Solar Sculpting: Building Form & Energy

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Rapid depletion of natural resources and increased environmental degradation demand a vigorous scrutiny of accepted design and construction methods. For more than ten years, New York City has promoted energy efficiency policies —including PlaNYC and the Greener, Greater Buildings Plan— that will radically reshape the education of architects toward energy performance in buildings, reduction of emissions, and the efficient use of resources. Our series of undergraduate studios investigates the relationship between the building form and energy performance, using form-finding algorithms based on solar radiation to shape mid-rise housing typologies for New York City. Currently funded by the Institute of Design and Construction Foundation, we have been exploring the important environmental design opportunities that exist within building envelopes, particularly in residential buildings that are responsible for most of the greenhouse gas (GHG) emissions and power consumption. By integrating and extending current solar technologies such as photovoltaic (PV) and solar thermal (ST) for the predominantly vertical infrastructure of the city, this research targets innovative building mass and surface strategies that are highly energy efficient, generate on-site renewable energy, and produce a new vocabulary for sustainable construction. As part of the initiative, we have also formed an international exchange program between our two institutions to share content and expertise.

The studios are structured to explore how solar design principles paired with formal models can supplant the reliance on

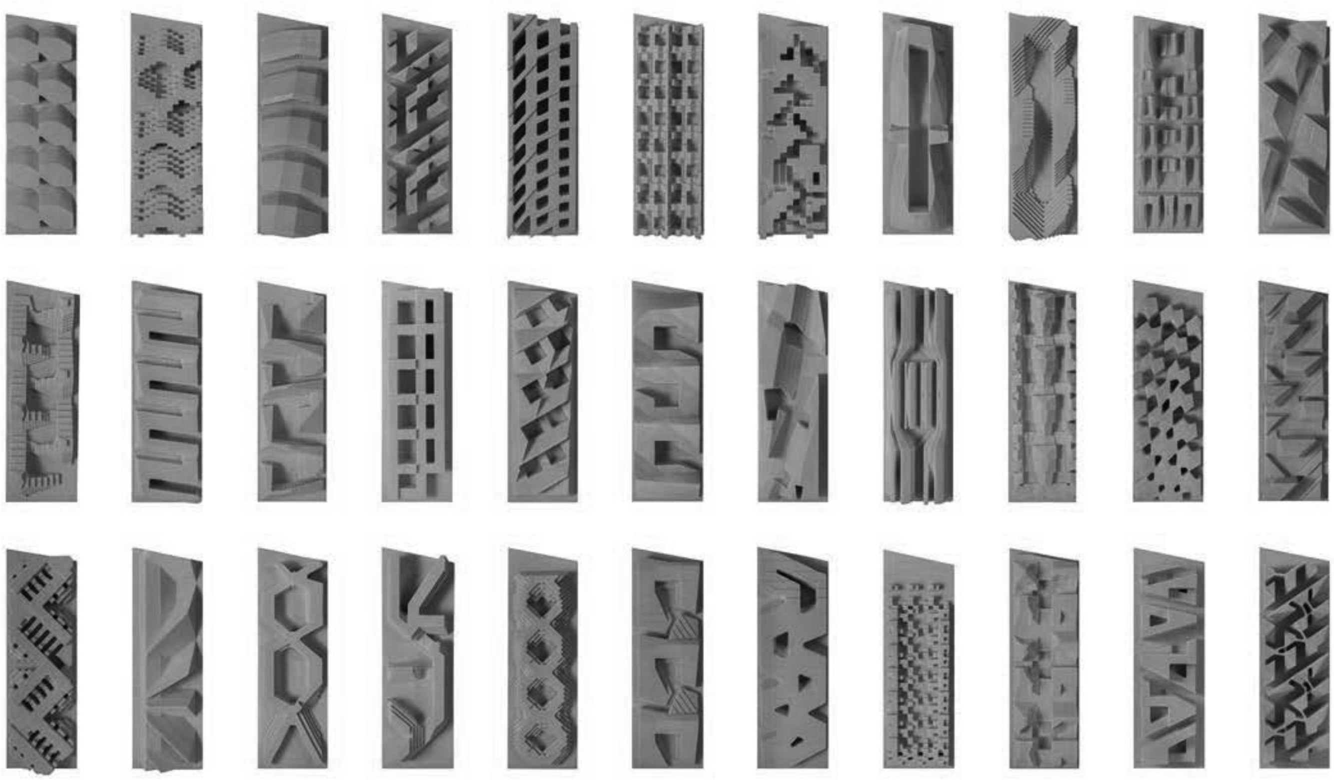

Figure 1. Milled models—morphology experiments. Blough and Giostra.

