR) value of 0.05 is chosen for the Buie model of the Sun [2].

The parameters are summarized below:

1. Select "Single experiment with plot of rays" and click on "submit". The simulation parameters will then be defined (see Fig. 12).
2. Sun position: $\phi = 0^o$ and $\theta = 0^o$.
3. Wavelength: $\lambda = 500\ nm$.
4. Number of rays for drawing: 50.
5. Collector aperture area for thermal: 19090215 mm^2. This is the aperture of the PTC.
6. CSR value: 0.05.
7. Click on "submit".

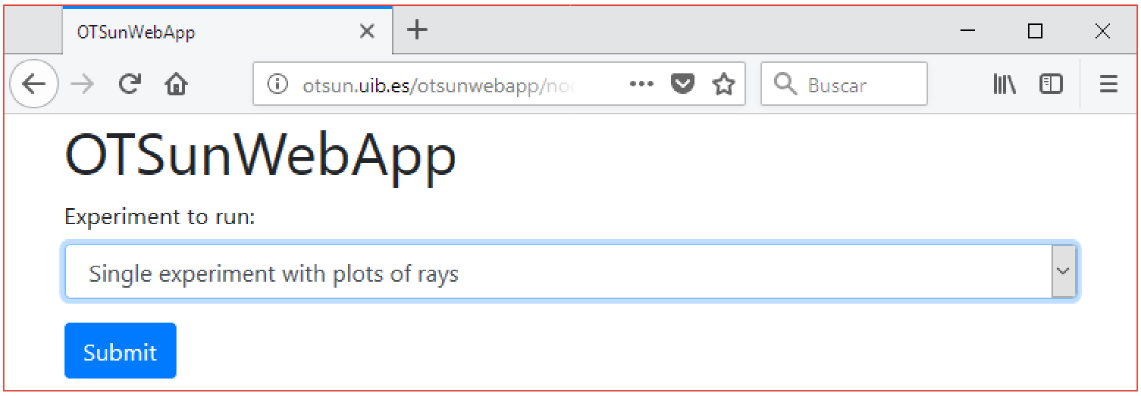

Fig. 11. On this web page, the simulation type can be selected. In this case, a "Single experiment with plots of rays" will be conducted.

