SOLAR DESIGN
"USER ORIENTED SOFTWARE TOOL FOR DESIGN DRIVEN APPLICATIONS ON THIN-FILM SOLAR MODULES"

This project has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 310220. Theme: NMP.2012.4.0-1

Principal Author: Mr. Jokin Garatea

Job Title: International Department Director

Organisation: GAIA

Postal Address: Parque Tecnológico Edif. 103, 2. Zamudio. 48170. Spain

Co-Author: Mrs. Idoia Muñoz

Job Title: International Department Technician

Organisation: GAIA

Postal Address: Parque Tecnológico Edif. 103, 2. Zamudio. 48170. Spain

The Challenge

Photovoltaic (PV) is widely recognized as one of the key technologies for the future energy supply. The photovoltaic industry has successfully achieved a sharp reduction in manufacturing costs over the course of the last 10 years that is also reflected in declining market prices. The cost reduction is a result of the utilisation of learning effects, expansion of production capacities, extensive automation and standardisation efforts[1].
The growth of the PV Industry has produced falling prices for photovoltaic installations despite some shortages in the supply chain between 2005 and 2008.

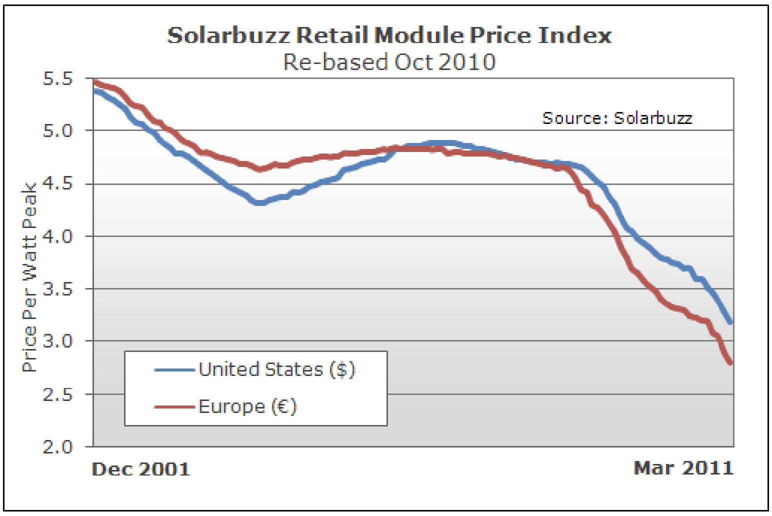


Figure 1: Development of market prices for PV systems per installed Watt peak (Source: Solarbuzz March 2011, online).

However, despite these achievements, the results have been standardized production processes and product lines that fail to respond to varying customer requirements. Conventional

mass produced photovoltaic modules are in most cases not suitable for integration into surfaces, roof tiles or electric devices due to their rigidness, appearance and electric constrains.
Nevertheless, the demand for aesthetically integrated photovoltaic materials is growing steadily in many industries. A growing number of designers, architects and industrial manufacturers across the world share a common interest in using Photovoltaics (PV) as a decentralized and sustainable source of energy in their product designs. Developing markets such as sustainable housing, temporary building structures, outdoor activities, electro-mobility and mobile computing will drive the demand for decentralized, attractive energy solutions. Indeed photovoltaic modules are the only viable renewable energy solution that can be integrated directly into objects such as devices, vehicles and buildings[2].
The manufacturing of products with integrated photovoltaic modules is normally a very troublesome work. To make a simple solar module like in the depicted radio solar cells are cut into pieces and then soldered again. This leads to high costs for PV integration (>3 € per Wattpeak only for the PV module), unnecessary shunts[3] and inhomogeneous surfaces which are prone to breaking.

Current needs for new PV applications

For these PV integrated product solutions are customisable shapes, sizes, colours, transparencies or specific electrical properties required, which have a decisive influence on the acceptance on the market. Therefore a new breed of solar technologies is necessary. These technologies should provide the right photovoltaic solution for the given requirements in respect of appearance, easy system integration and technical constraints. To achieve this goal new flexible production processes and materials need to be developed.
Furthermore the designer or architect who wants to incorporate solar electricity into his work needs a service environment to be assisted in the creative process. Therefore, a new user oriented design software tool should support the designer in conceiving, planning and producing sustainable solar design products.

Scientific and Technical objectives

SolarDesign addresses the challenge, among others, of developing the user oriented software tool following a living lab methodology approach where not only professionals but, also students participate in the creative development process; a system for building a future sustainable and innovative economy in which real-life user-centric research and innovation is the normal co-creation technique.