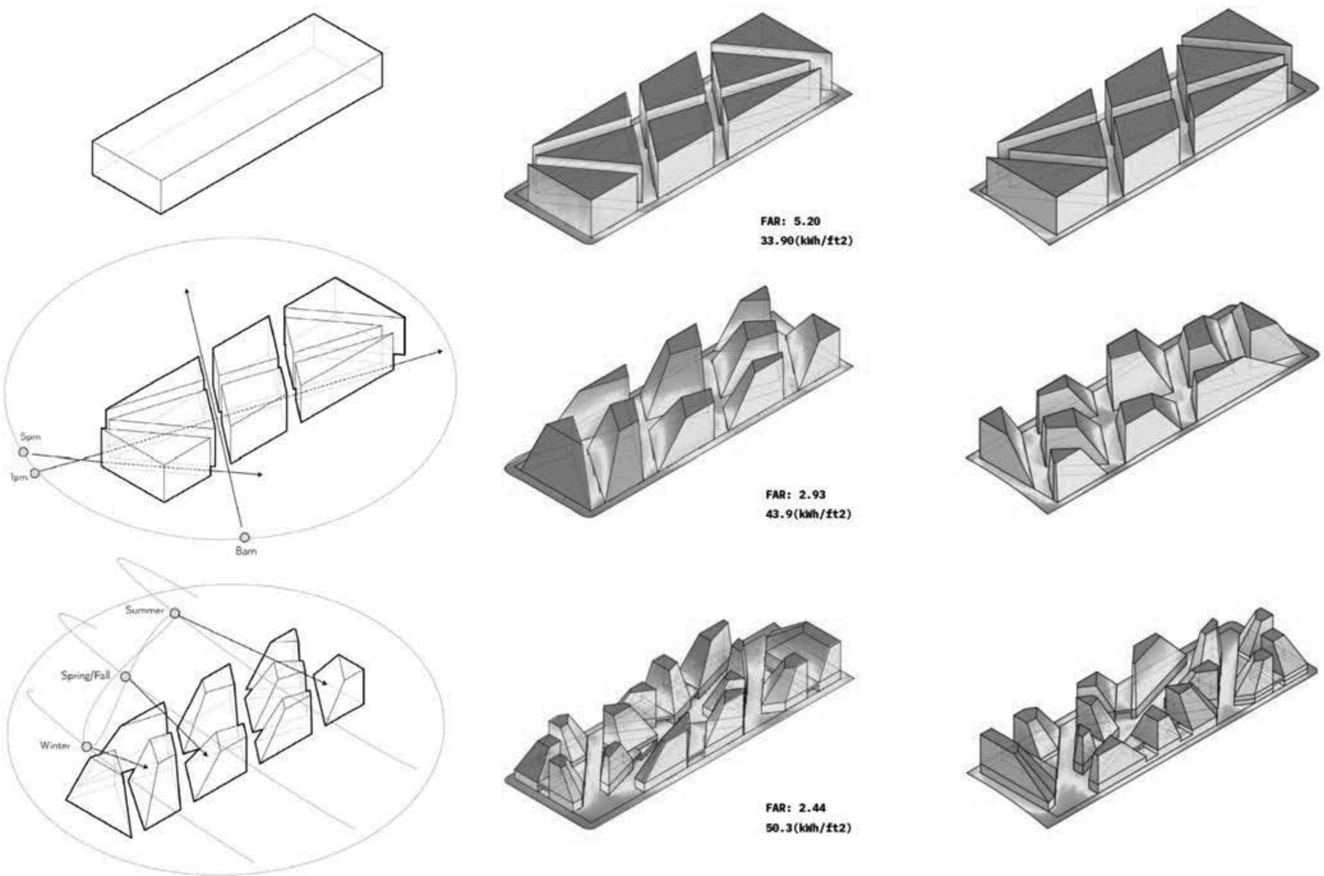

Figure 2. Operating system and optimization. Blough and Giostra.

mechanical systems and achieve comparable results in terms of energy performance and visual comfort. The research attempts to recast the ongoing debate on sustainability from a preeminently architectural position. Its overarching ambition is to identify a specific, measurable relationship between geometry—the traditional domain of the architect—and energy use along with GHG emissions. The semester is divided into "practices" where three scales were introduced to investigate the energy implications of the different formal strategies: urban morphology, building typology and building envelope. Each practice is also paired with a software workshop to teach analysis and simulation tools along with a class lecture to create historical, cultural and technological context for the research.

At the urban morphology scale, students investigate more general issues and opportunities that are not available at the scale of the individual building such as site orientation, distance between buildings and shading relative to adjacent lots (Figure 1). Students explore the relationship between morphology and site pressures by using indicators such as compactness, density, surface-to-volume, floor-area-ratio (FAR) and lot coverage tested against broad energy performance outcomes. Using trial and error paired with computational analysis to test their hunches, each student invented an "operating system" to mutate and adapt a base housing typology—slab, courtyard, pavilion—with the goal to improve solar radiation on the surfaces by up to 30%. A FAR of 3 was given as a parameter along with a height limit of 80' resulting in a mid-rise building up to 8 stories tall. Strategies were developed where the urban block was carved and shaped to maximize solar exposure and minimize overshading through a combination of solar tilt and angle (Figure 2).

