

Mobile Augmented Reality for Analysis of Solar Radiation on Facades

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Abstract: The recent developments of mobile devices have enhanced the possibilities of applications of Augmented Reality (AR), namely, providing data visualization *in situ*. The application prototype presented in this paper, SolAR, designed for Android tablet devices, allows the user to extract financial and energy feedback from a photovoltaic system, simulating its placement on facades. Such a solution can either serve as a support tool for technicians and researchers in the area or it can be useful for the average user, contributing to the dissemination of the use of renewable energies. SolAR provides a view of the real world augmented with graphical representations of aggregated irradiation data drawn over the facades of buildings. Starting from the previous work, this paper presents the various additions made, particularly the possibility of adding matrices of photovoltaic (PV) modules to several facades of a building and the possibility of obtaining contextual data through a web service. A user study was carried out with 32 volunteers. It revealed that the participants were able to successfully place the PV modules to acquire the best energy efficiency and that the relevance of the new functionalities implemented as well as the usability of the application was positively assessed.

1 INTRODUCTION

Augmented Reality (AR) combines, in real-time, computationally generated content with the real world captured by a camera. The portability of smartphones and tablets along with their processing capacity, the graphic characteristics of their screens and the incorporation of various sensors such as GPS, accelerometer, magnetometer, and gyroscope, among others, meet the required conditions for the development of mobile AR applications. In addition,

given the price, the diversity of features it offers and its natural interaction - only requiring the user to point the device at the area to be analysed (Ritterbusch, 2013) - its use is more and more widespread, and interest in the development of AR applications for these devices is growing.

Architecture, engineering, construction, and facility management can also benefit from AR, in tasks with high demands of information, such as model visualization, progress monitoring, defect detection, and safety inspections, typically targeting

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technicians working in the field (Rankohi, 2013). In these areas, numerical simulation techniques are often used to provide solutions to practical problems, generating large sets of data that, through mobile AR, can be visualized in the context of the physical environment, making problem analysis and information understanding more efficient (Li, 2017).

In this paper, we describe a prototype of a mobile AR system for raising public awareness of solar energy use in urban environments where, increasingly, most of the energy demand is concentrated, and for supporting the work of architects, designers, and technicians, who are major actors in the ongoing effort to reach near zero energy buildings, as established in the European Directive 2010/31/EU (Scognamiglio, 2012). For the future of sustainable cities, a significant fraction of the energy demand must be fulfilled with local, clean, and abundant sources, making solar power a great option.

The system, called SolAR, is an extension of the work reported in Carmo et al. (2014, 2016) and comprises a prototype of a mobile AR application for visualising and assessing the solar power potential of the buildings' facades, as well as the web services that provide the data relevant to the geographical position of the user. The buildings' facades offer an interesting alternative location for photovoltaic (PV) modules, complementing horizontal surfaces such as roofs, because they increase the area available for producing energy and widen the peak power production throughout the day, particularly in the winter and in the early and late hours of the day, during which solar panels in facades play an important role in satisfying electricity demand (Brito et al., 2017).

The SolAR user interface, designed for Android tablet devices, provides a view of the real world augmented with graphical representations of aggregated irradiation data drawn over the buildings' facades, showing their exposure to the sun using an appropriate colour scale. The solar radiation data was generated from numerical simulations that combine LiDAR (Light Detection And Ranging), digital surface models and climatic observations of a typical meteorological year, as explained in Redweik et al. (2013). This data is also used for another SolAR feature, which is the virtual installation of PV modules, by directly positioning the modules on the buildings' facades, from which the annual irradiation level is calculated, also considering the modules' dimensions and its efficiency.

These SolAR features have the potential for showing concerned citizens that their own buildings could supply a significant amount of their energy needs, and how much they would save on the

electricity bill if they installed PV modules in their homes. For architects, designers and technicians, the system may be of practical use when deciding the locations of PV modules on a facade, supporting a visual assessment of local shades, and providing detailed data for each square meter (represented by 1 point in the database) of facade. And, for researchers, SolAR may be useful for evaluating the accuracy of solar radiation models in the urban environment, by allowing close inspection of walls to identify outliers and model limitations, which are not easily determined in the office workstation.