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

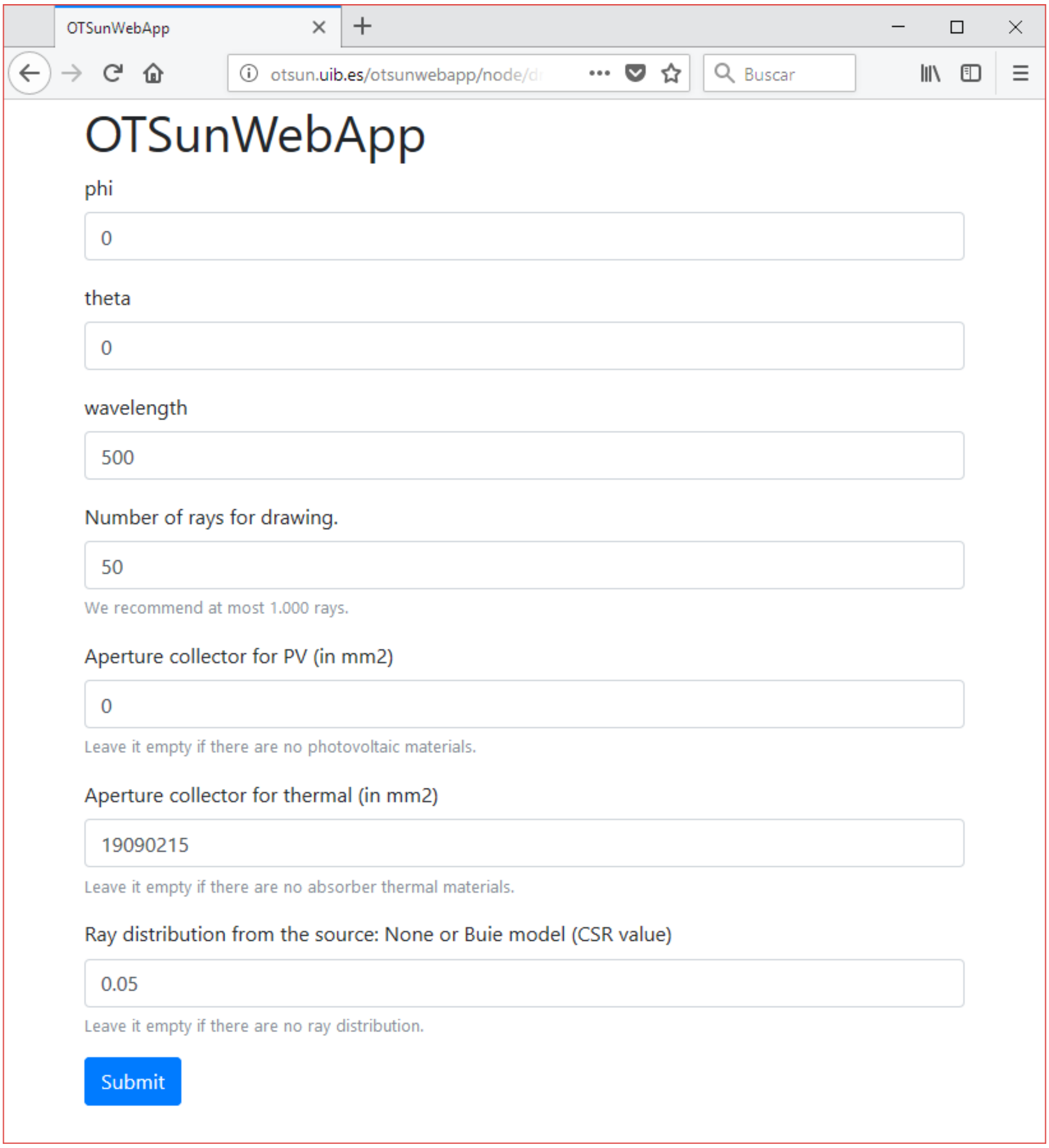

Fig. 12. Webpage with the ray tracing configurations.

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, This screen 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.

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

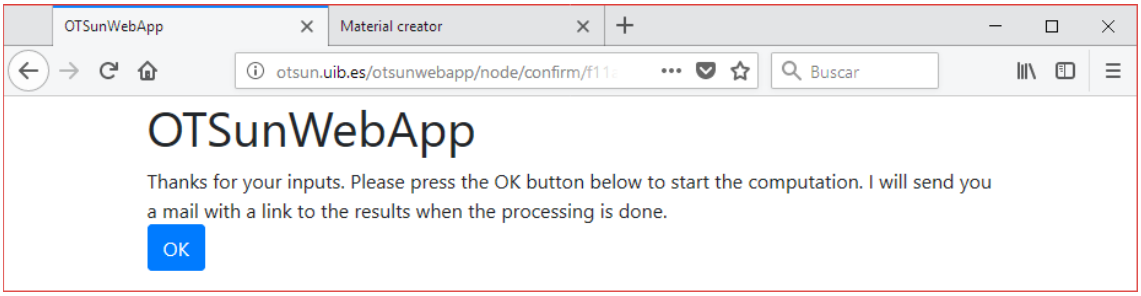

Fig. 13. Confirmation message after all ray tracing settings have been uploaded successfully.

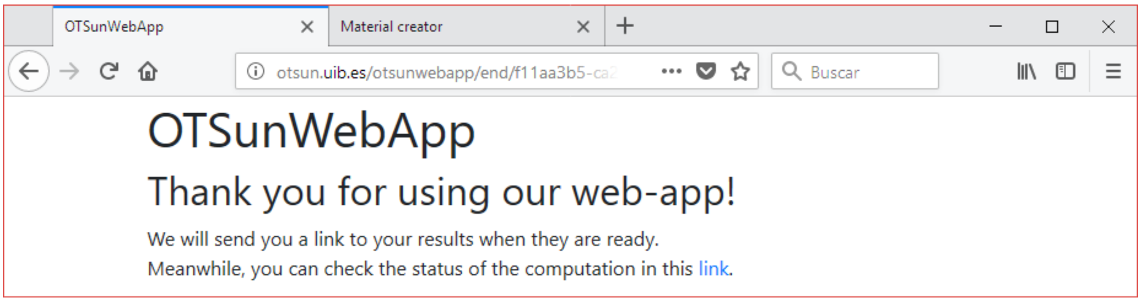

Fig. 14. "Thank you" message. The link that appears leads the user to the webpage with the computation status.