Each student starts with one of the three base building typologies and goes through an iterative, evolutionary process that selects the traits for solar capture and avoidance. A family of possible outcomes are then produced that we call "speciation". Each species contributes to a general taxonomy of solar typologies that should help identify the traits that are most effective in shaping buildings for solar access (Figure 3). Selected schemes are also tested within the urban fabric of Clinton Hill, Brooklyn considering their reciprocal effect with the context such as daylight availability at the street level and on adjacent building facades. Vernal and autumnal equinoxes were selected to map the composite shadows from 8am to

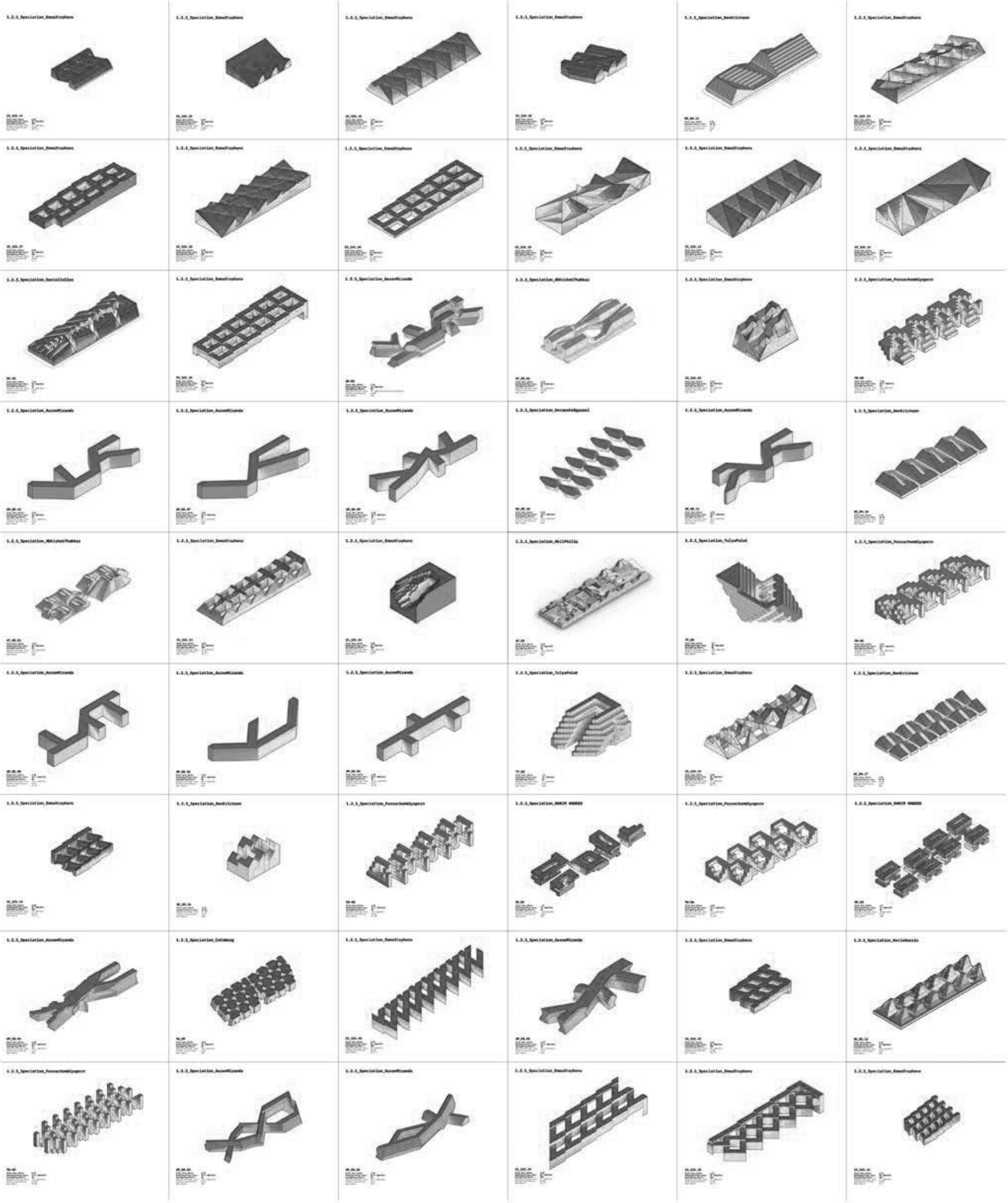

Figure 3. Speciation taxonomy—comparitive anatomy. Blough and Giostra.