The development of the mobile application to observe *in situ* an augmented reality simulation of PV modules installation on facades posed several challenges presented in this paper: 1) integrate a middleware component to get data on demand based on user location; 2) graphically represent over the buildings' facades solar radiation data to guide the user to a more efficient solution for PV modules placement; 3) correctly align the virtual elements with the facades of the buildings; 4) provide a locked view mode interaction to offer more comfort to the user; 5) support pre-defined placement of the PV modules and offer editing tools to delete, update, and save the configurations; 6) produce a report on energy and financial feedback.

The paper is organized as follows: Section I examines related works; Section II describes the SolAR system, covering the data, the mobile AR application, and the web services; in Section III we present the user evaluation carried out; and in Section IV we conclude the paper and point out future work.

2 RELATED WORKS

An advantage of AR in Data Visualization is the possibility of analysing the data in the physical context in which the data is concerned. White and Feiner (2009) called this feature situated visualization. Situated visualization using AR to support Decision Support Systems (DSS) captivates the attention and connection with the user through its natural and interactive interfaces, allows exploring data rapidly and intuitively, and promotes a faster understanding of the available options, increasing decision-making satisfaction (Marques, 2019), since the user is informed with relevant and appropriate information to base his/her choices, among multiple alternatives (Sauter, 2014).

The SiteLens system, developed by White and Feiner, to support the visualization of urban planning, uses spheres, cylinders or "smoke" to represent the

data. This last representation is used to simulate the concentration of CO. The colour and size of the symbols express the value of the variable they represent. To facilitate the interaction with the visualization, namely when the objects move as well as the visualizations associated with it, they freeze the image captured by the camera, as reported by Güven et al. (Güven, 2006). Another AR system for environmental data is HYDROSYS which uses 3D models of the urban environment to calculate occlusions (Nurminen, 2011).

In addition to scalar data visualization, AR has been also used to visualize vector quantities. Graf et al. (2010) proposed a system to this end in which they use streamlines superimposed on building models for the simulation in urban planning. Additionally, Ritterbusch et al. (2013) presented a model for vector quantities visualization in AR, wherein they have a 3D model of the buildings that allows invisible lines and surfaces to be hidden. These models are drawn on a transparent layer so that they are not visible in the final image.

Regarding PV modules installation, Mehta et al. (2020) developed an AR mobile application for Android systems, the SolAR Assistant, whose main purpose is to determine irradiation values to support the optimal placement of the panels. Resorting to ARCore SDK (Voinea, 2019) the app scans the surrounding area, detecting surfaces and determining their location and orientation. In addition, a location API service gets latitude and longitude that are used to calculate the shadows produced according to the position of the sun throughout the day. The surfaces are divided into a 2D matrix, and the intensity values are calculated at each cell. In our work, the irradiation data is determined using the SOL algorithm (Redweik, 2013).

An important issue in AR is the alignment between real objects and the corresponding graphic elements. The alignment based on the sensors of mobile devices has considerable imprecision that distorts the proper functioning of AR applications that require an alignment of the virtual elements with the real ones (Ritterbusch, 2013). An alternative approach is to use fiduciary marks. However, these marks, in addition to being less aesthetic, cannot be applied in a generalized way to all facades to visualize solar radiation data. To circumvent the employ of these marks, Honkamaa et al. (2007) considered two approaches to the alignment: a semi-automatic and an automatic. The first requires the user to manually align, by tactile interaction, the graphic representations with the real objects that correspond to them. The adjustment made is recorded and applied

in all subsequent transformations. The second approach combines the data obtained by the device's sensors with the building information described in the KML format. The solution presented in this paper combines automatic alignment with manual adjustments.

3 THE SolAR MOBILE AR SYSTEM

The development of a visualization application in AR requires, on the one hand, mechanisms to superimpose and correctly align the virtual elements to the image captured by the camera and, on the other hand, appropriate three-dimensional visualization techniques for the data under study, in this case scalar variables.

This section describes the data used and the application developed, including the tracking techniques adopted, the graphical representations chosen to visualize the data and the features of the simulator to virtually install a set of PV modules on several facades of a building.

3.1 SolAR Radiation Data and the Web Services to Provide Data on Demand

The solar radiation data was calculated using the SOL algorithm (Redweik, 2013) from LiDAR data and using 30-year time series of solar radiation observations. It covers an area belonging to the Campus of the University of Lisbon which includes nine main buildings. The algorithm was developed for urban environments taking into account the shadow effect caused on each facade by the neighbouring buildings and the amount of visible sky at a given point. This quantity, expressed as a percentage of the total sky, is called the Sky View Factor (SVF) of the point. The calculations were performed in a subsampling of the original point cloud in positions that are about 1m apart vertically and horizontally.

