addressing ambient, effect, and resulting lighting aspects for interactive urban lighting. It does this through four experiments using thermal cameras and computer vision analysis that allow designers to detect occupancy and flow patterns in the street. The data is utilized both as input to a real-time light control system and as a mapping of long-term occupancy and flow, allowing researchers and urban planners to access data on the use of urban spaces. In this paper, the evaluation of three interactive light strategies—glowing aura, glowing light, and red treasure hunt—reveal the potential for reactive lighting to be applied in public spaces and present significant energy savings of up to 90 percent. This result shows that dramatic light changes would not make people in transit space change behavior. However, the lighting does change the relation between observers on the edge of the square and people moving in the lighting. The responsive lighting amplifies the performance of the occupants, who become actors on a stage (Goffman 1959), people who attract attention; and it supports the concepts of passive surveillance by Jane Jacobs (Jacobs 1961). The majority of the visitors did not realize the changing of the light at their first visit to the square, but after observing other people perform from a distance, a new participatory novelty emerged. To uncover the full character of the public space would demand further examinations of space routines across seasons, which would allow us to develop deeper knowledge and understanding of social potential in situations with long-term occupancy. To address future challenges of response design in the field of reactive lighting, the authors of this paper suggest an interdisciplinary approach, where technologists and architects work closely together in search of new, robust tools and novel design methods to be tested in the "laboratory of the street."

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FORMAL AND FUNCTIONAL IMPLICATIONS OF DYNAMICS-RELATED SOLAR DESIGN SCHEMES

ABSTRACT

In recent years several solar radiation simulation tools have been developed to assist architects in analyzing the performance of existing building designs. However, it is often unclear how the results of these analyses can help to generate new solutions and thus be truly beneficial for innovation in sustainable architectural design. Recent developments in open source applications that allow links between energy simulation engines and 3D modeling environments open a new layer of understanding. The possibility of better understanding the dynamic interaction between incident solar radiation and building envelopes allows the synthesis of new architectural design schemes. This paper presents the results of a series of experiments based on the case study of a mid-latitude single-family house in Taiki-cho, Japan. The first experiment describes how the incident solar energy interacts with the exposed components of the envelope. The second experiment describes how the energy demand of the building can be partially reduced through the design of passive interventions that are based on the dynamics of the demand. Finally, the third experiment exemplifies how, based on the knowledge extracted from the first two experiments, it is possible to synthesize new dynamics-related solar design schemes that join passive techniques, active technologies, and formal aspects.

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1 INTRODUCTION

Solar radiation is one of the most important climate variables for human comfort and for the achievement of energy-efficient and emission-free building operation. In recent years several simulation tools have been developed to assist architects in evaluating solar heat gains, daylighting, and solar energy collection during the design phase (Dubois and Horvat 2010). Despite their increasing sophistication, these tools only allow architects to estimate the performance of an existing building design, which can then possibly be ameliorated through an iterative process. Current efforts in research aim at developing strategies to identify optimal design parameters through the automation of performance-based generative design processes. These design studies treat, for example, the integration of photovoltaic technologies (Cheng 2009), the balance between the minimization of heat losses and the maximization of solar gains (Jannsen 2009; Caldas 2007; Marin 2009), passive solar strategies for large buildings (Turrin et al. 2010), or daylighting questions (Zarzycki 2010). Bio-inspired approaches, such as (for example) phototropism, are used to grow architectural forms according to energy harvesting objectives (LaBelle et al. 2008). Other recent works are instead based on comparative analysis, trying to clarify the relationship between architectural form and solar energy in a global context (Rullán Lemke 2010), or the role of urban forms in dense sites related to daylighting and solar potentials (Kämpf et al. 2009; Montavon 2010; Cárdenas 2009).

Analyzing these research works, we can observe that, on the one hand, generative processes that are supposed to be able to generate new design solutions are in reality highly constrained by their own definitions (i.e., design schemes) and act only within the boundaries in which they have been defined. On the other hand, the generalizations extracted from the analytic studies are only able to judge existing cases and thus are not capable of proposing inventive solutions. Additionally, most of the available tools and approaches focus on analysis rather than synthesis, limited to the calculation of radiation values or performance indices. It is thus often unclear how the results of the analysis can help to generate new solutions that would be really beneficial for innovation in sustainable architectural design.

Recent developments in open source applications that allow links between energy simulation engines and 3D modeling environments (OpenStudio 2012) open new and interesting opportunities for architectural design. Based on simple building sketches, these applications allow quick but precise evaluation of how solar radiation dynamically interacts with a given building design. Based on this new understanding, it is possible to derive suggestions for the synthesis of innovative design schemes that embrace this interaction. These design schemes can be easily evaluated in terms of both functional (energy-related) and formal implications, allowing the exploration of innovative concepts that join passive techniques, active technologies, and new formal expressions.