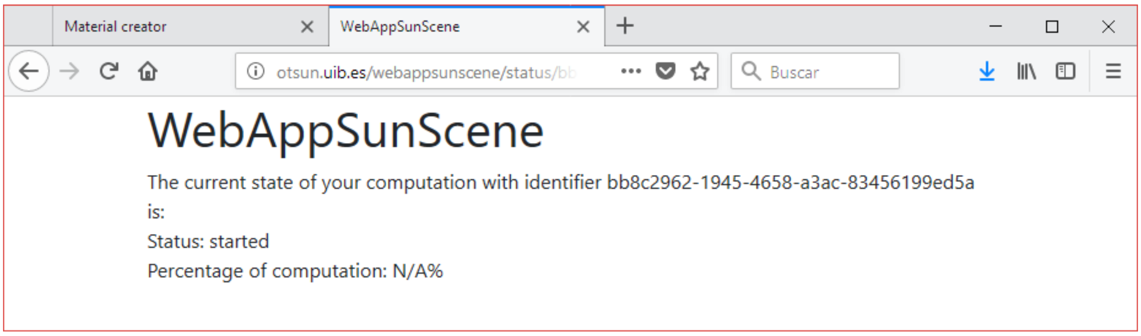

Fig. 15. Webpage with the computation status.

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 following files:

- "source_wavelengths.txt": it contains information related to the source, such as photovoltaic and thermal collector apertures, the number of rays and the wavelength of the rays.
- "drawing.FCStd": it contains the geometry of the solar collector with the traced rays.

To visualize the plot of rays, the user should follow these steps:

1. Open the "drawing.FCStd" file with FreeCAD.
2. Select all of the objects in the drawing.
3. Change the "Visibility" property to "true" (see Fig. 16).

In Figs. 17-18, the traced rays in the PTC are plotted in different perspectives.

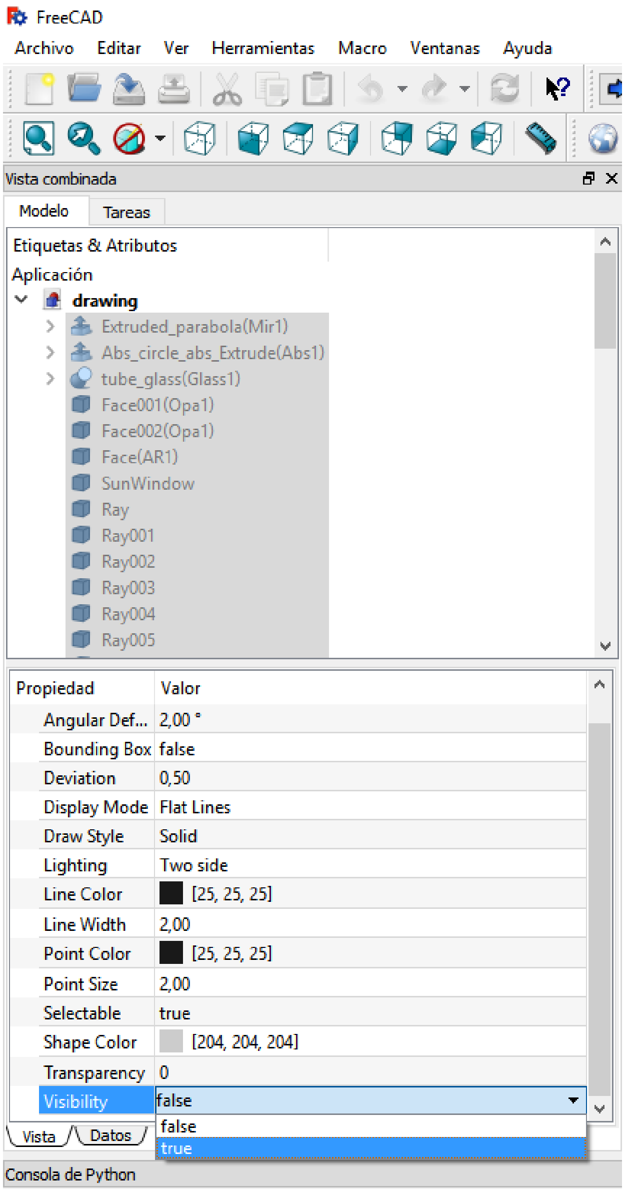

Fig. 16. FreeCAD view of the objects present in the "drawing.FCStd" file, and the visualization properties.

