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RESEARCH ARTICLES

OPTIMAL DESIGN OF HOUSING ATTICS WITH INTEGRATED SOLAR COLLECTORS

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ABSTRACT

In order to reduce the increasing energy consumption for the domestic demands of existing single-family housing and take advantage of frequent building enlargements, this paper presents a methodology and supporting software tool for determining the optimal design configuration of an attic with integrated solar collectors. The analysis procedure is based on parametric modeling, energy simulation and the use of evolutionary algorithms for finding optimal designs. It has been implemented as a Web-platform for public use that provides users with a proposal of an attic shape with maximum solar energy collection, maximum living space and minimum construction envelope for each house according its size and orientation. The attic integrates PV, thermal and hybrid solar panels on one side of the roof. This paper describes the methodology and software design, assessment of the Web-platform usage and case-studies to verify its behavior. In a matter of minutes, the Web-platform enables users to select a specific attic design for each house that has integrated solar collectors that can produce energy to cover almost 100% of domestic energy consumption. The attics designed provide a nearly 30% increase in living space through the extension of one to four rooms, and the construction cost of the envelope is similar to that of a standard housing extension.

KEYWORDS

web platform for attic design, integrated solar collectors, attic spaces, energy consumption of single family housing, parametric modeling, energy simulation, optimal designs

1. INTRODUCTION

The design of buildings must satisfy diverse requirements and usually there is a lack of support to relate those different conditions (Brunsgaard, et al., 2014). One of the most compelling challenges currently is to reduce the energy dependence of houses, as they are responsible for a great part of fossil fuel consumption and greenhouse gas emissions, which lead to poor environmental

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conditions, particularly in developing countries (Carassus, 2013). Single-family houses, the most common dwelling typology in these nations, usually have wide roofs that receive a large amount of solar radiation, which could be used for domestic needs through thermal and/or photovoltaic panels (O'Brien, 2009). For example, in the city of Concepción, Chile, single-family dwellings have an average annual energy consumption of close to 13,500 kWh, which is used for electricity, hot water and space heating, with a mean of approximately 75 m^2 of roof surface receiving solar energy that can potentially be transformed into around 110,000 kWh per year (Zalamea and Garcia, 2014). Nevertheless, this amount varies greatly depending on the slope and azimuth of the roof, thereby requiring the careful installation of solar collector systems (Gajbert, 2008). As a matter of fact, in Chile several government programs exist that promote the integration of active solar systems into houses, although their implementation is still partial mainly due to the lack of technical knowledge and initial investment (O2B, 2013). The expenditure for the installation of solar panels in dwellings could be mitigated by combining it with building enlargements that are eligible to receive mortgage financing. In addition, housing growth is a common need in this dwelling type (González, *et al.*, 2009). However, the design of the extensions and the installation of solar panels with proper slope, are usually addressed independently.

For these reasons, this paper proposes the integrated development of residential attics with solar panels on the roof for existing single-family houses in the city of Concepción, Chile (Figure 1), which aims to reduce fossil energy consumption while extending houses through low-interest loans. This requires the definition of an upper volume for each house, basically consisting of a triangular prism that grants on its roof the most adequate sun energy collection to supply domestic demand and generate adequate living space at an affordable building cost. The isolated analysis of each of these requirements may lead to incompatible results. Increasing the effectiveness of the panels to maximize solar energy collection may require an extensive surface area disposed to the solar trajectory, thus resulting in a design with little living space and/or a high cost of execution; or conversely, large enclosures may produce outdoor surfaces with an orientation that receives low radiation, hence leading to the low operational efficiency of the integrated panels. This is common in existing housing extensions, in which panels are installed with a different slope than the roof, and therefore with low performance and unsatisfactory aesthetic appearance. This is partly due to the technical difficulty for proper estimation of attic spaces, particularly when adding photovoltaic systems, as noted by (Fallhi et al., 2013; Fontaninin et al., 2016). Some initiatives have been carried out to develop more accurate attic simulation tools, e.g. (New et al., 2016; Garg et al., 2016), highlighting in general a good performance of the energy simulation program EnergyPlus (Crawley, et al., 2004).

The simultaneous computational analysis of several factors has increasingly been applied as a strategy of "design optimization" to determine more effective shapes (Marler and Arora, 2004; Machairas, *et al.*, 2014). Through the generation of different design alternatives, and then the evaluation of each with specific values in a "fitness function," various quantifiable and possibly conflicting objectives are linked (e.g. greater living space vs. lower cost). Computational procedures evaluating all possible alternatives (called "brute force") guarantee, at least theoretically, prompt the creation of the design that best reconciles the objectives (Conn, *et al.*, 2009). However, these procedures are usually very costly in terms of computer processing time. To decrease search times, it is possible to set restrictions that reduce the number of alternative designs to be evaluated. Another strategy is to create a smarter search by taking into account the results obtained with the previously generated designs, in order to "guide" the search process.

FIGURE 1. Conceptual images of solar attics in existing houses.

The procedures that use this strategy are known as heuristic algorithms, which despite their strategy do not guarantee the best solution, but make it possible to find alternatives quickly that significantly fulfill the objectives (Mahdavi and Guterkin, 2004). Among these, evolutionary algorithms are a widely used approach based on the natural mechanisms of evolutionary selection (Goldberg and Holland, 1988; Deb, 2001). These have been successfully used to address building design (Machairas, *et al.*, 2014). They can be classified as single-objective optimization, which seek to improve one criterion, e.g. minimize the cost of construction; and multi-objective optimization, which seek to improve several criteria simultaneously, e.g. energy cost and thermal discomfort of the occupants. Examples of the latter are described by De la Barrera (2010) and Betancourt (2012), where different geometric configurations or building materials are analyzed to quantify their performance. It is important to note that possibly there is no solution that simultaneously obtains the best values for each objective in a multi-objective, optimization problem (i.e. conflicting objectives). In these cases, the optimization process identifies a set of non-dominated solutions, called the "Pareto frontier." In non-dominated solutions, none of the objective functions can be improved without degrading some other objective (Attia, *et al.*, 2013).

Various experiences of analysis with genetic algorithms have sought shapes of buildings that minimize energy consumption and environmental impact (Griego, *et al.*, 2012; Ihm and Krarti, 2012; Bichiou and Krarti, 2011). In some cases, the life cycle costs have been used to integrate expenditure on operational energy requirements relating to investments in refurbishment and possible reductions in consumption based on thermal simulations (Murray, *et al.*, 2014; Magnier and Haghighat 2010, respectively). Some implementations, such as GenOpt, developed by the Lawrence Berkeley National Laboratory (Coffey, *et al.*, 2010), or BEopt, created by the National Renewable Energy Laboratory (Anderson and Christensen, 2006), consider linear numerical changes, applied dimensions of materials or values for cost optimization. However, these experiences have not examined solar collection in relation to different orientations or configurations, nor proposals for public dissemination of alternatives, as outlined in this work focused on habitable attics.