The application uses the data related to direct, diffuse, and global solar radiation, measured in KWh/m², as well as the number of annual shade hours. Each point is identified by a unique numeric code that identifies the building's facade to which it belongs, and its coordinates are expressed in the cartographic system ETRS89-TM06/PT (EPSG:3763). To perform the conversion, in real-time, of the coordinates obtained by the location

system (which are in geographical coordinates in the WGS84 datum) to the coordinate system, in which the data is referenced, the PROJ4 (<https://proj.org/>) cartographic projections library was used.

The data, stored in the device's internal memory, is read from a file in CSV format with values separated by “;”, with a header line - which identifies the variables in the file - and the rest with the respective values of the variables at each facades' point. The positions along the facades, where the values of the variables are known, constitute the grid that serves as a spatial reference for visualization.

This CSV file can be placed directly on the device's internal storage in a folder with a specific name or can be requested in real time, according to the user's location.

For this purpose, a middleware component was created to request data from a spatial database - where the data for the various buildings were organized and stored - according to the user's geographic position, as well as a search radius (Soares, 2016). In this way it is possible to automatically retrieve only the data around the user, avoiding the need to pre-add data to the device's internal storage. The data of the spatial database can be accessed through the PostgreSQL (<https://www.postgresql.org/>) graphical interface using the SQL console or by creating a link to PostGIS (<https://postgis.net/>) using QGIS (<https://www.qgis.org/>). If there is no connection to the internet, the application keeps data stored in the cache, but does not update it.

3.2 Graphical Representations and Tracking

Solar radiation data calculated on the buildings' facades are represented by parallelepiped glyphs aligned with the real facades and centred on the grid points. We are, therefore, facing a case of "situated data representation" according to Willett et al. (2016), that is, a data representation whose physical presentation (the virtual facades) is located close to the data's physical referents (the real facades).

The virtual objects are drawn with the OpenGL ES graphic library for Android (<https://developer.android.com/develop/ui/views/graphics/opengl/about-opengl>). The user can choose between three predefined parallelepiped sizes in the general settings of the application. In addition to the size, it is possible to select which variable is shown, the colour scale and the opacity of the virtual walls.

The PV modules, organized in matrices of modules, are also represented by thin parallelepiped glyphs superimposed on the virtual walls.

The automatic alignment of the 3D graphics with the real world is performed using the GPS coordinates - obtained through the Google Play Services API - and the values of the accelerometer, magnetometer, and gyroscope. In order for the orientation value to be more reliable, Paul Lawitzki's Sensor Fusion filter was used (Lawitzki, 2014). This filter first uses a junction of the accelerometer and magnetometer values to obtain a basic fused orientation, and then resorts to the gyroscope to compensate for the inaccuracy of these two initial sensors. The gyroscope, being accurate but decreasing its accuracy over time, is used to obtain the orientation value in short time intervals, while the accelerometer and magnetometer are used to “adjust” the information acquired by the gyroscope at relatively long periodic intervals of time (when the drift begins to make itself felt).

Given the extreme importance of a good alignment for the proper functioning of this application, we address the inaccuracies of the position and orientation sensors that still prevail using a manual alignment mechanism similar to the solution proposed by Honkamaa et al. (2007). This mechanism allows the user to rectify the positioning of the graphic elements layer by dragging them with the finger on the touch screen until the virtual walls are aligned with the buildings' walls that correspond to them. This works as a calibration process.

3.3 PV Modules

To simulate the installation of PV modules on the facades of a building, the modules are organized in matrices of modules that can be placed on the facade to which the device is pointing.

To provide more comfort to the user, the interaction with the PV modules is performed in a locked view where the user is able to place, edit, remove, save configurations, and obtain energy and financial feedback.

3.3.1 Unlocked and Locked View Modes

The SolAR application has two distinct modes of interaction: the locked view mode and the unlocked view mode. These modes vary depending on the context of the interaction.

When the application starts, by default, the unlocked view mode is on, which corresponds to the tracking and personalization mode of the application. In this mode, it is not possible to add PV modules matrices, as it is not comfortable to interact with PV modules while the user keeps the arms stretched,

pointing the device towards the facades. Therefore, the actions with PV modules are carried out in the locked view mode, with prior calibration being recommended, in the unlocked view mode, so that the experience is minimally realistic.