2 METHODOLOGY

This paper presents the results of a series of experiments. The first two experiments allow us to gain the necessary knowledge of the topic, clarifying some aspects related to the solar energy incident on the building and illustrating the effects of archetypical interventions of passive solar design such as south-oriented openings and overhangs. The third experiment is then an example of how, based on the developed knowledge, it is possible to synthesize new design schemes to explore new concepts of sustainable architecture.

The experiments are based on a case study of a mid-latitude, single-family, residential house located in Taiki-cho, Japan. The site is at 42.47° of latitude, 143.37° of longitude, and 24 m of altitude. The location has a humid continental climate involving an alternation of hot and cold seasons, with large daily average temperature differences spanning between a minimum of -11° C (12° F) and a maximum of 25° C (77° F). The site presents no obstruction from neighboring buildings or trees and has a relatively flat horizon. The house has a square floor plan of 6.6 × 6.6 m and two floors in a building 6 m high, with a resulting use area of 87.12 m2.

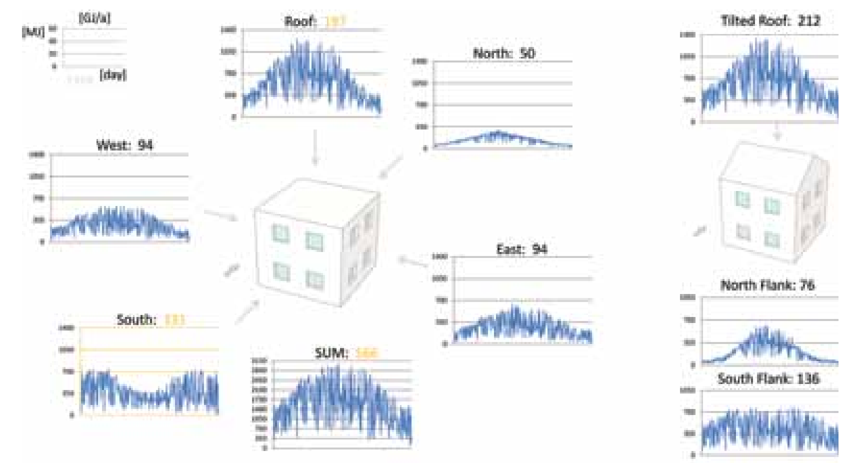


figure 1

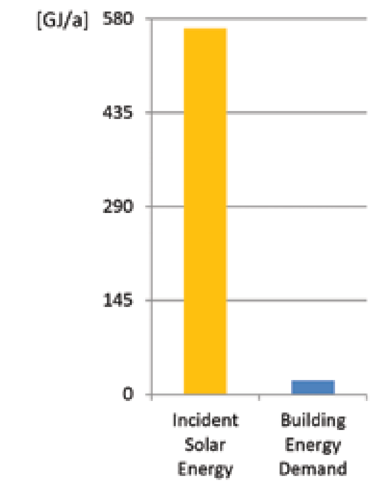


figure 2

The presented results are the outcome of energy simulations based on the OpenStudio plug-in (OpenStudio 2012) that allows a link between the simulation engine EnergyPlus and the 3D modeling software SketchUp. In order to set up the models for the simulations, average parameters have been selected for occupants' behavior, materials, lights, electrical appliances, infiltration, ventilation, thermostats, etc. The simulations allowed the estimation of the solar energy incident on the envelope, the solar heat gains, and the building energy demands in terms of heating, cooling, and electricity. The models also include daylight control objects that are able to reduce the electricity demand for artificial lighting according to the availability of natural daylight. These models do not include the energy demand of domestic hot water and additional HVAC systems (heat pump, air conditioner, etc.).

3 EXPERIMENT 1: SOLAR ENERGY INCIDENT ON A HOUSE WITH REGULAR FACADES

The starting model of the study represents a house that is oriented to the cardinal directions and has four square windows distributed regularly on the four walls. The first step was analysis of distribution of the solar energy incident on exterior opaque surfaces (walls and roof) across the five exposed flanks throughout the year. In Figure 1 we can observe how 35 percent of the yearly total incident energy of the building arrives on the roof (197 of 566 GJ/a), 23 percent on the south wall (131 GJ/a), and the rest in a decreasing way on the east, west, and north walls.

The roof features the highest total incident energy for several reasons. Firstly, it receives almost all the solar rays on its front face and with a relatively high average angle of incidence (thus reducing the projection effect). Secondly, the rays that feature an elevated energy value (the more vertical the rays, the less their atmospheric losses) have an elevated angle of incidence. Moreover, compared to the walls, the roof surface is not reduced by windows, doors, or other building components and, even if not relevant in our case, it is less affected by shading from environmental elements (trees, neighbors, horizon) and from the building itself (walls, balconies, or overhangs).