This article first presents the background of the problem, the objective of the research and similar experiences, and then describes the methodology of programming and software design, including a Web-platform for public dissemination. After that, surveys on usability, web use and some case studies are discussed, and the conclusions of the experience are given.

Solar attics are proposed for houses in the Concepción metropolitan area, located in southern Chile, at 36° 46' South latitude and 73° 03' longitude, on the coast of the Pacific Ocean. It is the second-largest urban area of the country and home to more than one million people. It has a temperate, seasonal, humid climate, with an average winter temperature of 9 °C and summer temperature of 17 °C, 70% relative humidity and an annual rainfall close to 1,110 mm. The monthly solar radiation obtained in a horizontal plane in Concepción shows a clear decline during the winter months, with an annual gross solar radiation of 1,675 kWh/m^2. There are approximately 250,000 existing dwellings. Similar to other Latin American cities, residential areas are comprised of detached or semi-detached, one or two-story, single-family homes made of reinforced masonry, with wood framing in the second floor (Salinas and Perez, 2011). The houses are orthogonal rectangular in shape, varying from 4 to 20 meters per side, with minor lateral extensions, and low sloping roofs.

2. PROPOSED METHODOLOGY

A methodology to determine the optimal configurations of attics with added solar collectors for integration into existing buildings is described in this section. The methodology involves the analysis of the energy demand of the inhabitants of the existing building, the electric potential and thermal energy production from added solar panels on the roof and the available habitable space. For this purpose, the methodology includes 5 main steps, which are described in Section 2.1. Section 2.2 presents the software developed to implement this methodology, and Section 2.3 details the Web-platform created to facilitate the use of this software by the general public.

2.1 Optimal attic design

Step 1: Energy demand estimation. An estimation of the annual energy requirement of the existing dwelling, to which the attic will be added, is defined using the main dimensions of the building layout and number of stories. These values indicate the built surface, and according to the regular domestic consumption, the corresponding energy demands are estimated, which is influenced by the number of solar panels to be integrated into the attic roof. A parametric relationship is used in this step because it facilitates the testing of diverse houses with similar typology and location.

> *Step 2: Attic modeling.* A parametric geometric model of the attic to be built is developed. This model is supposed to be built on top of the existing housing. It should be noted that the development of a parametric design-based model is mandatory in this step (Woodbury, 2010), in order to quickly test alternative attic designs during the optimization procedure.

Step 3: Simulation setup. The additional data required for simulations of energy demand and generation are input in this step. The climatic conditions of the geographic location are entered, as well as the solar panels' configuration, e.g. the efficiency of the solar panels under study (PV, Thermal and Hybrid).

Step 4: Simulation-based optimization. In this step, an optimization process is performed. It is guided by an iterative process of generating a new attic model and simulating the energy production of the solar panels integrated into the attic. This procedure results in the generation of key indicators from the simulation that are measured according to the adaptation to the existing housing function: an estimation of the available indoor space, the obtained energy and building materials required.

There are three objectives during this optimization step: i) to maximize the living area of the attic, ii) to maximize the energy contribution from solar panels, and iii) to minimize the materials required for building the attic. A simple fitness function incorporating these three objectives was defined, as shown in eq. 1:

$$\frac{LAR \times EP}{BM} \qquad \text{(eq. 1)}$$

where,

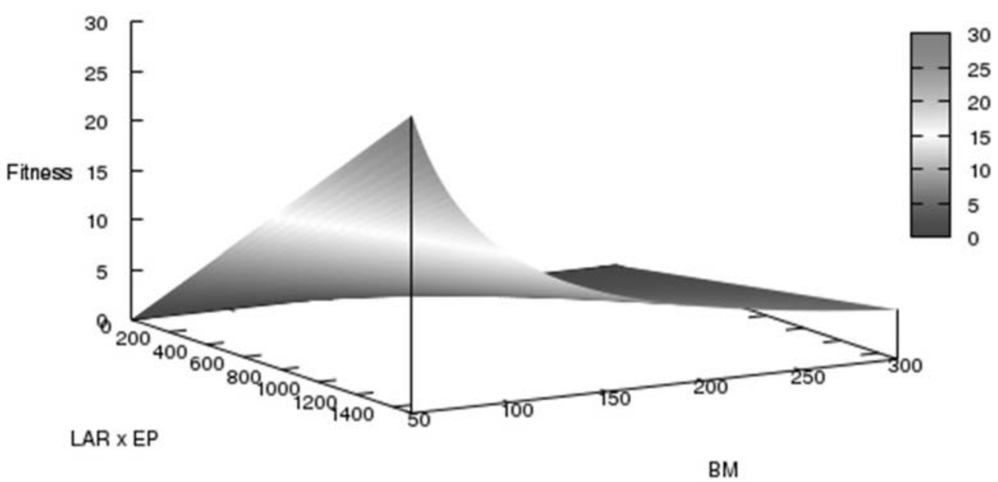
LAR denotes the *Living Area Ratio*, that is $LAR = \frac{\text{attic's living area}\,[m^2]}{\text{attic's total area}\,[m^2]}$

EP denotes the *Energy Production* of the solar panels, in kWh

BM denotes *Building Materials*, which is measured as linear meters of roof pieces required for building the attic, in m.

Figure 2 shows a schematic view of the surface generated by this function. It may be observed that the fitness improves as *LAR* and *EP* increase and the fitness worsens as *BM* increases.

FIGURE 2. Schematic graph of the fitness function.



This step requires a dynamic simulation procedure as well as an optimization engine. The simulation must be capable of calculating: the energy production according to the specified model of the attic, climatic condition information, and solar panel configurations. The optimization engine must be able to generate different possible attic designs and evaluate the geometric conditions of space and materials, considering a reduced set of parameters. The specific engines used are detailed in Section 3.2.