In the locked view mode, the image of the camera and the representations of the walls are static. However, it is possible to move the PV modules over the representation of the wall. This corresponds to a freeze feature (White, 2009), in agreement with what was proposed by Nóbrega et al. (2015) to provide more comfort to the user.

3.3.2 Placement of PV Modules Matrices

There are two possible modes in the application to place PV modules: Automatic or Manual.

In Automatic mode, a matrix of PV modules is created filling the wall in front of the user with the maximum number of PV modules that fit on that facade, both horizontally and vertically. In Manual mode, the user is asked to input the number of lines and columns of the matrix of PV modules to be inserted.

Each PV module is represented by a parallelepiped glyph in such a way that the object is in front and aligned with the wall where it was placed. These modules are organized according to rows and columns of the PV modules matrix to which they belong. By default, the centre of the object that represents the PV modules matrix is placed in the centre of the wall where the device points. The algorithm developed for this purpose is described in (Meireles, 2019).

After adding a matrix of PV modules in Manual mode, the user can move it by dragging the finger on the touchscreen until the PV modules matrix is positioned where it is intended. The displacement of the matrix is controlled to avoid exceeding the limits of the wall where it is inserted. And, as there is space on the wall for more than one matrix (unlike what happens in the Automatic mode), the user can continue to add more PV modules' matrices, moving them to the desired locations.

It is possible to add matrices of modules in more than one wall if the user faces them when adding a new matrix. For this, the matrices of PV modules are stored together with the wall's identifier where they belong.

3.3.3 Selecting a PV Module Matrix

After adding the desired PV modules matrices on the virtual walls, the user can select one of the matrices already added by simply clicking with the finger on

the matrix he/she wants to choose. When a matrix of PV modules is selected, it has a red outline that highlights it at the interface to stand out and, at the same time, not be confused with colors already present in the augmented reality layer, due to the chosen color scale. Figure 1 shows the red outline of a matrix that is selected, highlighting it.

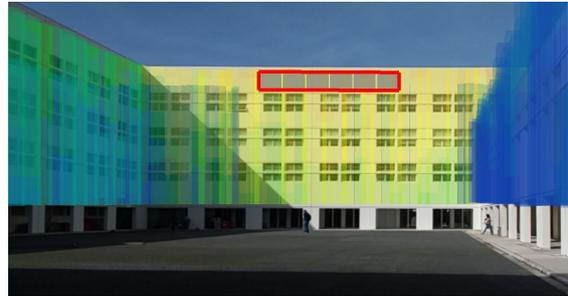


Figure 1: Red outline in a matrix selected from the SolAR application.

The user can simulate the placement of matrices of PV modules encompassing more than one building facade and, if focused on a given area of the building, the user can move all the matrices of PV modules already placed on the building's facades, as long as the screen shows the entire zone.

3.3.4 Editing, Deleting and Saving Options

Another option of the application allows the addition or removal of modules, from a selected matrix, by directly touching on the modules to be added or removed. When the user removes a module from a matrix, the place where the module was located shows a dark gray outline.

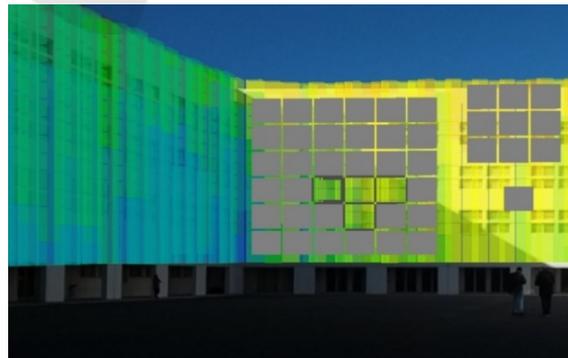


Figure 2: Part of a screenshot of the SolAR application that shows deleted PV modules in a matrix of PV modules.

Figure 2 shows an example of three matrices of PV modules where the one on the left has four PV modules eliminated - represented by the gray

outlines. As this option is reversible, if the user clicks on the location where the modules were located, these modules reappear on the screen - and their contours are eliminated.

In turn, the user may delete the selected matrix of PV modules or delete all added PV modules.