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

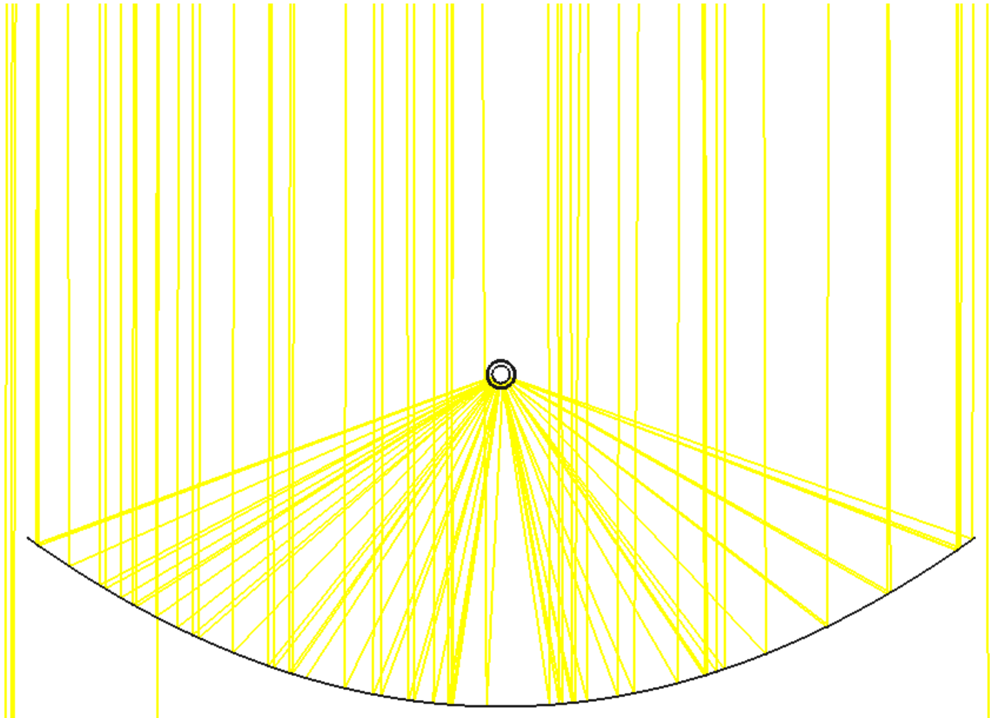

Fig. 17. Cross-sectional view of the plot of rays traced on the PTC. The parabolic mirror and the receiver are shown.

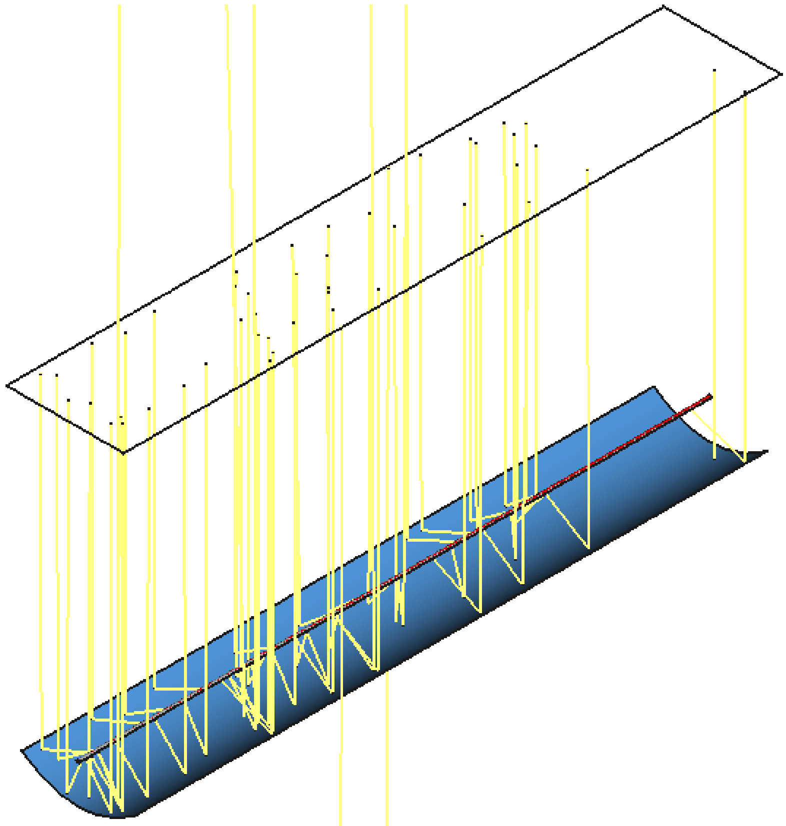

Fig. 18. Axonometric view of the plot of rays traced on the PTC. The emitting source (white rectangle) and the rays are shown in this plot.

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

References

1. 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).

2. 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).