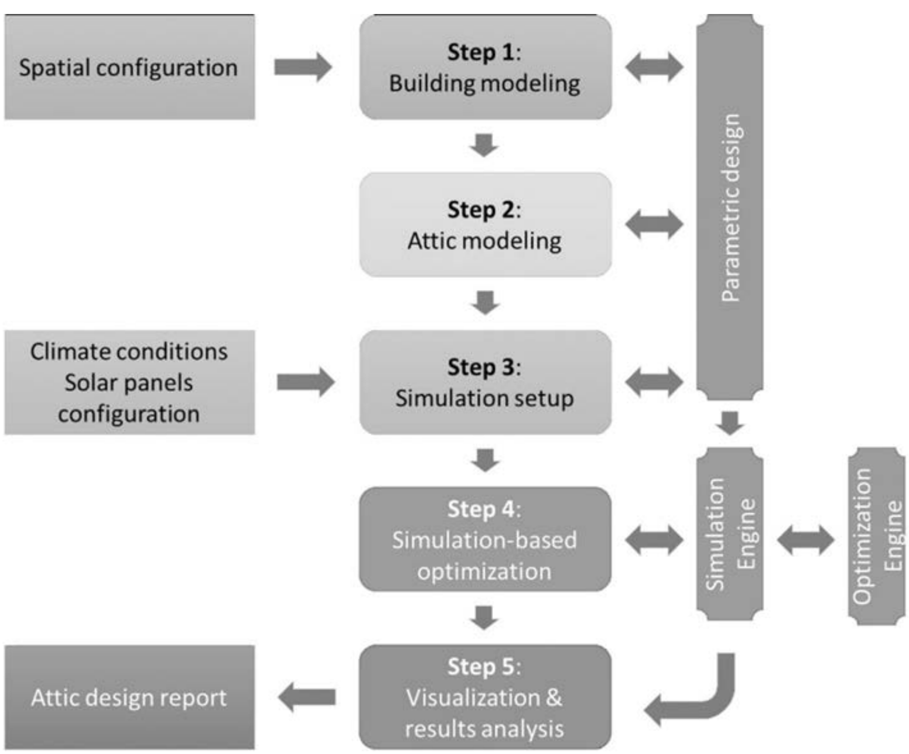
Step 5: Visualization and analysis of results. Once the optimization process is finished, a report is produced with the attic designs that give the best values for the key indicators in the fitness function.

Figure 3 summarizes the steps described previously.

2.2 Computer implementation of methodology

To implement the methodology proposed in the previous section, a specific software platform was developed. This platform is structured around the main steps of the methodology and includes three main components: i) an engine for the dynamic simulation of energy generation and demand, ii) a parametric design library for the development and manipulation of parametric models, and iii) an optimization engine to improve the design considering the objectives included in eq. (1).

FIGURE 3. Workflow of the proposed optimal attic design methodology.



EnergyPlus[4] was selected for computing dynamic simulations due to its widespread usage as an energy simulation engine (Crawley, *et al.*, 2004). This engine was used for computing dynamic simulations. The Python language (Zelle, 2010) was employed to develop the parametric design. In particular, the EPPY library[5] was used, due to the easy programmatic manipulation of IDF files (EnergyPlus Input File) it provides. For the optimization step, a genetic algorithm (Goldberg and Holland, 1988) was implemented. This decision was based on the advantages of this type of optimization algorithm: i) the ease of generating different parameter values such as roof slope angles, and number and type of added solar panels. This is due to its ability to produce different individual representations of distinct parameter values. ii) The positive results achieved in optimization tasks from different domains, including the optimization of building design (Machairas, *et al.*, 2014). And iii) the ability to handle complex fitness functions.

The domestic requirements of the house (step 1) are estimated by regular occupation and built surface, as calculated by the main dimensions of building layout (width and length) and number of stories. These values are used as input into an EPPY script that estimates energy demand based on statistics, records of expenditures, and dynamic simulation carried out for this dwelling typology in the area (Garcia, *et al.*, 2016).

Attic modeling (step 2) is performed using an EPPY script, taking as input the house model built in the previous step. This corresponds to a parametric attic model adaptable to diverse house layouts (i.e. different lengths and widths), as well as diverse roof slope angles.

To set up the simulation (step 3), weather data files corresponding to the target geographic zone were used. These data were arranged by the World Meteorological Organization and are published at the EnergyPlus Web site[6]. Also, the specific data of the solar panels to be added to the attic is incorporated. The relationship of the simulation and the parametric modeling is also established through the computer language (Miller, *et al.*, 2013).

For the optimization process (step 4), a simple genetic algorithm is used. The implemented algorithm use the classic operators of "roulette wheel" selection of individuals for reproduction (probabilistic selection proportional to the fitness of the individual), and the crossover and mutation of genes (where the genes represent the values of parameters). The initial population of individuals is formed by assigning random values to each individual parameter representing different attic configurations that fits the housing model generated in step 1. The fitness of each individual is computed by generating a concrete attic model with the corresponding parameter values, and running a simulation in EnergyPlus with the house with the attic model. Afterwards, the energy production computed by EnergyPlus, including the living area ratio and the building materials obtained from the EPPY scripts, are used for computing the fitness function. Using this fitness value and the above-mentioned genetic operators, new generations of individuals are produced, which iteratively approximate to better fitness values, until the maximum number of generations is reached. It should be pointed out that by using the genetic algorithm it is possible to obtain an optimized and attic model in a fraction of the time required to analyze all possible cases (brute force approach). In fact, the analysis of just the slope angles of both roof sides, with a step of 1° would require $90 \times 90 = 8100$ evaluations[7]. We restricted the algorithms to a maximum of 500 evaluations, obtaining a good tradeoff between response time and quality of results (Tuhus-Dubrow and Krarti, 2009).