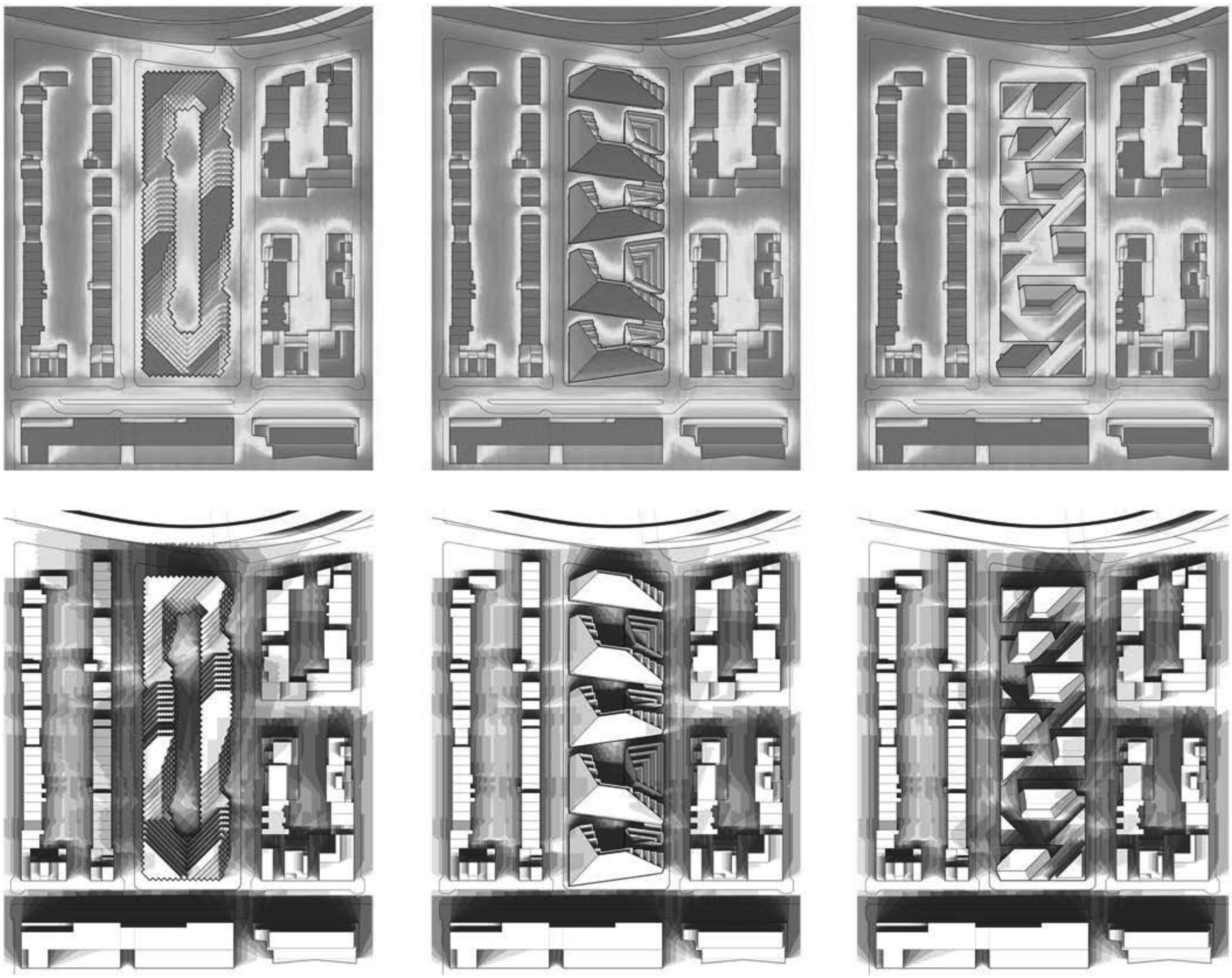

Figure 4. Solar neighborhood—average yearly radiation and fall equinox composite shadows. Blough and Giostra.

5pm studying the solar envelope or overshading. Urban average yearly radiation is of particular interest because of related thermal comfort and the potential for neighborhood scale shared energy generation. It also brings to bear on the question of "solar rights" that could lead to new urban solar zoning guidelines (Figure 4).

Digital energy analysis and simulation tools are used throughout the process to test and verify empirical speculations about the relation between form and energy-based metrics such as solar potential, daylighting and energy demand. Objective functions are an integral part of the design process where work is conducted based on two closely related indicators: solar irradiation (kWh/m2 floor area) on the building's exteriors and spatial daylight autonomy (%) in the interiors. Solar irradiation is used as a reliable indicator for on-site energy generation potential, while sDA for daylighting and interior visual comfort. Both indicators depend on the overall shape and degree of resolution of the building form and surfaces. The goal is to differentiate between areas of the envelope that are suitable for solar collectors, opaque cladding, shading devices, patios and openings for natural light and ventilation. At the end of the process, students can look back and compare results to the initial base typology to measure the degree of success for each evolved species (Figure 5).

At the building scale, students investigate the articulation of the mass through setbacks, cantilevers, cavities and slanted faces in order to regulate the exchange of daylight and heat between the building and its surroundings. This scale affects the primary structure of the building and can have important repercussions on the way program and circulation are organized within the building volume. A balance needs to be considered between the exterior and interior pressures—environmental aspects of energy flows with human demands for comfort and occupation. Solar optimization at the urban scale