Method: User-driven design methodology

Following three principles[4]: early and continual focus on users; empirical measurement of usage; and iterative design involving the user in the process, within SolarDesign we follow the Living Lab methodology which involves end-users and distinguishes the following levels of user involvement[5]:

1. BE: The user not only supplies information to the developers, but also is part of the developers, but also is part of the development team generating ideas and prototypes.
2. TEST: Users can test products for instance at home or in a real environment.
3. WATCH: Users are invited to focus groups, for example.
4. HEAR: We ask and listen to what the user thinks to the product or service.
5. IMAGINE: We imagine what the user might think and make assumptions based on our knowledge of, belief in or know-how of the matter.

It is a key challenge to carefully balance energy performance/standardization needs and architects/designers', professionals and students, desired freedom. For this reason, a multidisciplinary approach following a user-driven design methodology fosters the collaboration between "creative partners" and "technician partners" integrating university students from both sides within the process.
We look for sustainable and responsible innovation, focusing on what is needed rather than on what we can produce, offering a tool that enables users and stakeholders to take active part in the development an innovation process.
Therefore, our methodology consists on a parallel work together with other scientists and students to construct a sustainable ecosystem for the project and its further dissemination and, service and products exploitation through a joint co-creation, exploration, experimentation and

evaluation; also monitoring and validation in order to enhance performance and reliability of the solar integrated products.

Material: Life Cycle Assessment tools for PV

The development of the user oriented software tool is based on the Life Cycle Assessment concepts and parameters previously identified within another European project, LCA to go: “Boosting Life Cycle Assessment Use in European Small and Medium-sized Enterprises; Serving Needs of Innovative Key Sectors with Smart Methods and Tools”.
The main focus on the identification of Life Cycle Assessment concepts and parameters in renewable energy products like thin-film modules is the design for minimum energy-payback times and maximum savings potential regarding greenhouse emissions.
Nowadays Industries assert Life Cycle Assessment as the most successful tool to address environmental impacts during the design process, but only large companies widely use this tool because of the high complexity and time input, resulting in increased expenses. Most of standards have a general perspective on life cycle and eco-design but the implementation of suitable measures in the companies needs experts and well trained staff. SMEs on the other side do not have, in most cases, an environmental department to take care of the necessary coordination[6].

Results

SolarDesign is working on the development of a user oriented software tool taking into consideration all the parameters for the establishment of a numerical modeling and simulation tool that allows gathering the necessary information during the design process.
The actual innovation of this tool is that enables the user to calculate solar radiation received on any shape, being no problem to simulate any scenario on a complex shape. The user oriented software tool provides design rules for the best solar cell super-structure and module design layout, and addresses the efficiency in the incorporation of thin film to the different products or structures designed. The tool will allow users to calculate a performance simulation to subsequently design the electronic and pattern for production process.

Pilot solution chosen
To develop and test the software tool, a building structure with a characteristic and complex shape called “domo” has been chosen on a first approach.

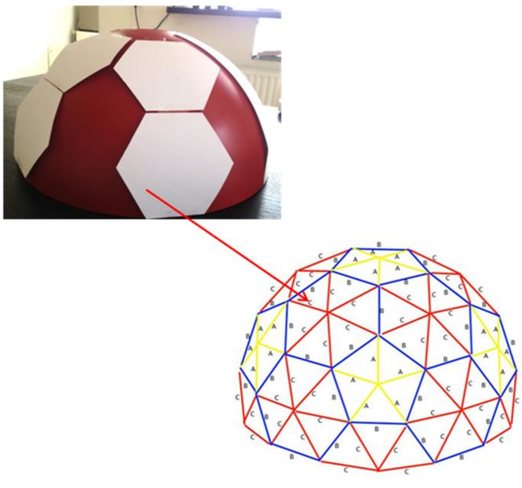


Figure 2. Domo Structure (Source: Julien Bollaro, GAIA, Application simulant la radiation solaire sur une installation afin d’assister le développement de la technologie Thin-Film dans le cadre du projet européen:Solar Design. 2013)

Between the different proposed solutions to design the structure and calculate its solar radiation, it was decided to divide the shape in polygon surfaces, especially in triangle surfaces, as with this method we can model all shape, from a sphere to the most complicated building roof. Moreover, we know how to calculate solar radiation on a flat surface; so the strategy is to process with the same algorithm each triangular surface in which the “domo” structure, in this case, is divided taking also into consideration the slope and inclination of each face’s modeled shape.

File format

Moreover, the file format used in the software application is a universal format accessible by most modeling software and, therefore, compatible with most of them; which gives an easy solution to import and export data from and to most modeling softwares.