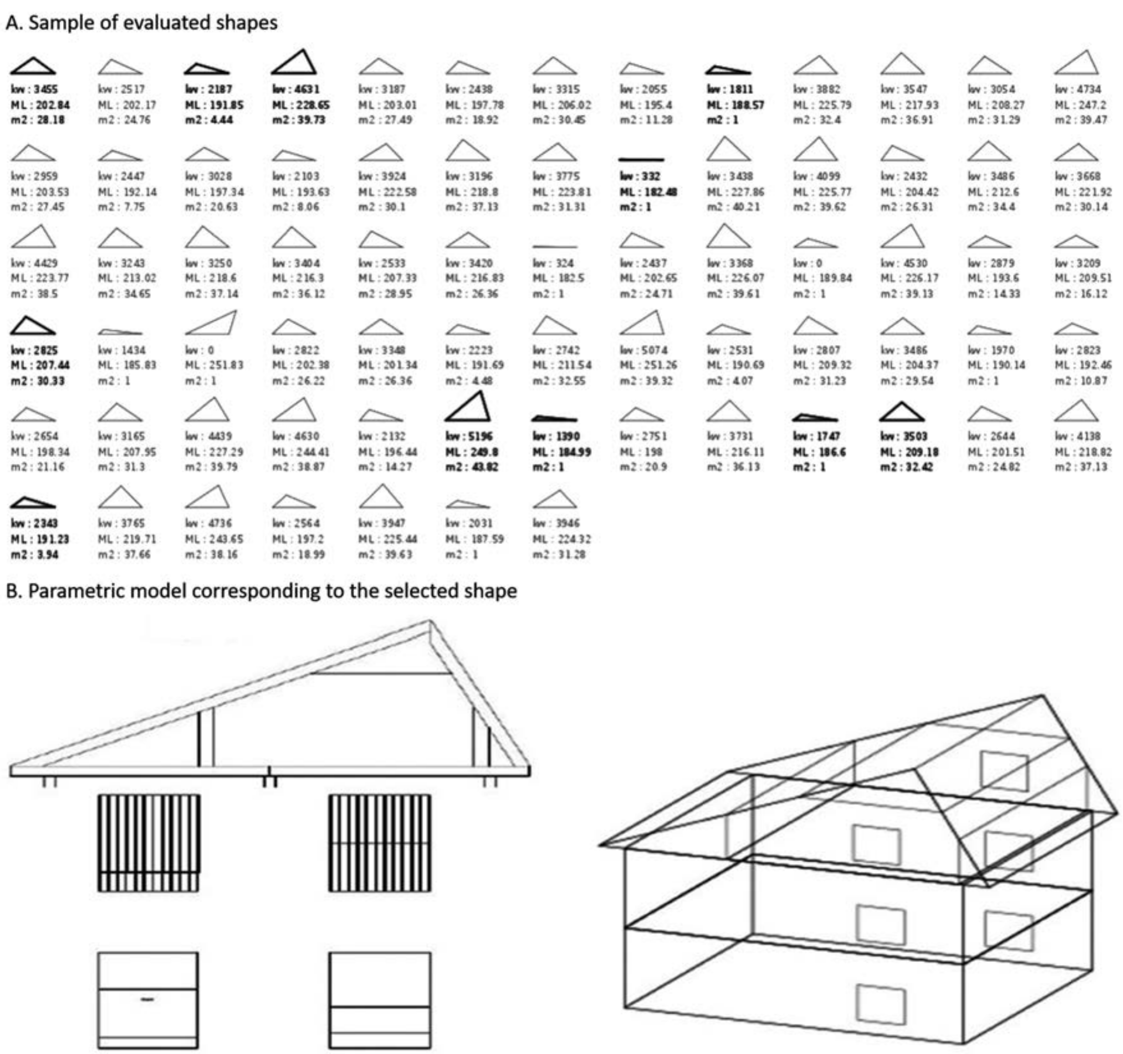
4. EnergyPlus energy simulation software, available at: https://energyplus.net/
5. EPPY Python-based scripting language for EnergyPlus IDF files, available at: https://github.com/santoshphilip/eppy
6. EnergyPlus weather data, available at: https://energyplus.net/weather
7. Actually, this number would be lower since not all combinations are feasible, but anyway it requires several thousand evaluations.

Finally, to visualize and analyze the results of the optimization process (step 5), the attic models corresponding to the last generation of individuals (i.e. the individuals with best fitness) are shown in a report, including a graphical view of the models (Figure 4).

2.3 Development of the online platform for solar attic proposal

In order to promote the building of solar attics for dwellings in the area, a website (http://mansardasolar.ubiobio.cl/) with general information and the ability to generate suggested designs using the proposed methodology was setup. As the analysis involves calculation through a dynamic simulation engine, which takes more time than the typical user interaction with websites (in the order of minutes), the Web implementation uses pre-calculated values. It might be noted that, according to (Nielsen, 1993), a typical user will leave a Website after ten seconds of waiting. Thus, a database of attic designs was pre-computed using dwellings designs in Concepción, with widths and lengths in the range of 5–15m (in 1m increments). Although this approach limits the analysis of specific designs, sacrificing high precision of the results, it

FIGURE 4. Evaluation of shapes and generation of a parametric model.



covers most existing dwellings in Concepción and the 1m increments enable soft approximation from the actual dimensions of real houses. Regarding solar orientation, 8 different layouts were considered (45° increments), due to the diversity of placements of real dwellings. These alternatives involve a repertory of 968 cases (11 sizes of width x 11 sizes of length, in 8 possible orientations). This way, a minimum response time is achieved with a reduced loss in precision of results.

Using this set of alternatives, suggested designs for each attic design were computed using the proposed methodology. From the set of design results obtained, the procedure suggested optimal slopes for the roof side oriented towards the solar trajectory of between 11° and 52° with an average of 28.32° (Figure 5). There is a great range of roof slope, which is in general related to the length of the roof (with smaller angles related to longer volumes). The annual energy generated by a different number of panels according to domestic consumption, varies from 9,900 to 74,000 kWh/year, and is also related to house size. The relation between generation and consumption ranges from 0.47 to 1.38, with an average of 0.96. In the worst cases, solar panels generate almost half of the total domestic energy consumption (Figure 6). In the

FIGURE 5. Roof slope angle selected per case.

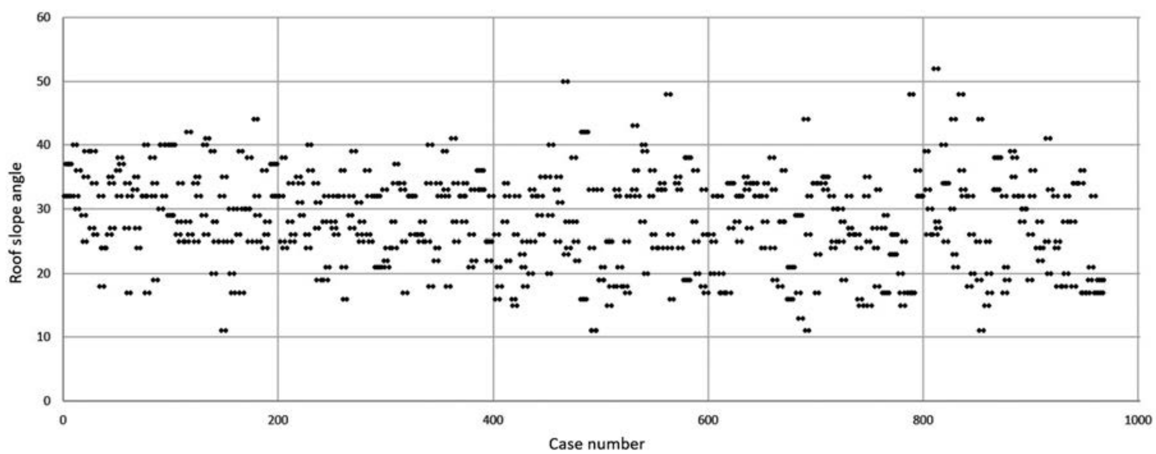
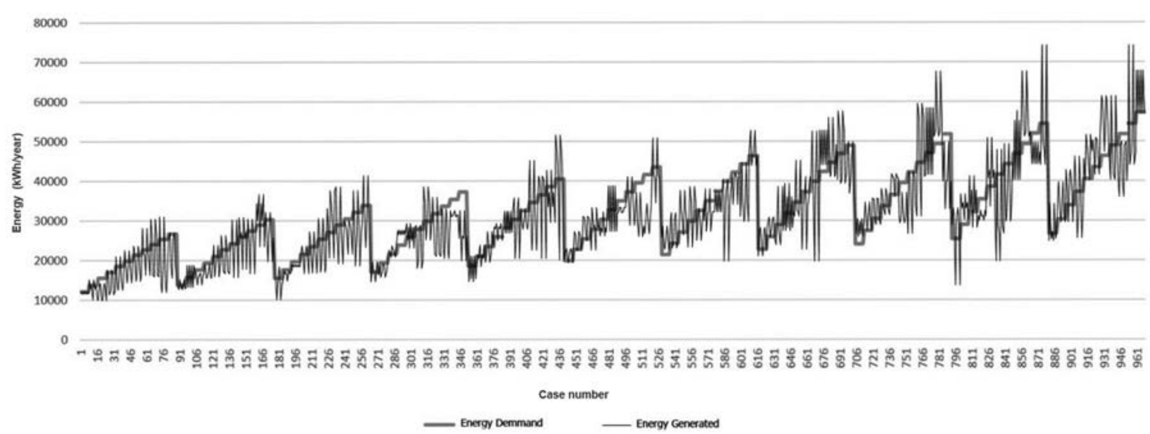