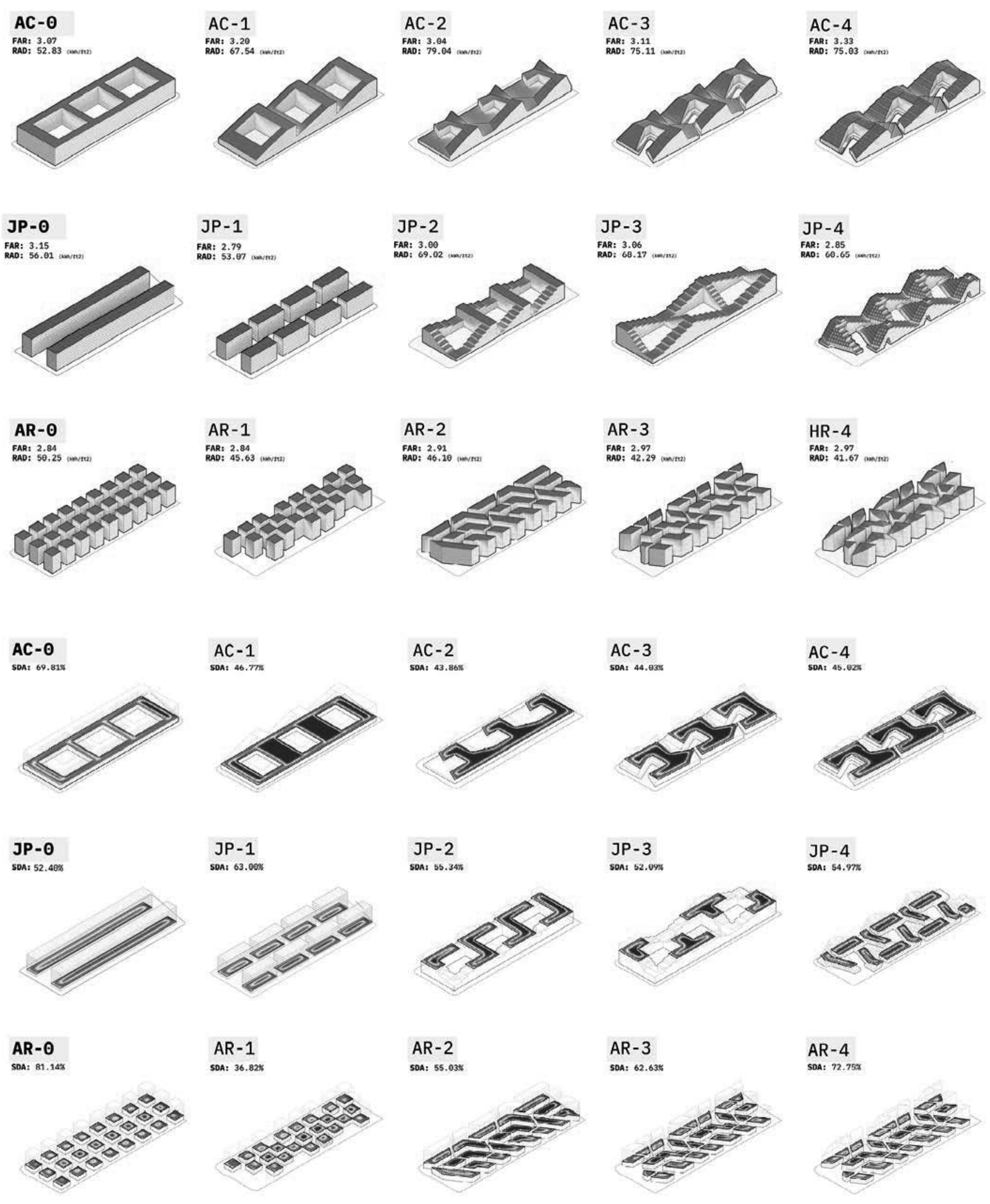

Figure 5. Mutations of base typologies using radiation and sDA—courtyard, slab and pavilion. Blough and Giostra.