Looking at the graphs of Figure 1 with the annual dynamics, we can observe how four flanks out of five feature an energy peak in the hot season and how, interestingly, the south wall presents two peaks close to the cold season in which the energy demand (heat and electricity) is typically higher than in the rest of the year. This dynamic pattern is due to a balance between the amount of rays reaching the front face of the surface, their angle of incidence, and their energy. It must be said that the equator-facing wall that features this dynamic pattern would correspond to the north wall if the

figure 1

Solar energy incident on external opaque surfaces (units top left).

figure 2

Yearly incident solar energy.

site were located in the Southern Hemisphere.

From these first observations, we can ascertain that the roof and the south-facing wall present interesting particularities in relation to the quantity of incident solar energy, and that the south wall dynamics are particularly advantageous for collecting energy during the cold season. The knowledge obtained from these simulations can now be proficiently exploited for both (1) reducing the building energy demand through passive measures according to its dynamics, and (2) increasing the energy supply and its synchronicity with the remaining demand through active technologies.

In general the solar energy incident on a building is exploited passively through transparent surfaces (daylight and solar heat gains) and actively through opaque surfaces (photovoltaic panels and thermal collectors). It must be said that solar heat gains are not always favorable; the goal is indeed to increase them during the cold season and avoid them during the hot season. The solar energy incident on the transparent surfaces (windows) will feature energy values and dynamics with the same relative proportions of their hosting walls due to the regular distribution of the windows on the walls.

The second model represents a design scheme with a pitched roof tilted by 30°. In the results we can observe how the incident energy of the whole roof and its dynamics are similar to the flat roof. The slight increase is partially due to the increase in surface of the pitched roof. However, if we observe the two sides separately we can realize how the south-exposed side offers both a higher total energy value and a better dynamic spread over the year.

In Figure 2 we can observe how apparently the incident solar energy is abundant compared to the building energy demand (see Figure 3 for more details on energy demand). It must be said that both the incident solar energy and the energy demand values computed by this simulation and indicated in this graph are ideal, i.e., they do not comprise the efficiency of the technical systems which would in a real case reduce the supply and increase the demand. However, the graph highlights that the incident solar energy is abundant and that the technology- and design-related questions should focus on how to gather this energy and how to match the demand dynamics.

4 EXPERIMENT 2: ARCHETYPICAL INTERVENTIONS OF PASSIVE SOLAR DESIGN

A second series of models was set up to verify the archetypical interventions of passive solar design and to generate reference figures for the last experiment. The starting model is the house with regularly distributed openings from the previous example rotated by 30° according to the building orientation pattern of the local neighborhood. Four passive interventions are progressively implemented to this Initial model (uppercase terms are used to refer to the model or variable names in the figures) in order to reduce the energy demands. In Figure 3 we can observe the gradual evolution of the following variables: Solar Heat Gains (energy transmitted through transparent surfaces), Collecting Potential (energy incident on external opaque surfaces), and Lighting, Heating, and Cooling Demands.

By concentrating all the transparent surfaces on a side which is partially south-exposed, we can observe an increase in Solar Heat Gains with a positive impact on the Heating Demand and a negative impact on the Cooling Demand.

By orienting the house exactly to the south we can observe, compared to the previous model, an interesting increase and change in dynamics of the Solar Heat Gains that has essentially only a positive impact by reducing the Heating Demand. As seen in the first experiment (Figure 1), this is due to the dynamic nature of the energy incident on the south wall, which features peaks close to the cold season.

By adding correctly dimensioned overhangs, it is possible to selectively obstruct the rays during the hot season. This leads to the reduction of the Cooling Demand and also, even if in smaller proportions, to the increase of the Heating Demand. It must be said that heating and cooling demand values cannot be directly correlated because they have different natures in relation to human comfort, and because they will be supplied by different solutions that will involve different efficiencies. For example, it could be preferable to maintain a high cooling demand and solve it by natural ventilation,