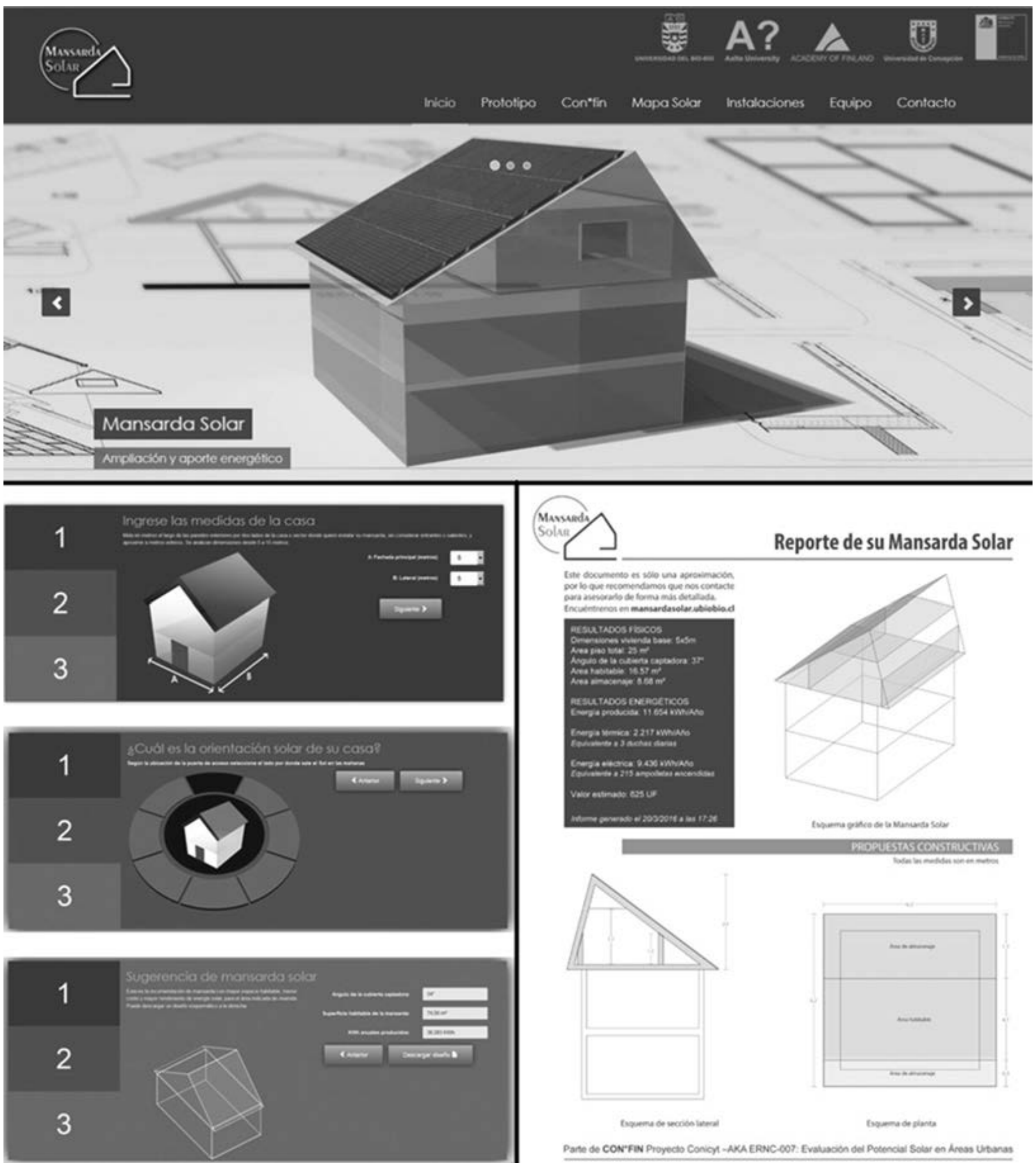
FIGURE 6. Energy Collected by Solar Panels (in black) and Dwelling Energy Demand (in grey) per case.



best cases, solar generation exceeds energy consumption by more than 30%. The differences are produced by the hourly match estimated by the simulation. The suggested habitable spaces range from 7 m^2 to 154 m^2, in relation to the built surface range of from 9% to 39%, with an average of 29%. This implies the extension of almost a third of the built surface with the attic addition. The total length of building pieces ranges from 150 to 858 m, with an average of 454m. These values are comparable to those of a similar surface, but using a regular construction. These results are part of the database of pre-calculated values and are integrated into the website to show the set of possible extensions layouts and attic design suggestions to the final user.