It is also possible to view and edit a PV modules matrices configuration saved in a previous session, since at any time the user can save the configuration he/she is working on - the information necessary for that purpose is stored in the device's memory so that it can be loaded whenever the application starts.

3.3.5 Energy and Financial Feedback

The Energy and Financial Feedback option of the application displays the values for the following variables concerning the configuration of matrices of PV modules existing on the interface at the time this option is selected:

- Number of PV modules;
- Area covered;
- Annual energy produced;
- Investment needed;
- Annual corresponding electric bill;
- Payback period.

These values are fundamental to the choice of the PV system desired by the user.

To calculate the energy obtained by a configuration of PV modules matrices, it is necessary, for each PV module of each matrix added, to carry out the following procedure:

- 1) Calculate the point on the wall (that is, the point that makes up the grid that forms the wall) closest to each of the vertices of the PV module;
- 2) Calculate the value of the Global Radiation variable at each of the points calculated in 1;
- 3) Save the minimum value of the variable by comparing the four values calculated in 2;
- 4) Calculate the energy with the value returned in 3 considering the following formula, valid for PV modules integrated into facades (BIPV):

$$Electricity [kWh /year] = \frac{PVCE \times PR \times Radiation}{1000}$$

where PVCE is the photovoltaic conversion efficiency, with value 0.08, and PR is the performance ratio, with value 0.8. Values for PVCE and PR are discussed in Pillai et al. (2022), and in Rodriguez-Martinez and Rodriguez-Monroy (2021), respectively;

- 5) Add the value returned in step 4 for each of the PV modules of the existing matrices;

- 6) Calculate the resulting value of energy considering the units selected in the user interface (Wh, KWh, MWh).

The financial payback of the PV system is defined as the financial return time and can be estimated considering that the user avoids buying electricity produced by the PV modules from the electrical network. The interface shows, not only the payback amount, but also the annual electric bill corresponding to the energy produced by the PV system. In the interface it is possible to change the default values of the average cost and the investment per area of the PV system. Figure 3 shows an example of possible financial and energy feedback for a given configuration of PV modules.

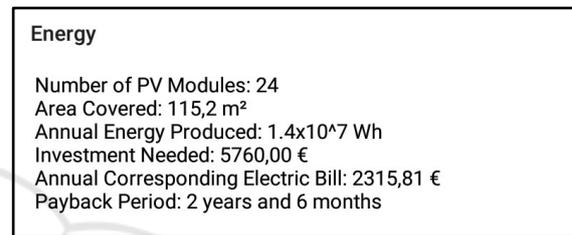


Figure 3: Dialog presenting the financial and energetic feedback of a configuration of 24 PV modules covering an area of 115.2m².

3.3.6 Energy User Interface

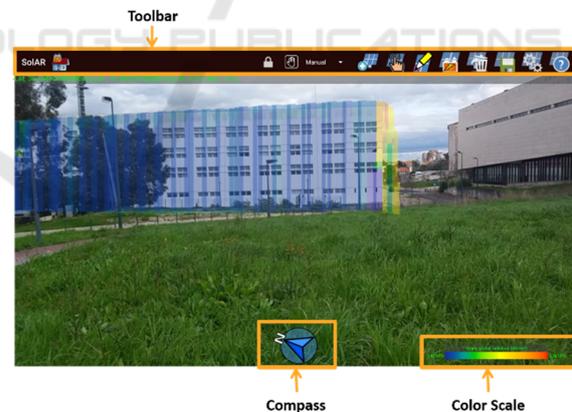


Figure 4: Screenshot of the SolAR application identifying its main components.

Figure 4 shows the overall appearance of the SolAR application. The various items of the user interface were positioned so as not to overlap with the buildings that are shown in the drawing area. At the top of the screen is the toolbar with buttons that give access to the application's features such as locking/unlocking the view, the addition of PV modules and the financial and energy feedback of the

module configuration placed. Immediately below this bar, there is a line showing the GPS coordinates (latitude, longitude, and altitude). At the bottom of the screen are the compass and the color scale.

The Unlock view Toolbar

As actions with PV modules are carried out in the locked view mode, in the unlocked view mode the toolbar has few buttons (Figure 5).



Figure 5: Screenshot of the buttons present in the Toolbar in the unlocked view mode.