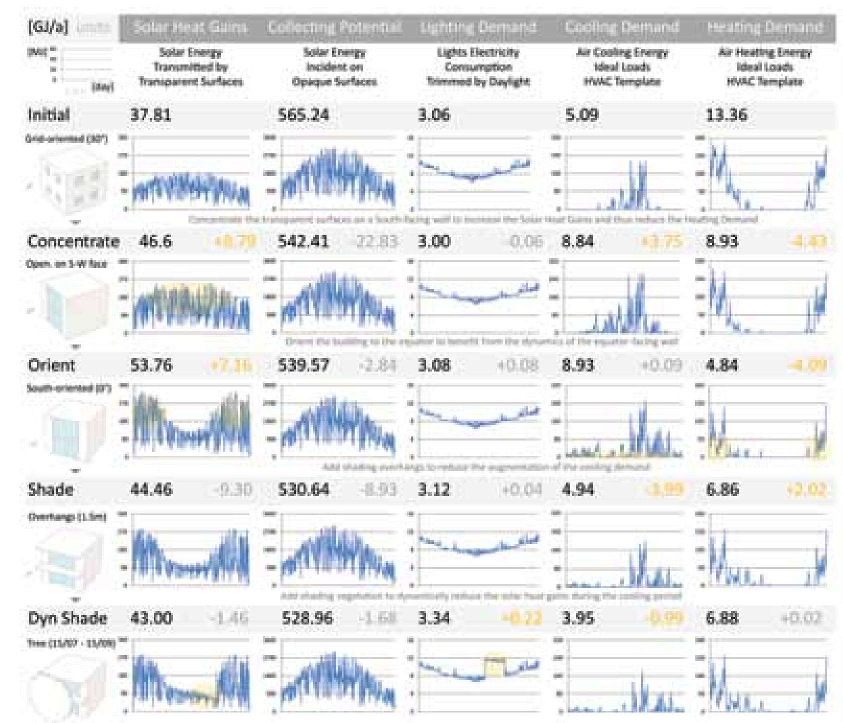


figure 3

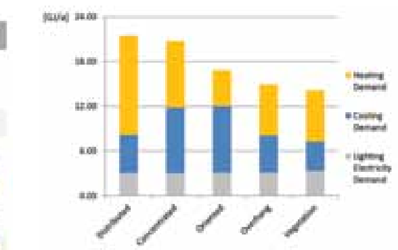


figure 4

than to have a high heating demand that would require an active supply of energy.

The last model of the series shows another way to influence the dynamics of the solar heat gains by exploiting external vegetation that has a leafing period that corresponds to the cooling period. To underline its effect, the tree was modeled by a totally opaque surface that appears in front of the building during the cooling demand peak (July 15– September 15). We can also observe how this measure can have a negative impact by increasing the lighting electricity demand.

Figure 4 shows the evolution of the yearly energy demands of the five models. The results confirm the effectiveness of archetypical passive solar design interventions and underline the importance of their dynamic implications in relation to the building energy demands. The development of these models showed that, even in these abstract and stereotypical examples, all the elements (openings, overhangs, vegetation, etc.) have to be very carefully dimensioned in order to obtain the desired dynamic effects.

From Figure 4 we can also observe that if passive measures allow a reduction of 34 percent of the building energy demand, the other 66 percent still remains uncovered and needs to be supplied by active technologies. Indeed, demands such as heating during the winter and lighting during the night cannot be totally solved by passive techniques.

In this model series we can also observe how the south wall is gradually occupied and obstructed by openings, overhangs, and vegetation. However, in the first experiment (Figure 1) we have seen that this wall is potentially interesting, also, for the use of active technologies. We can thus imagine how, depending on the design constraints, active and passive solutions will have to compete in order to "conquer" this side of the building, which involves the most interesting energy features.

We suggest that to achieve sustainable operation of a building it is necessary to consider passive measures, active technologies, and formal questions in a joint way during the conceptual design phase.

figure 3

Archetypical interventions of passive solar design (units top left).

figure 4

Evolution of the energy demands.

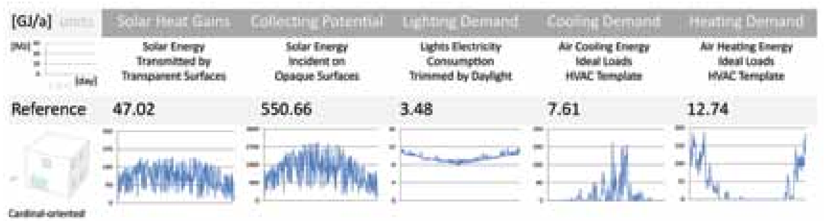


figure 5

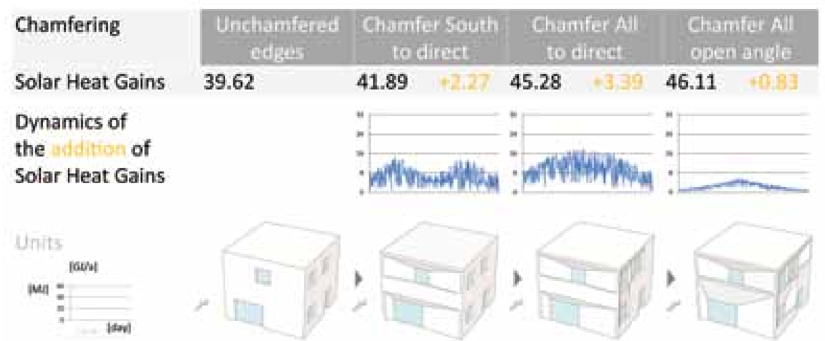


figure 6

The next section presents an example in which these aspects have been considered in such a joint way.