Process data

To determine solar radiation outcome in each triangular surface, vector product is been used to get the normal of the surface. When having the normal vector with its Cartesian coordinates, we convert them in spherical coordinates to have the inclination and orientation of each surface.

Photovoltaic power: P= eff x S x IR x PR

With: eff = conversion efficiency of the solar panel

S = surface m²

IR = radiation received in kWh/m²

Performance ratio: coefficient of the external conditions

Radiation received**:** IR = region sun power (kWh/m²) x CI

CI is coefficient of incidence angle

CI = Sin(i) x Cos(h) x Cos(o - a) + Cos(i) x Sin(h)

With: i = incline angle from 0° to 90°

o = orientation angle (-180° to 180°)

h = height of the sun

a = azimuth of the sun

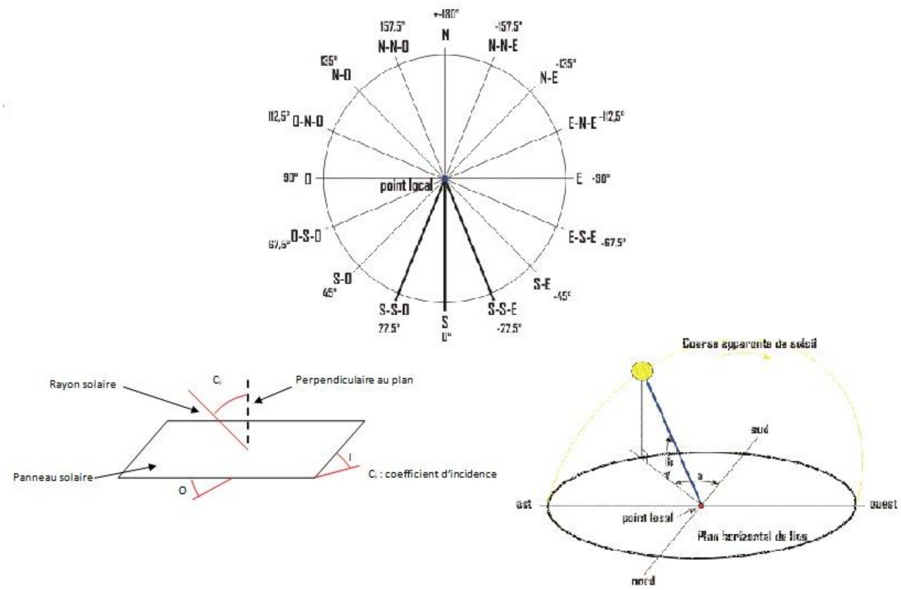
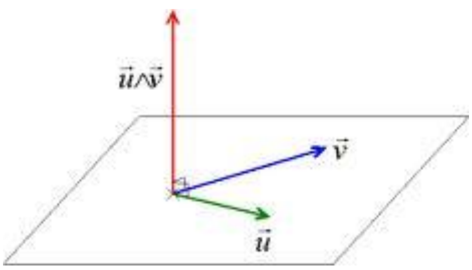


Figure 3. Photovoltaic power calculations. (Source: Julien Bollaro, GAIA, Application simulant la radiation solaire sur une installation afin d’assister le développement de la technologie Thin-Film dans le cadre du projet européen:Solar Design. 2013)

Sun’s height and azimuth can be determined with external conditions (latitude, longitude, altitude). Slope and orientation have to be known.

Vector product:



$$\vec{v1} = \begin{bmatrix} x1 \\ y1 \\ z1 \end{bmatrix} \quad \vec{v2} = \begin{bmatrix} x2 \\ y2 \\ z2 \end{bmatrix}$$

$$\vec{v1} \wedge \vec{v2} = \begin{bmatrix} y1*z2 - z1*y2 \\ z1*x2 - x1*z2 \\ x1*y2 - y1*x2 \end{bmatrix}$$

Figure 4. Photovoltaic power calculations. (Source: Julien Bollaro, GAIA, Application simulant la radiation solaire sur une installation afin d’assister le développement de la technologie Thin-Film dans le cadre du projet européen:Solar Design. 2013)

Benefit of vector product

We have the three points of each triangular surface. For example, for face 1 we have points “1,17 and 16”

308	s	1					
309	f	1	1	17	17	16	16
310	f	1	1	65	65	2	2

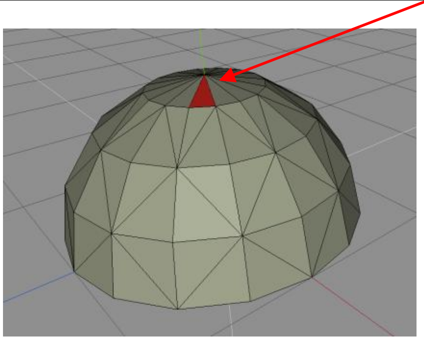


Figure 5. Vector product calculation. (Source: Julien Bollaro, GAIA, Application simulant la radiation solaire sur une installation afin d’assister le développement de la technologie Thin-Film dans le cadre du projet européen:Solar Design. 2013)

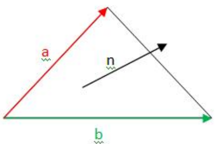
With them, the software takes the Cartesian coordinates of each point and calculates two vectors representative two side of the triangle.