Numbering the five elements, from left to right, the caption of the corresponding functionalities is as follows:

- 1) Alerts the user of the need to perform the calibration and then lock the view to insert PV modules;
- 2) Switches between locked and unlocked view;
- 3) Starts the manual calibration to align the visual walls with the “real” walls that appear in the camera preview;
- 4) General customizations of the application, namely the change of the size of the walls’ glyphs, the color scale, the units presented in the color scale and the variable to be visualized;
- 5) Help option.

The Locked view Toolbar

The locked view toolbar contains the buttons to perform the operations with the PV modules (Figure 6). Numbering the ten elements, from left to right, the caption of the corresponding functionalities is as follows:

- 1) Return to the unlocked view mode;
- 2) Select placing PV modules mode: Manual or Automatic;
- 3) Add matrices of PV modules;
- 4) Select matrices of PV modules already placed to reposition them;
- 5) Edit a selected matrix, removing or reinserting PV modules from it;
- 6) Return energy and financial feedback of the current configuration of PV modules;
- 7) Delete the selected matrix or all added matrices;
- 8) Save the current configuration of PV modules matrices;
- 9) Set PV modules parameters;
- 10) Help options.



Figure 6: Part of the Toolbar of the locked view mode of the SolAR application. The Button 2 shows the Manual mode chosen.

4 USER TESTS

The developed application was evaluated by a group of volunteers, selected to cover various age groups and specialties, through interviews. This step made it possible to assess the application’s functionalities and collect information on users’ satisfaction as well as criticisms and suggestions that could be used in the future to enrich the SolAR application.

4.1 Participants

The user tests included 32 volunteers from different age groups: 11 (34%) belonging to the age group 18-25, 9 (28%) to 26-35, 5 (16%) to 36-45, 3 (9 %) to 46-55 and 4 (13%) to 56-65.

Regarding the study area, we can separate the participants into three different categories: Informatics (12 participants), Specialists (8 participants) and Others (12 participants). The Specialists group included users of GIS (Geographic Information Systems), Geospatial Engineering and Energy, since these three areas are directly related to the data used by the application, therefore there is a more specialized opinion by these users. The “Others” group joined the users from dispersed areas who did not exist in sufficient number to be grouped more finely. Among them are people from Arts, Economics and Information Management. The opinion of the Experts was particularly important for the evaluation of the current version of the application, given the new features in the locked view mode. However, it was important to test the SolAR application with an audience from different areas since it is not intended to limit its use to specialists. This application must be able to be used by different users with different experiences.

Considering their familiarity with smartphones or tablets, most users were comfortable with the use of these devices. On a scale of 1 to 5, with 1 being “Not Familiar” and 5 “Very Familiar”, 21 participants (66%) rated themselves as “Very Familiar” (Level 5), 6 (19%) with a Level 4 familiarity, 3 (9%) with a Level 3 familiarity, 1 (3%) with a Level 2 and 1 (3%) as “Nothing Familiar” (Level 1).

4.2 Apparatus

User tests were performed on a Samsung Galaxy Tab A tablet with the Android operating system. This device has 1920 x 1200 pixels of resolution, a screen size of 26.7 cm (10.5 inches) and an Octa Core Processor of 1.8 GHz. The device also integrates two cameras (front and rear), an accelerometer, gyroscope, magnetometer, and GPS.

4.3 Procedure

User tests were carried out in the courtyard of FCUL building C6. This building was chosen because it has vast wall areas available for placing matrices of PV modules. At the beginning of each test, a brief introduction was made about the SolAR application and the evaluation that would be carried out. The test was divided into four distinct parts: first, the users answered a demographic questionnaire; then, all elements of the SolAR application interface were presented; afterwards, the user was asked to perform a set of tasks; and, finally, the user answered some open-ended questions - whose main purpose was to identify possible improvements and inconsistencies in the SolAR application -, a 5-point Likert scale questionnaire to assess the relevance of the added features and a System Usability Scale (SUS) test (Brooke, 1996).

The interviewer allowed users to interact with the application before the tasks started, but most wanted to move directly to the tasks, saying they did not feel the need for initial "training".

4.4 Tasks

The users were asked to complete four tasks. The tasks were designed to give some freedom of interaction to the user, allowing the interviewer to observe the solution adopted by the user to accomplish the task. The interviewer observed the way the participant interacted with the application, pointing out hesitations, doubts, notes, and mistakes made.