It has to be observed that other parameters, which have not been considered in this example, can play an important role in relation to solar radiation. Examples of such parameters are the wall-window ratio, mobile shading devices, material properties, building form, etc.

5 EXPERIMENT 3: EXAMPLE OF THE SYNTHESIS OF DYNAMICS-RELATED SOLAR DESIGN SCHEMES

5.1 Reference Model

The experiments in this section will be based on the Reference model presented in Figure 5. This model has been obtained by adapting the openings of the Regular house model (Figure 3) to a more plausible internal floor plan. Compared to the Regular house, the increase in Solar Heat Gains increases the Cooling Demand and reduces the Heating Demand.

Starting from the given building shape and the given opening distribution, we will try, by acting on the envelope, to reduce the demand and increase the supply according to dynamic criteria. For this purpose we will model two different solar design schemes, and we will verify their functional and formal implications. The first design scheme will be passive and will regard the chamfering of the edges of the transparent surfaces (windows). The second design scheme will be active and will regard the structure of the opaque surfaces (walls and roof).

5.2 Chamfering Design Schemes

This edge-treatment design scheme consists of the chamfering of the outer edges of the openings to increase the passive solar heat gains of the building (see application example in Figure 13). The experiment is carried out on both the south-oriented and the grid-oriented models (i.e., 30° rotation according to the neighborhood's building orientation). For this experiment a wall thickness of 20 cm has been considered. The reduction of the solar heat gains of the Unchamfered model (Figure 6) in comparison to the Reference model is due to the shading caused by the introduction of the wall thickness. The Reference model (Figure 5) was in reality composed of single-surface walls with no thickness.

In the first chamfered model only the south-exposed side of the house is chamfered according to the solar path: lower-edge horizontal, upper-edge following the summer solstice, and side edges totally open. In the second chamfered model all sides of the house are chamfered according to the solar path, considering the winter solstice sunrise and sunset angles for the rear chamfering angles. Finally, in the last chamfered model all edges are furthermore opened to also gather diffused and reflected radiation.

Observing the evolution of the solar heat gains and their dynamics in Figure 6, we can state that (1) the total increase of the solar heat gains is considerable compared to the heating demand of the Reference house (up to a total of 6.49 GJ/a, i.e., 50 percent in the last model), (2) as expected, the south side has a higher impact and dynamics that are closer to the cold season than the other sides, and (3) in our case the chamfering to direct radiation has a much higher impact than the chamfering to diffuse and reflect radiation (this is context dependent). Models with thicker walls are expected to feature even more significant effects.

The grid-oriented models feature similar solar heat gain values but have different design implications. This is due to the interplay between the building orientation and the solar path angles, which results in different chamfering angles.

5.3 Racking Design Schemes

This is a surface-treatment design scheme (see Figure 8) that consists of racking the opaque surfaces of the house and orienting them toward the sun to increase or adapt the dynamics of the incident solar energy (see application example in Figure 14). This allows a more efficient implementation of active technologies such as photovoltaic panels, thermal collectors, and hybrid collectors.

The racks are oriented according to a specific mean solar energy direction. That direction can be, for example, the yearly mean direction (to collect the maximum of energy over the year) or the cold season mean direction (to collect the maximum of energy over the heating period). The sides of the house that are exposed to that direction are subdivided into racks. Each rack is composed of a "front surface" that is oriented perpendicularly to the solar direction and a "back surface" that is parallel to the solar direction. The low angle of incidence between the front surface and the solar radiation will thus increase the solar energy incident on this surface. This design scheme will generate a total area perpendicular to the solar direction equivalent to the biggest section of the house in that direction (i.e., from the sun's point of view, all the visible surfaces of the house will "look" at it).

It has to be noted that the width of the racks is an arbitrary parameter that can be determined according to formal or technical criteria. The design scheme implemented in this experiment generates the

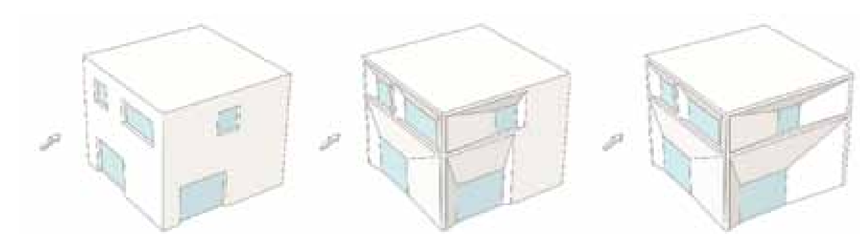


figure 7

figure 5

Reference model (units top left).

figure 6

South-oriented chamfering design schemes (units top lef

figure 7

Grid-oriented chamfering design schemes.

most packed racking of a given surface (in our case the available amount of surface is limited). It has to be remarked that due to the solar motion, self-shading between the racks will affect the energy collection. In some cases, depending on the goals of the project (maximal energy, maximal efficiency, formal aspects, etc.) a more spaced racking could be preferable, typically if the available surfaces are abundant.