175	#65	vertices,	112	faces
176	v	0,38268343	0,92387953	4,33E-20
177	v	0,35355339	0,92387953	0,14644661
178	v	0,27059805	0,92387953	0,27059805
179	v	0,14644661	0,92387953	0,35355339
180	v	2,47E-17	0,92387953	0,38268343
181	v	-0,14644661	0,92387953	0,35355339
182	v	-0,27059805	0,92387953	0,27059805
183	v	-0,35355339	0,92387953	0,14644661
184	v	-0,38268343	0,92387953	4,69E-17
185	v	-0,35355339	0,92387953	-0,14644661
186	v	-0,27059805	0,92387953	-0,27059805
187	v	-0,14644661	0,92387953	-0,35355339
188	v	-6,90E-17	0,92387953	-0,38268343
189	v	0,14644661	0,92387953	-0,35355339
190	v	0,27059805	0,92387953	-0,27059805
191	v	0,35355339	0,92387953	-0,14644661
192	v	0,70710678	0,70710678	4,33E-20
193	v	0,65328148	0,70710678	0,27059805

Cartesian coordinates of points “1,16,17”

Figure 6. Cartesian coordinates. (Source: Julien Bollaro, GAIA, Application simulant la radiation solaire sur une installation afin d’assister le développement de la technologie Thin-Film dans le cadre du projet européen:Solar Design. 2013)

Calculation: If A and B are two points with coordinate (xA;yA;zA) and (xB;yB;zB), so the vector AB has as coordinate : (xB−xA;yB−yA;zB−zA).When I have two vectors, I can do product vector to determine the normal surface:



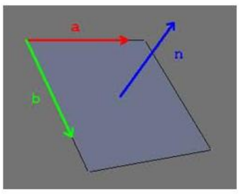


Figure 7. Product vector calculations. (Source: Julien Bollaro, GAIA, Application simulant la radiation solaire sur une installation afin d'assister le développement de la technologie Thin-Film dans le cadre du projet européen:Solar Design. 2013)

Finally, when we have the Cartesian coordinate's vector, we convert them in spherical coordinates: representing Theta the orientation and Sigma the slope.

$$\begin{cases} x &= \rho \cos\theta \cos\delta \\ y &= \rho \sin\theta \cos\delta \\ z &= \rho \sin\delta \end{cases}$$

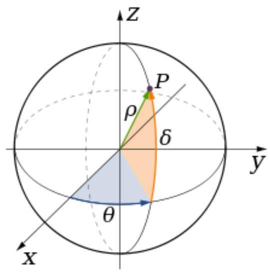


Figure 8. Conversion to spherical coordinates. (Source: Julien Bollaro, GAIA, Application simulant la radiation solaire sur une installation afin d'assister le développement de la technologie Thin-Film dans le cadre du projet européen:Solar Design. 2013)

User interface

Furthermore, SolarDesign is working with potential users on a user friendly software tool, enabling industries and designers not used to work with solar cells to work with it and supporting the designer in conceiving, planning and producing sustainable solar design products.

Next Steps

The tool, as it is a design oriented application for decentralized solar power generation, it will be demonstrated in two pilots: and eco-tablet and a "domo" structure. New technology ideas can only be considered innovative if they can be commercialized.
Within the eco-tablet, the objective is to design a tablet or laptop with a thin film as a charger meaning taking into consideration the different parameters considered in the user oriented software tool, and also test and validate if a future franchise industrial network could be implemented in Europe.

Figures 9 and 10. Eco-laptop and eco-tablet (Source: GAIA, Smart Wood Eco-design Competition. 2013).

In the other hand, SolarDesign's user oriented software tool will be tested through a pilot in a "domo" structure, which at the same time will be a pilot for creating an artificial ecosystem for defining and testing measures for the conservation of the habitat of a specific region in the

Basque Country. The domo structure will benefit from thin-film solar panels as a form of decentralized energy supply, among other renewable energy sources.

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