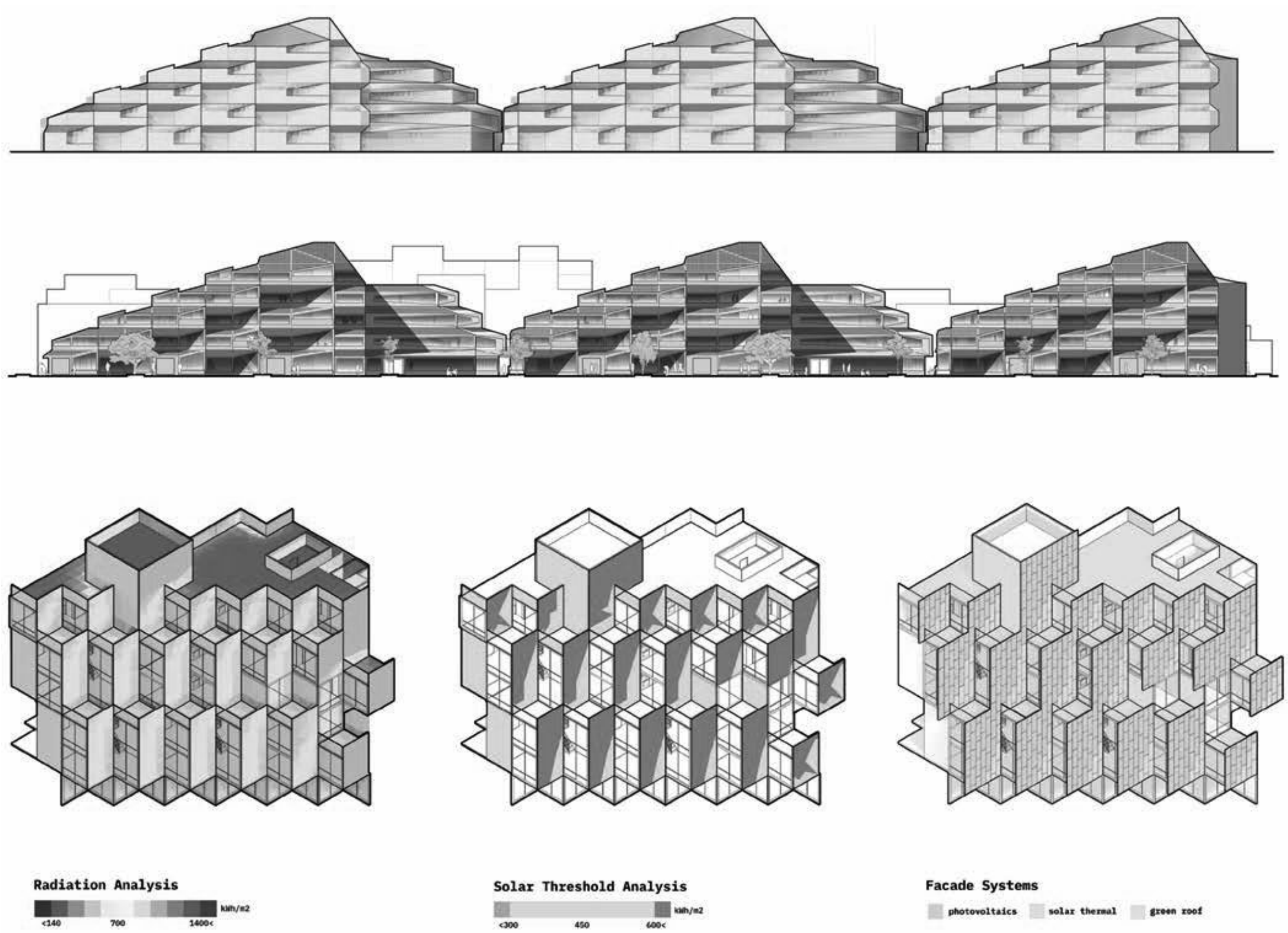

Figure 6. System allocation of PV or ST based on radiation thersholds. Blough and Giostra.

does not necessarily account for domestic organization at the middle scale—such as proximity to light and air, dwelling unit types, access and lifestyle choices. Conversely, dwelling organization does not necessarily account for the solar envelope and capture. The design provocation became how to hybridize solar inputs with housing typologies—on the one hand to "domesticate" the solar feedback, and on the other to allow these pressures to challenge the housing types to produce novel programming and organization.

At the scale of the building façade, issues such as surface geometry, subdivision, and tessellation are studied to produce multi-functional façades. While building massing affects primary structure and interior space with a floor-to-floor resolution regulated by control points resting on floor slab edges, cladding only affects secondary structure with geometric variation limited by the depth of the enclosure. Students investigated the articulation of the envelope to identify areas suitable for solar panels, opaque cladding, shading devices and openings for daylighting in order to maximize both energy production and visual comfort (Figure 7). Active system designation and location was refined was by determining efficiency thresholds through radiation analysis on the building skin—for ST panels areas above 300 kWh/m2 and for PV panels areas above 600 kWh/m2 (Figure 6).

A sectional core sample of each project was developed to study the tectonic and spatial consequences of the building enclosure system. Deep multi-functional facades create balconies, sun rooms, greenhouses and privacy screens to balance solar capture and avoidance. Results from the optimization of the building form and envelope provide the basis for the integration of a cost-effective, low-maintenance façade energy system into a unitized curtain wall assembly. Strategies range from a "solar shield" deploying photovoltaic panels incorporated into the building enclosure, to a "solar veil" designed as rain screen integrating evacuated tubes that generate heat for domestic hot water (Figures 8, 9). At the conclusion of the studios, preliminary analysis of the total yearly energy use indicates the potential for over a 40% energy offset. This is achieved by producing up to 30% of required electricity using