This design scheme is applied to the Reference model with the three following dual variations, resulting in eight different models:

- yearly mean direction (36° of elevation), and cold season mean direction (23° of elevation)
- racking of all exposed surfaces, and racking of the roof surface only
- south-oriented, and grid-oriented

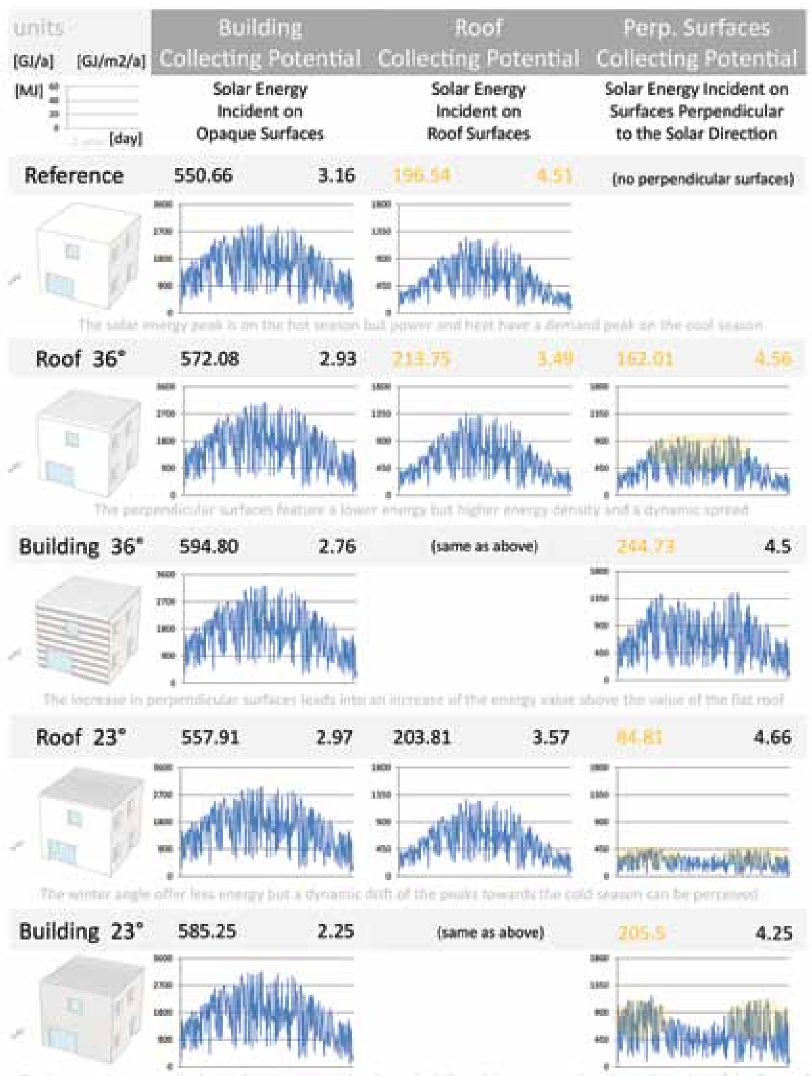


figure 8

figure 8

South-oriented racking design schemes (units legend top left).

figure 9

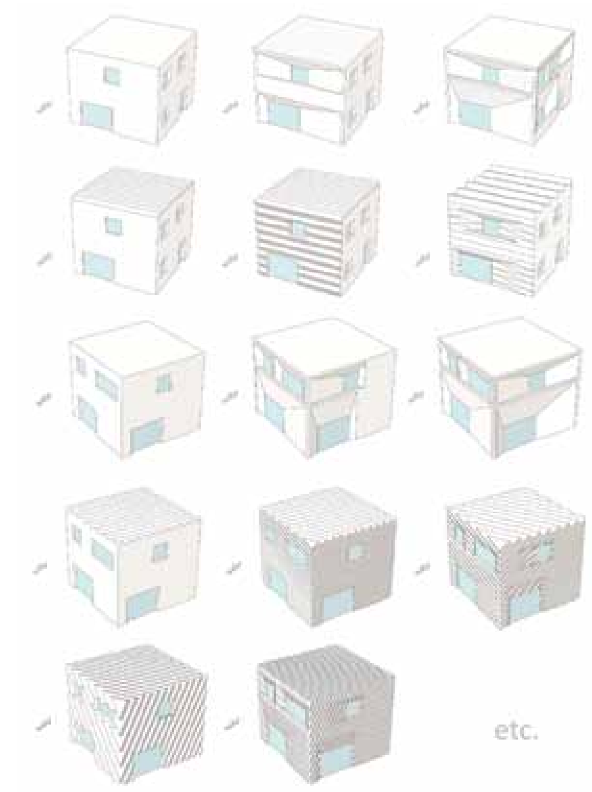


figure 10

figure 9

Design scheme examples—perspective views.

figure 10

Design scheme examples—perspective views.