In the first task, the user was asked to add PV modules, with horizontal orientation and larger dimension, using the Automatic mode, to the wall in front of him/her; the user was then asked to select the application's financial and energy feedback option.

In the second task, the interviewer emphasized the high payback period of the solution obtained in the previous task, asking the user to improve the solution. In this task, it was intended to verify if the user would use the Edit option to remove the PV modules - from

the previously added matrix - that were more in the shade, or if the user would opt to delete the PV module matrix added in the first task, adding later a new matrix in the Manual mode in an area with higher solar irradiation. In the end, the user was asked to obtain financial and energy feedback of the new solution.

In the third task, the user was asked to place 5 PV modules to obtain a higher profit. In this task, it was intended to observe the mode of placement of the PV modules chosen by the user, his/her management of the addition of the five modules, as well as to observe whether the participant positioned the PV modules in the zones corresponding to the highest energy efficiency. In the end, the user was asked to obtain financial and energy feedback of the solution, and the interviewer pointed out the values of the annual energy produced and the payback period of the solution.

In the fourth task, the user was asked to save the final configuration of the five PV modules added in the third task.

4.5 Results

Regarding the execution of the tasks, the interviewer observed that, in the first task, where the user was asked to use the Automatic mode to place PV modules with a specific orientation and dimension, 50% of users first added the matrix and only then sought to change its characteristics, which meant adding the PV modules again.

In the second task, the user was asked to improve the solution of the first task to increase its performance. 26 participants (81%) chose to Edit the existent solution (that is, removed the modules of the matrix that were in areas with less solar irradiation instead of eliminating it and creating a new solution, using the Manual placement mode of PV module matrices.

In the third task, when the user was asked to place 5 PV modules having in mind to obtain the greatest profit, all users chose the Manual mode, with 13 participants (41%) opting for a line of PV modules on the top of the wall (where there is, in fact, a higher annual solar radiation value). Other users added matrices of PV modules with more than one row and then removed the excess modules. There were also those who choose to add two matrices of PV modules at the top of the facade. The energy feedback resulting from the solution of this task was $3,4 \times 10^6$ Wh for 63% of the participants and $3,3 \times 10^6$ Wh for 25% of the participants. Users who deviated from the values of greater solar radiation did so for aesthetic reasons,

not because they misinterpreted the representation used, namely the color scale. Figure 7 shows the configuration of PV modules most chosen to accomplish this task: a line of 5 PV modules at the top of the facade.



Figure 7: Main configuration of photovoltaic modules chosen to perform the third task.

In the fourth task, the user was asked to save the current configuration of the matrices of PV modules. All users accomplished the task without difficulty.

Although some users did not use the most direct way to carry out the various tasks, in no situation did they need help to accomplish them.

In terms of the answers to the open-ended questionnaire, the participants suggested new functionalities and improvements in user interaction. The new features suggested were:

- Save different configurations of PV modules, including their financial and energy feedback values;
- Besides the annual mean global radiation, provide also global radiation data for each month of the year;
- Enable the addition of different types of PV modules such as the semi-transparent ones used for windows;
- Provide an optimized solution for placing matrices of PV modules, given certain input values, for example, the existing budget;
- Make it possible to choose the dimensions and orientation of the matrices of PV modules, through the presentation of the existing interface for configuring them, after selecting the add operation;
- Graphical presentation of the financial and energy feedback values, in order to make these values more intelligible;
- Enable the recognition of the physical windows on the facades;
- Graphically display the different dimensions of the PV modules, instead of just referring to their length, width and depth dimensions;

- Change the icon of energy and financial feedback to emphasize and remember that it also has a financial aspect;

- Integrating a fake GPS application into SolAR so that the application can solve the problem of existing location uncertainty.

Regarding user interaction with PV modules the most frequent suggestions were:

- Allow a more direct movement of the PV modules, by simply clicking on the desired final position for them, instead of having to accomplish this task by continuously dragging the PV modules to the location;
- Enable the selection of several matrices of PV modules to delete.
- Delete more than one PV module at once by dragging your finger over them;
- Allow the addition of PV modules to a wall using only the touch of the user’s finger on it, instead of having to select the “Add” button;
- Improve the application drag recognition;
- Add the possibility to zoom in on the matrices of added PV modules, to facilitate their finer movement.

Concerning the relevance of the included operations to deal with the PV modules, the users answered a questionnaire with 7 items with answers on a 5-point Likert scale: 1 corresponding to “Not relevant” and 5 to “Very relevant”.