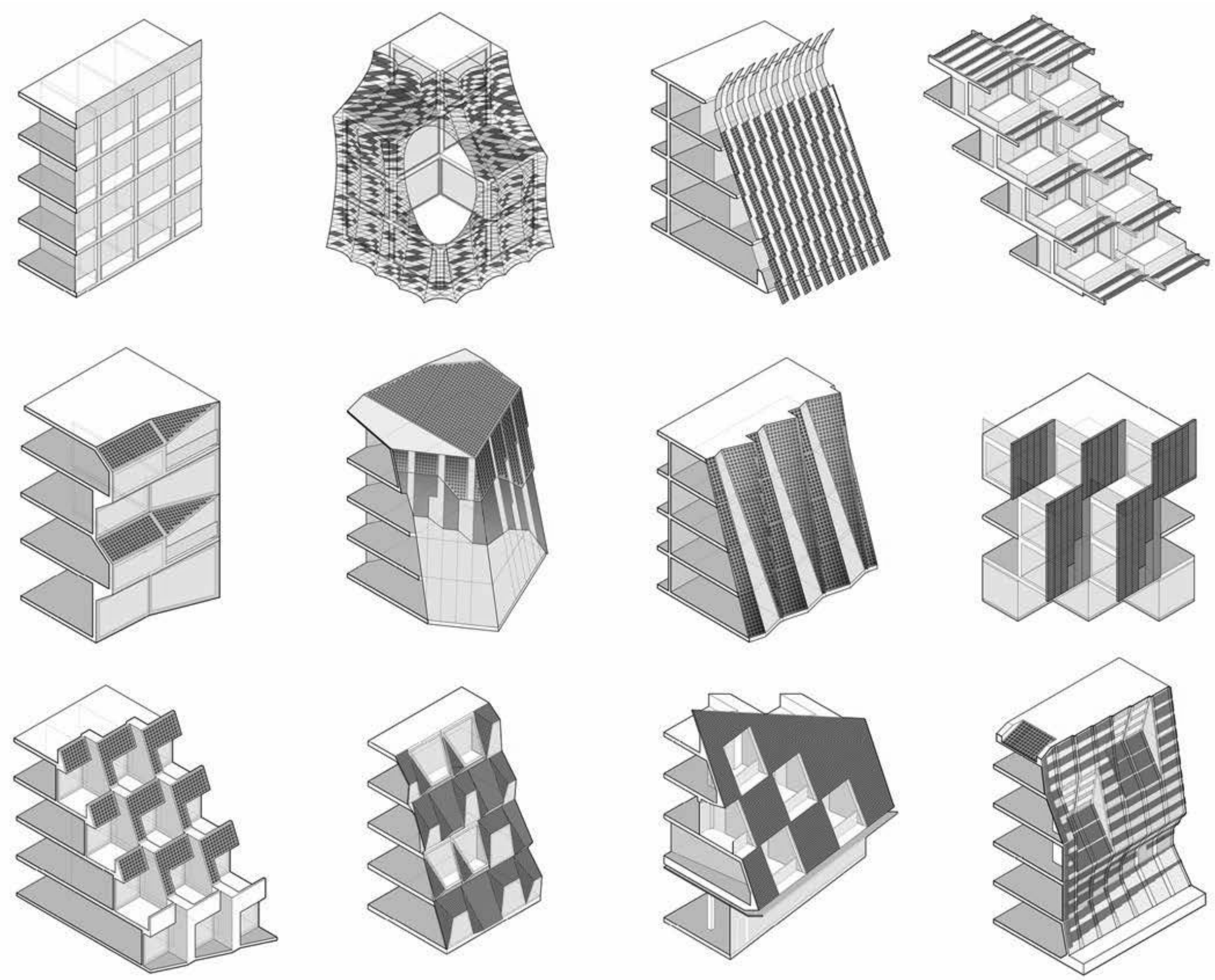

Figure 7. Multi-functional facade strategies for solar capture and avoidance based on exposure. Blough and Giostra.

photovoltaics, in addition to 50% of hot water demand using solar thermal systems.

Finally, models were printed in color to map average yearly solar radiation. An innovative PolyJet printing process was chosen because it provides infinite color combinations and gradients (Figure 10). These models clearly show how the forms and surfaces are manipulated by enmeshed external and internal pressures. Aesthetically the colors point and signal, similar to how color works in the natural world of non-human species, indicating the character specific to each scheme. The forms and surfaces at multiple scales express the competing environmental and human factors that informed their making, yet exceed a one-to-one reading that form is equivalent to performance. The multi-objective approach used in our studio process, demands that the designer weigh and select the parameters that carry the most value for them. This leads to a diverse family of novel formal outcomes.

CREDITS

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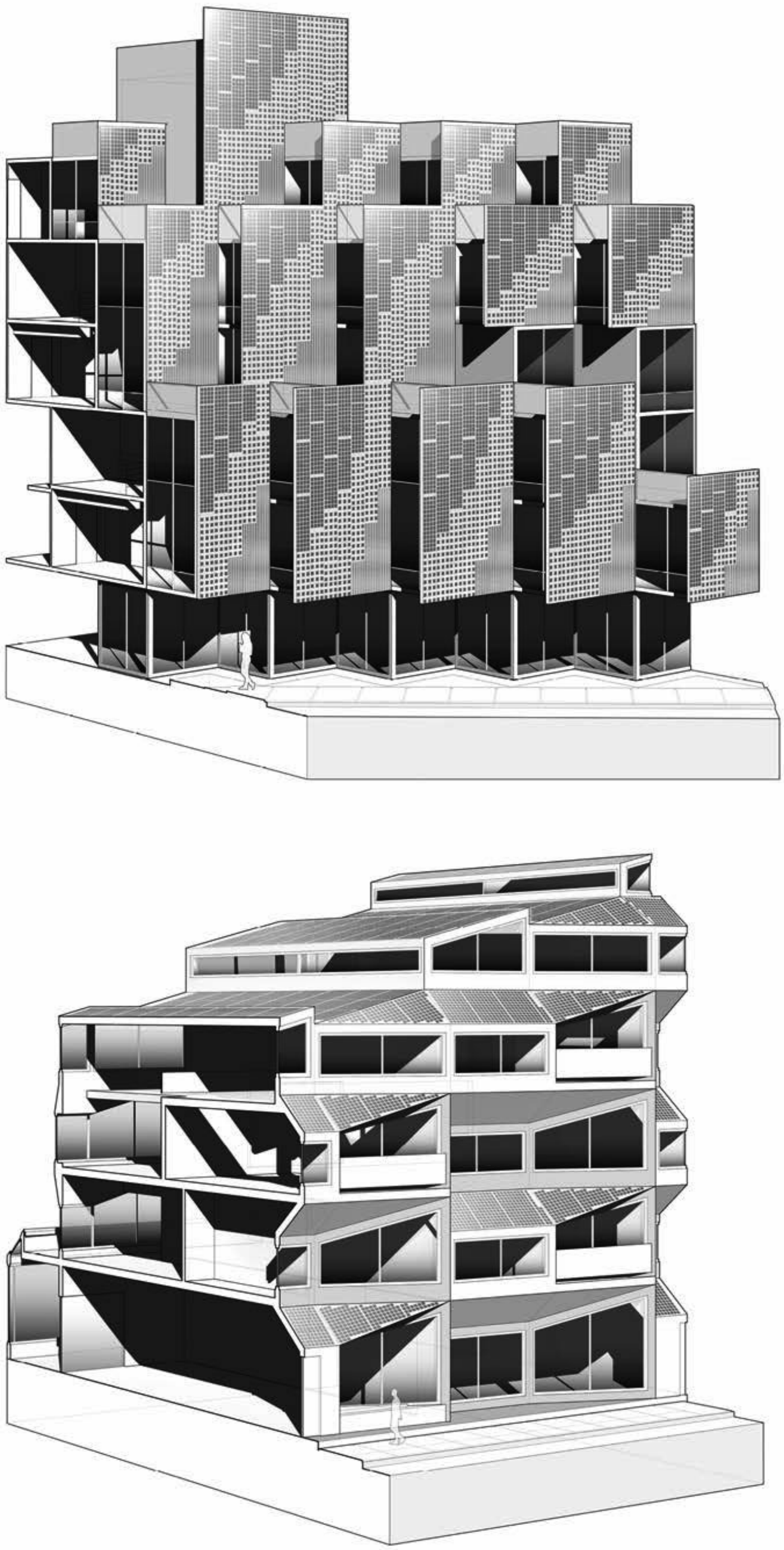