As we have seen in Figure 1, the roof is the surface that collects the most solar energy, and we will thus take its incident energy and its dynamics as a reference. From the first racked model, we can observe how the solar energy incident on the roof increases but the energy per square meter decreases. This effect is due to the increase in surface of the roof, which is composed of front surfaces perpendicular to the solar direction and back surfaces parallel to it. If we observe only the perpendicular surfaces we can see that, compared to the flat roof, the total energy value decreases but the energy per square meter increases. It has to be remarked that the energy per square meter could further be increased by increasing the spacing of the racks and thus reducing the self-shading effect.

By extending the racking to the south-facing wall, we can observe that the perpendicular faces of the racks feature a total energy value that surpasses the reference value of the flat roof and offers a better dynamic spread.

In the last two models the same design scheme is applied to the mean direction of the cold season.

Compared to the two previous models, we can observe a predictable decrease in the total energy values but an interesting dynamic drift of the peaks toward the cold season. By comparing the values of the perpendicular surfaces of the last model with the reference values of the flat roof, we can observe how the racked model can offer a higher total energy value and dynamics that better match the dynamics of the building's energy demand.

This information allows the designer to select a design strategy—based on the design goals of his or her project—that can span from the maximization of the total collected solar energy down to a careful and efficient placement of a limited amount of collecting surfaces. It has to be noted how the front and back surfaces of the racks offer different characteristics that can be skillfully exploited. For example, installations that mainly rely on direct radiation such as photovoltaic panels could be placed on the front, and light wells that exploit diffused radiation, avoiding glare, could be placed on the back (see application example in Figure 14).

The grid-oriented models (see Figure 9) feature different design implications due to the interplay between the building orientation and the solar direction, which results in different racking angles and in two walls instead of one involved in the racking process. The dynamics of the incident solar energy resulting from these models is similar to the south-oriented models. The total energy values are higher, mainly due to the greater amount of surface involved in these models. The highest increase (+8 percent) is presented by the Building Collecting Potential of the last grid-oriented model (631 GJ/a).

5.4 Formal Implications

The next pages (Figures 10, 11, and 12) present an excerpt of the developed models to illustrate how, in parallel to the previously described functional (energetic) implications, formal implications can also be evaluated. This allows the designer to consider all of the different implications and to conceive concepts that integrate passive measures, active technologies, and formal aspects. Some

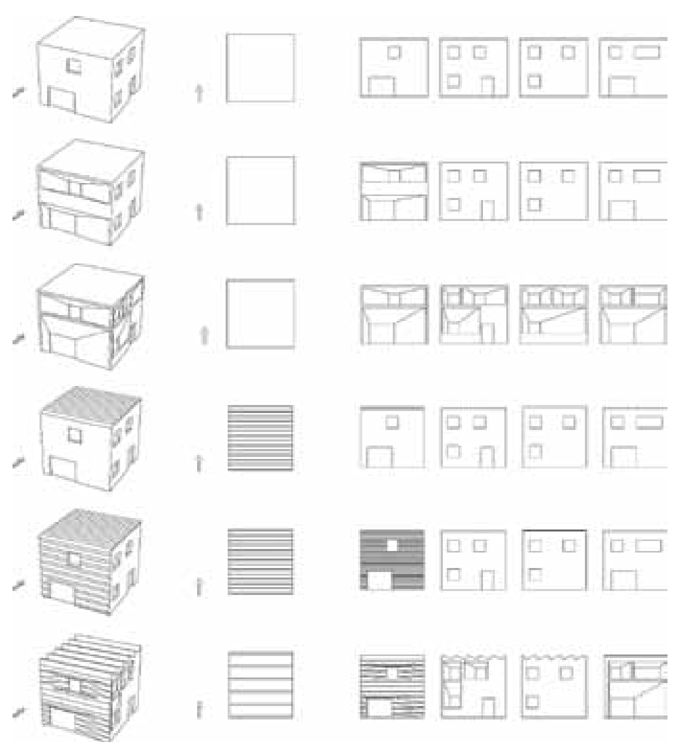
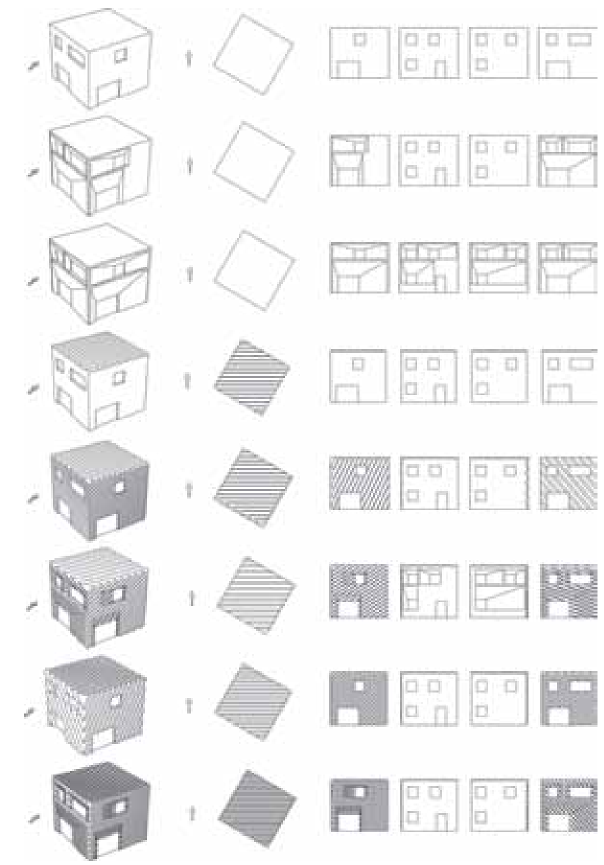