The website includes information on the proposal and example pictures. A user menu (upper portion of the screen, see Figure 7) gives access to more technical information, data

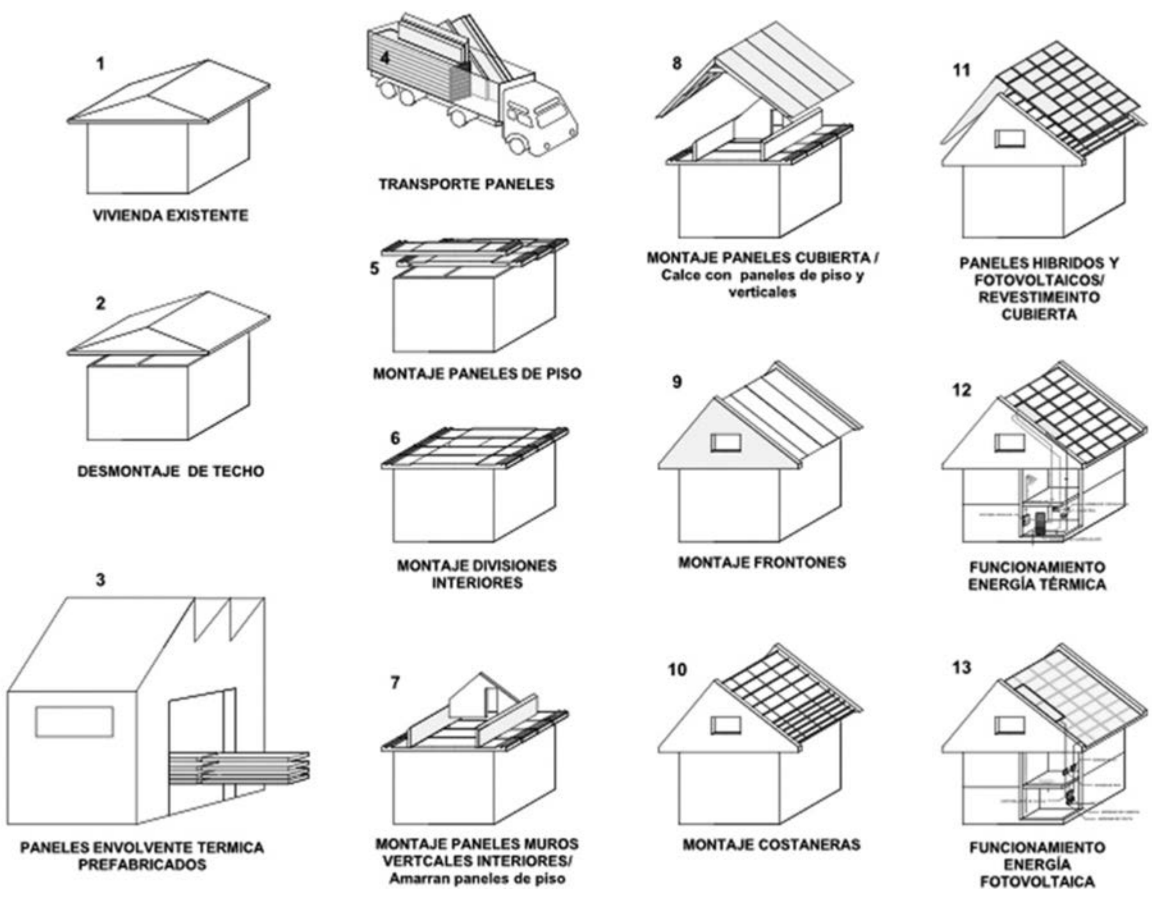
FIGURE 7. Solar attic website, main screen (upper), design steps (lower left) and report generated (lower right).



on the developers and a link to a map of the solar radiation potential of buildings in the city. Additionally, a graphic animation (lower side of the screen) explains the building procedure (Figure 8) and a report of structural systems and details of some cases are given, which can also be downloaded. The design suggestion request process consists of three steps (Figure 7, left). Upon entering the webpage, a notice appears stating that the results are specifically for houses located in Concepción, Chile. Then, in the first step, the width and length of the house must be selected, next to a simplified dwelling model with the main door highlighted. In the second step, the same model is surrounded by a segmented circle to mark the solar orientation of the house based on the main door position. The third step shows the main results of the analysis (previously calculated): the degree of slope of the side of the roof facing the solar trajectory, the total living surface, and the annual amount of energy generated. Additionally, a basic three-dimensional geometric representation of the attic is shown and the option to generate a detailed pdf report in is provided.

The report is a one-page summary with data about the annual energy production of each system included in the attic design, and their contributions to energy production in regular appliances, an estimated budget for the entire construction project, and a section and layout of the attic (Figure 7, right). The drawings show the position of panels on one side of the roof and the layout of the living space inside. A warning requiring the user to verify the suggested design with professionals and suppliers is included, as well as the developer contact information.

FIGURE 8. Explanation of building procedure.



Regardless, it is hoped that the information provided by this website will promote the option of installing solar panels for meeting domestic energy demand in housing extensions by delivering knowledge about the shape and size of the roof, the number of panels, and the potential for energy generation to inhabitants, and facilitating further requests for detailed plans and budgets.

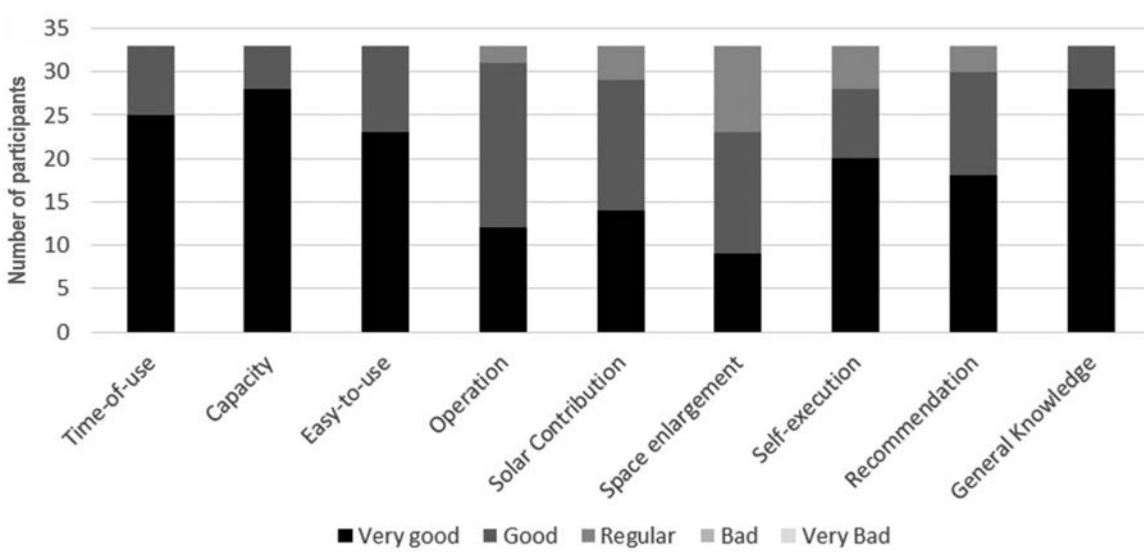
3. EVALUATIONS

3.1 Usability

In order to refine the website, a preliminary test was conducted with a group of first-time users. College freshmen—residents in the area and without specific knowledge on the subject—were invited to participate in the test, which was carried out in a computer lab where each individual had to access the website. A brief verbal explanation of the initiative was provided and afterwards a pedestrian picture of a house and aerial view with the direction north marked was given to each participant (four different houses for the whole group). They were asked to review the website, make a request for a design suggestion for the provided example using the website, and complete a survey. A total of 33 students participated. The survey measured utilization, understanding and assessment of the information provided using three Likert-scale questions for each aspect. At the end, respondents had the opportunity to write comments and participate in a group interview.