Figure 8. Energy envelopes—east and west orientation integrated facade systems. Blough and Giostra.

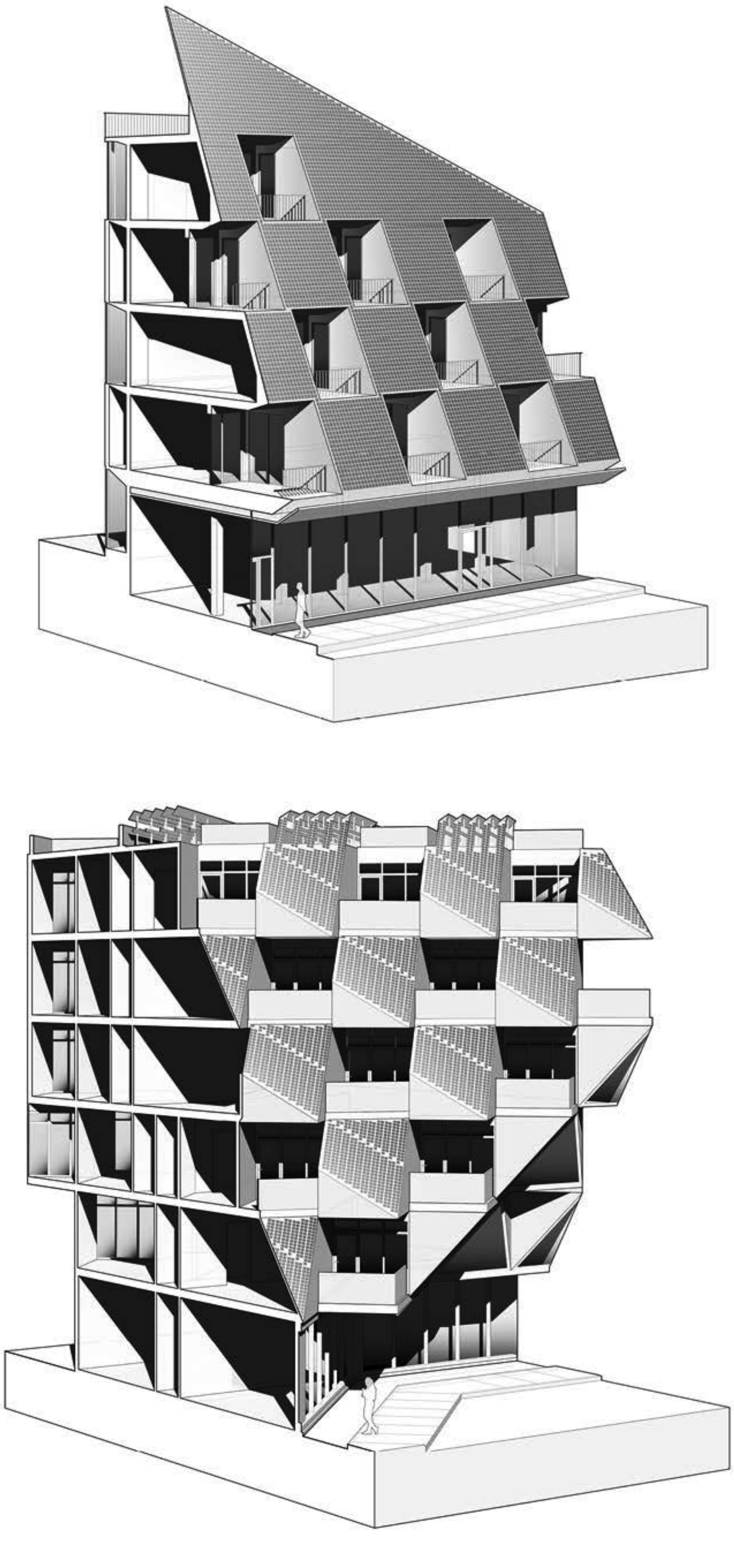

Figure 9. Energy envelopes—south orientation integrated facade systems. Blough and Giostra.

Figure 10. Printed models—surface mapping indicating average yearly solar radiation. Blough and Giostra.