Table 1 shows the value of the mean, mode and standard deviation, as well as the maximum and minimum, of the answers for each of the features assessed. The Automatic mode was the one that generated the most antagonistic results, nevertheless, with a mode of 5. On average, none of the features was rated below 4 (Figure 8).

Table 1: Minimum, maximum, average, mode, and standard deviation values corresponding to the relevance assessment of each of the evaluated features.

Funcionalities	Min	Max	Mean	Mode	SD
Automatic	1	5	4.2	5	1.10
Manual	4	5	4.9	5	0.30
Select	4	5	4.8	5	0.40
Edit	4	5	4.9	5	0.30
Delete	3	5	4.7	5	0.60
Save	4	5	4.9	5	0.30
Help	3	5	4.8	5	0.57

The usability of an AR application is extremely important as 25 out of 90 survey respondents commented that the usability of these applications is generally bad, poor-looking, or contains a lack of feedback (Kim, 2018).

The SUS test allows the evaluation of the usability of an application, as well as the user's satisfaction with it (Brooke, 1996). This test consists of a 10-question questionnaire in which the answers are given on a 5-point Likert scale 1 equivalent to "Totally Disagree" and 5 to "Totally Agree". For the tests, the Portuguese version of SUS was used (Martins, 2015). The SUS score ranges from 0 to 100; the SOLAR application got 88.

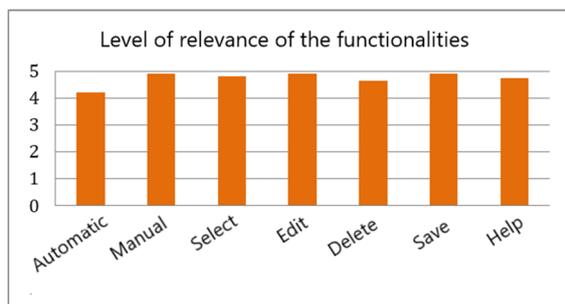


Figure 8: Graph representing the mean of the relevance level, from 1 to 5, of the functionalities implemented, as assessed by tests with the user.

4.6 Discussion

The tasks proposed in the user study allowed the participants to perform all the operations available to virtually install PV modules on facades.

The participants accomplished successfully all the tasks proposed. When asked, in task 3, to obtain the best performance with a given number of modules, all participants used the Manual mode, and all placed the PV modules in areas with a higher value of solar irradiation. Moreover, in task 2, given an initial solution that covered all the facade, the users were able to identify which PV modules should be removed to improve the solution. This means that all the participants understood the representation of solar radiation through coloured glyphs, realized how and where to place the PV modules to obtain the best energy efficiency, and used the operation to get the energy and financial feedback of the conceived configuration to assess their choice.

The need to update PV modules settings was not so easy to understand, as 50% of the users did not adjust the dimension and orientation of the modules before adding them in task 1. As suggested by the users, it would be easier to modify the settings after choosing to add a PV modules matrix, not requiring the user to previously access the definitions of the PV modules.

The SUS test, to measure the usability of the application, obtained a score of 88, which is an excellent result according to Bangor et al. (2009).

Regarding each of the operations to place the PV modules, although the automatic placement was not appreciated by all the users, the assessments of the operations obtained high scores with an average above 4 and the mode equals 5, in a scale 1 to 5.

5 CONCLUSIONS AND FUTURE WORK

The SOLAR application evolved from a previous version with the addition of functionalities to virtually place matrices of PV modules in several facades of a building and the presentation of information about energy and financial feedback, as well as the inclusion of a middleware component that allows obtaining data on demand, according to the user's location. This middleware component also manages data previously obtained and stored locally, avoiding repeating their download.

The 32 volunteers that participated in the user study to assess the application accomplished successfully all the tasks proposed. They scored the functionalities to deal with PV modules above 4, on average, on a scale of 1 to 5, and their answers to the SUS test revealed an excellent level of usability.

Future developments of the application will take into account, besides the improvement of the dragging interaction, the access to more data, allowing the visualization of solar irradiation monthly; the addition of new functionalities, such as the installation of different kinds of PV modules for windows and walls; the managing/storing of several PV modules placement solutions, tested by the user, with their respective energy and financial feedback, and the creation of a recommendation approach to guide the user to optimal configurations.

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