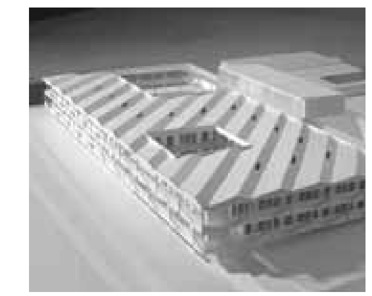
figure 11

figure 11

South-oriented design scheme examples—hairline views.

figure 12





figures 13 and 14

of the presented models combine the results of the previous experiments, suggesting the possibility of exploring new designs that can emerge from the interaction of different design schemes.

6 CONCLUSION

The experimental study presented in this paper illustrated how, on the basis of a deeper understanding of the interaction between solar radiation and the building, it is possible to synthesize new dynamics-related solar design schemes. The presented design process allowed the evaluation of the formal and functional implications of different design schemes considering both quantitative and dynamic questions. The first experiment showed how the roof and the south-facing wall feature interesting particularities in relation to the incident solar energy and its dynamics, which are suited to respond to the dynamics of the building energy demand. The second experiment showed how, if through passive interventions it is possible to partially reduce the building energy demand, a substantial part of the energy demand still persists and has to be covered by active solutions. Finally, in the last experiment an example illustrates the synthesis of new dynamics-related solar design schemes in which passive measures, active solutions, and formal aspects can merge in cohesive concepts.

These simple and abstract design schemes can then be integrated into a broader architectural concept that, by naturally evolving through the design process, can result in finite architectural designs, as shown in the contemporary examples of Figures 13 and 14.

figure 12

Grid-oriented design scheme examples—hairline views.

figure 13

Example of chamfering (Rossier 2010).

figure 14

Example of racking (agps 2010).

This case study is intended to serve as a reference example for educational purposes and for further research investigations. The specific results of this work can be applied to cases featuring similar conditions in terms of latitude, climate, surrounding context, building proportions, etc. The design process presented in this work is generalizable and applicable to any case.

Further investigations will regard more complex, shaded sites in urban contexts where, in addition to directionality and dynamics, the volumetric distribution of solar radiation plays an important role.

ACKNOWLEDGMENTS

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WORK IN PROGRESS

SYNCHRONOUS HORIZONS:

REDEFINING SPATIAL DESIGN IN LANDSCAPE ARCHITECTURE THROUGH AMBIENT DATA COLLECTION AND VOLUMETRIC MANIPULATION

ABSTRACT

This paper addresses the limited shared vocabulary of landscape architecture and architectural design, evident in the application of terms such as "spatial design" and "spatial planning." In their current usage, such terms emphasize the visible, terrestrial, pedestrian-perspective level, often to the absolute exclusion of a spatial, i.e., volumetric comprehension of the environment. This deficit is acutely evident in the teaching of landscape architecture and architecture and discussion of these fields' shared ground. The dominant document type for mapping such analysis and design is the plan, or three-dimensional representations of the same, restricted to an extrusion or height map. GIS techniques in spatial design tend to be weighted toward visual, surface-based data (slope analysis, exposure, viewshed, etc.). Within this domain, our goal is to transform aspects of the intangible—the characteristics of open space itself—into a form that is legible, quantifiable, and malleable.

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