Concerning the use of the website, survey results and comments showed that users evaluated the process of obtaining the suggestions they require as good (Figure 9). The clarity of information was also assessed as good, but to a lesser degree, and the appraisal of the proposal was strongly positive. The deterioration of understanding may be due to the mandatory task with an example home, rather than the participants' dwellings, which may lead to lower motivation to analyze the information. This was revealed in the discussion. The participants stated that they ignored the supplied energy equivalence in the report. Furthermore, it was noted that

FIGURE 9. Results of questions about usability of website.



respondents obtained diverse designs for the same examples because they interpreted the data in the pictures differently.

3.2 Prototype

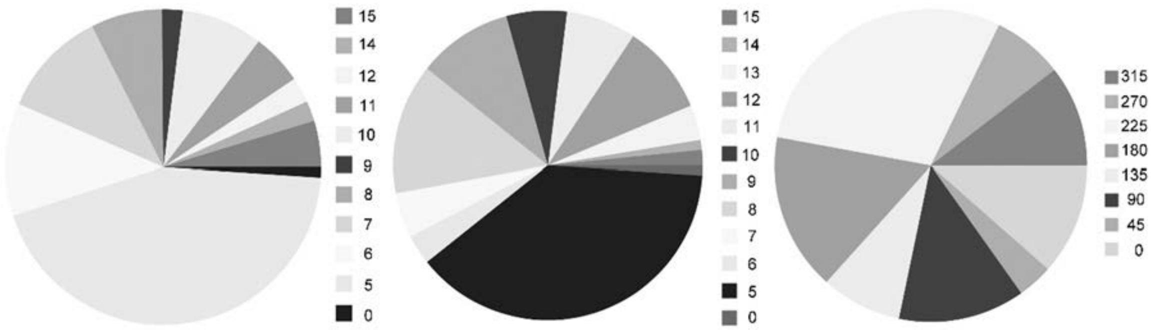
To promote this initiative to the local community and review the execution of the roof and installation of solar systems, a section of a full-scale prototype was built. The prototype includes a portion of a typical attic with limited technologies, in order to be able to move the structure to public places for live demonstrations. The structure built was 2.4m in width and 8m long divided in two parts for transportation, with a height of 3.2 m. It was constructed of pieces of wood and boards and covered with asphalt shingles. A hybrid (PV-T) panel was installed with a 120 L tank inside and piping to the live demonstration space to show the arrangement of the hot water system. In addition, two photovoltaic panels of 40 W feeding LED-lights, outlets and a screen showing the electrical charge were included. There were few problems with the execution of the timber structure and roof, although it is not common to have wooden boards in an indoor space. The solar panels were expected to be integrated into the roof, but they were overlaid due to lack of connections to the outer roof material. Moreover, the piping was somewhat difficult to install in the small space available, but the panels and devices worked properly. The prototype was exhibited on the University of Bío-Bío Campus and has been visited by students and professionals. It was also installed for three days in Concepción's main square (Figure 10).

3.3 Use of Website

The website was first available for several weeks for testing purposes. Afterwards, the website was publicized during the live exhibition of the prototype. Over this period, around 200 daily site visits were registered. Subsequently, website use has stabilized at about 10 to 30 visits per day. The website also recorded the house layout data provided by users along with the suggested

FIGURE 10. Prototype on exhibit in the city's downtown area.

FIGURE 11. House characteristics input on the website; width (left), length (center) and orientation (right).



designs. Of all the website visitors, around 10% requested an attic design. According to the records (Figure 11), the users solicited attics for houses with a variety of dimensions and orientations; one-third of the requests had the minimum dimensions in both directions (5 m), as well as the standard original building orientation (225° north of the main facade). These could be visitors testing the generation of designs with the basic system data. Thus, the remaining approximately 65% of visits can be inferred to be real data from actual houses, in which no more than 12% have the same size or orientation. This shows consistent use of the site for users interested in the proposed solutions.

3.4 Case-studies

In order to review the analysis for ordinary existing homes in the area of Concepción, four cases were studied. They correspond to two-story houses in which the first floor is built with reinforced masonry walls and the second with a timber structure. Regarding the roof, they usually have two sides with a low slope (approximately 15°). Two cases are isolated, individual dwellings, i.e. with volumes separated from neighbors, and two others are attached at the sides (one on one side only, and another on both sides). These cases represent common housing conditions in the area. The living surface in the cases varies from 83.4m^2 to 144.5m^2, and includes two floors of similar size with an orthogonal configuration. Each house was located in a site with two different solar orientations in order to study alternatives.

In all four cases, the main length and width of the built volume were identified as a rectangular base for the attic, excluding projecting or indented sections that can complicate the execution. In some cases, this implied the attic had to have additional support in a small portion of the floor due to the reduction of the base (i.e. in one corner), or it required a minor roof to cover a small extension (or include the eaves). In the computer procedure, the main floor measurements and orientation of the main façade are provided as primary input data for each case.

The shapes resulting from the genetic algorithm were different for each case (Table 1). Defining angles on the more exposed side (from 27° to 37°), living spaces from 24 to 43 m^2, equivalent to two to four additional rooms and an increase of around 30% in the total surface of the house. The estimation of energy collected ranges from 18,000 to 23,000 kWh/year, which varies primarily by house orientation and built area. The cases with different sides in the geometry of the roof generate higher amounts (as it is recommended to execute a habitable attic on the longest side), while in the houses with more equal dimensions (a squarer floor), the

TABLE 1. Case analysis and results.

Case Number	Built Surface (m^2)	Annual Electricity Consumption (kWh)	Length (m)	Width (m)	Azimuth (°)	Solar Elevation (°)	Living Surface	Energy Generated (kWh)	Building Materials (ml)
1	110.64	3,377.27	9.22	6.00	0	29	30.46	20,857.7	276.87
					270	42	23.61	7,398.3	223.52
2	83.39	2,714.58	7.02	5.94	0	27	24.62	18,666.5	219.59
					90	32	24.29	11,660.7	190.27
3	144.76	4,119.43	10.07	7.19	306	31	43.14	23,388.9	331.92
					36	32	34.18	15,241.4	287.67
4	117.13	3,525.07	8.18	7.16	325	37	37.20	18,710.9	276.06
					55	36	36.08	16,223.8	256.06

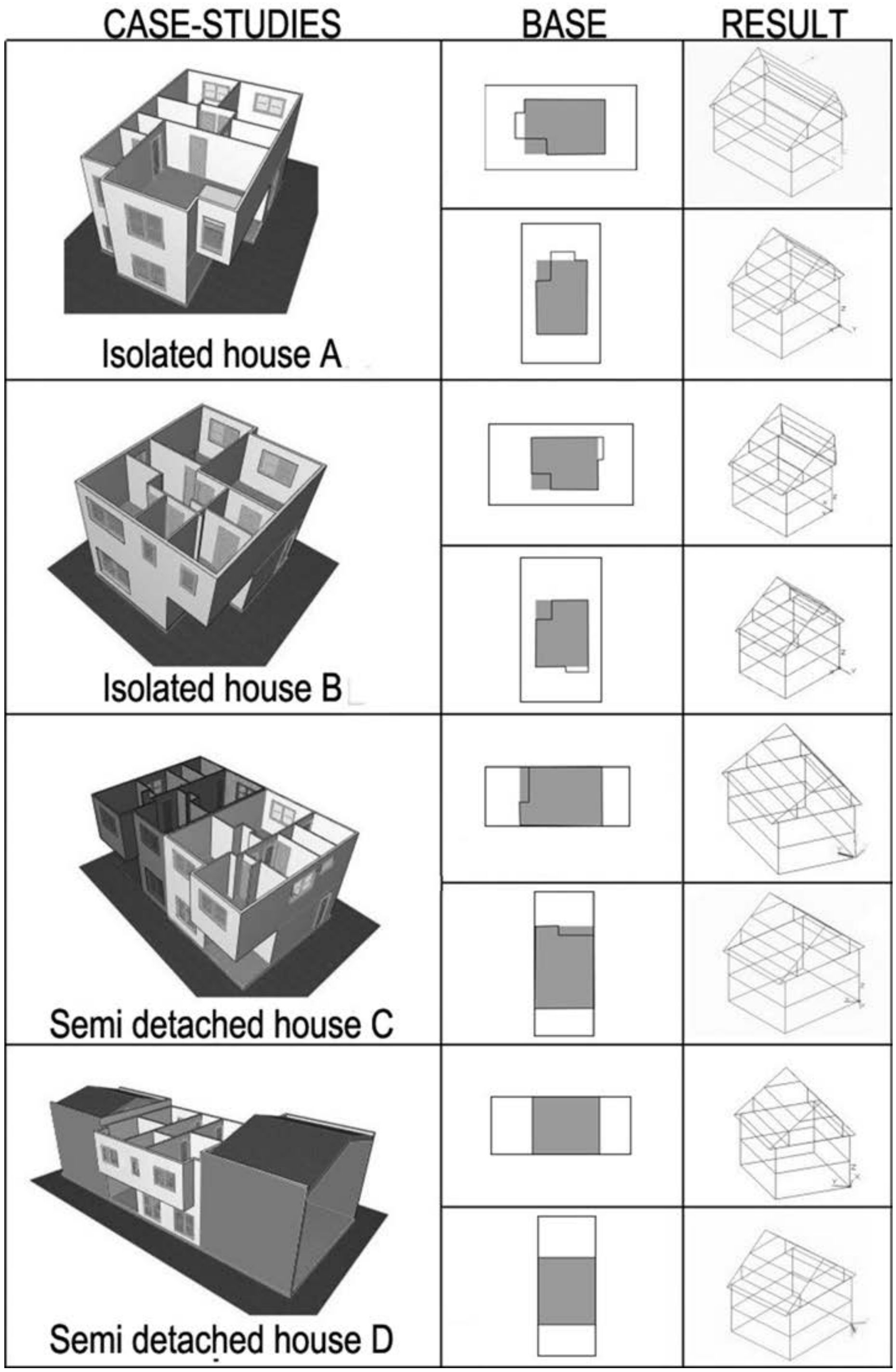
possibilities for each side are similar. The energy contributions range from more than double to almost six times the annual electricity consumption of each house, which can be distributed with batteries and the surplus can be used either for hot water, heating or to feed the urban network. Although the magnitude of structural parts for construction varies between 190 and 330 ml, the costs are very similar

Therefore, it is evident that the program suggests specific configurations that expand housing by one third, with equivalent construction costs, but generating an energy contribution that covers all of the dwelling's electricity demand and much of other home requirements.

CONCLUSIONS

This article describes the implementation of a computer system to design residential roofs with integrated solar panels for houses in the area of Concepcion, Chile. It uses genetic algorithms and dynamic simulation to optimize shape. The procedure maximizes a volume's interior space, as well as the solar radiation collected by one side of the roof with different solar panel technologies, pursuing the objective of satisfying part of the energy consumption of houses requiring lower construction cost (which depends on the extent of their faces). The analysis uses an evolutionary strategy by means of a genetic algorithm implemented in the Python programming language that uses Energy-Plus as simulation engine. This research project includes the development of a website taking advantage of results for house side lengths in discrete 1m increments and solar orientation every 45°, in addition to general information on the attic proposal, the creation of a full-scale prototype, testing with users and cases. The performance and functionality of the analysis and the website is suitable according to preliminary assessments and user pilot tests. Based on some cases analyzed, the system can propose an attic with solar collection systems that meet total electricity demand, and half of the hot water, and one third of the heating requirements. It suggests volumes that provide about an additional third of living space in comparison with the existing house (two to four bedrooms), with a cost equivalent to

FIGURE 12. Case studies with four different layouts (left), location on the site with two solar orientations each (center), and proposed attic design (right).



traditional construction. This possibility can be applied to more than half of existing residences in Concepción, like other cities in mid-latitudes, which have a similar high amount of single-family housing, energy demands and relevant solar radiation amount. In the case of applying these attics in new homes, it manages to deliver more energy efficiency and strong links with the natural environment. Accordingly, this tool can also be useful for architects, building engineers and other professionals who work on solar-based energy improvement, in order to give dwellers a first insight of the benefits of incorporating solar collectors in their homes.

The performance of solar panels has been tested on a test-bench and execution of the roof has been verified in a partial prototype, but a full attic should be built and measured to review the performance of the systems for at least one year to fully validate the suggested proposal. Also, the performance of genetic algorithm analysis should be checked with different implementation strategies and basic equipment and construction cost assumptions, as well as notions of usability and adoption time of the proposed design with inhabitants. Overall, this experience shows a path through innovative suggestions of efficient designs based on multiple objectives, which reconciles the requirements of housing enlargement and reduction of domestic consumption with lower environmental impact, and consequently contributing to urban growth and sustainable development of habitat.

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