THE LANGUAGE OF SOLAR ENERGY

Research Plan Draft

Bregje Walkate

MSc3 Architecture, Urbanism and Building Sciences

Studio: AR3TA001 Technologies and Aesthetics

INTRODUCTION

When the first solar collector was mounted on top of a building in 1974, the application was first considered as a green and sustainable practise. As more and more solar modules were attached onto already existing building structures and rooftops, concerns started to arise about the integration of the solar collectors in the architectural field. A solar collector or photovoltaic cell is hereby understood as a device that converts sunlight into usable energy.
There are three main types of solar collectors that are used on the rooftops of buildings: photovoltaic (PV) panels that generate electricity, photovoltaic-thermal (PV-T) panels that generate both electricity and heat, and solar thermal panels that generate heat only.
According to Pelsmakers et al. (2022), solar thermal and PV panels are the most suitable options in urban areas, if they are placed on a south-facing roof. This paper is further written according to the use of PV panels.
During the first conference of 'Solar Collectors in Architecture: integration of photovoltaic and thermal collectors in new and old building structures' in 1983, architects argued about the PV panels being an add-on to buildings and some even called the panels 'ugly' and 'eyesores' (Palz, Vianello, & Bonalberti, 1984).

From that moment, architects and building developers have been trying to define requirements for the integration of solar PV panels in architecture. Requirements like the electrical safety regulations or the efficiency rate of the panels, as well as the morphological freedom wherein architects can design the panels (dimension boundaries or a colour palette).
Throughout the years, several theories have been proposed in order to capture these integration requirements, however a univocal consensus among the different stakeholders has not yet been reached according to Haghighi, 2022. In his book 'Architectural Photovoltaic Application' Haghighi highlighted various research projects that defined requirements for integration (2022). He concluded that vague definitions of the concept 'integration' by different stakeholders led to ambiguity in the requirements of recognising integrated PV in architecture. It must be noted that all the defined requirements for integration that Haghighi brought forward, are focussed on the adaptation of the PV panel alone. None of the requirements define alterations that could be made in the architectural building itself or describe the architectural connection between the PV panel and the building.

But it is not only the regulations that are a bottle-neck for the integration of solar PV panels into an architectural design, it is also the architects. Hagemann interviewed various architects and building developers in 1996 and noted that even though all the interviewed architects had added PV panels to at least one of their designs, the willingness to integrate PV panels in a building design was lacking. According to Hagemann, the architects that he interviewed in his research were either missing knowledge about photovoltaics or missing an overall understanding and interest in integrating PV panels into their building designs.

The PV technology industry responded to the lack of interest of architects by trying to alter the design of the PV panels in colour and size to increase their popularity. Architects call these altered panels BIPV (Building Integrated Photovoltaics) as the panels function as a homogeneous element dissolved in the architecture of the building (Haghighi, 2022). Although this BIPV approach is praised by many architects, the BIPV panels account for only two percent of all the PV panels installed worldwide as stated in the report of the market and stakeholder analysis of the BIPV and related technologies, published by the European Commission in 2016. Besides from the BIPV panels, PV panels are still often attached to a building after the design phase, creating a chaotic and incoherent appearance due to window openings or shadowing from the surroundings, see Figure 1&2.

How to proceed?

Is there a way instead of adapting the panels to the aesthetic of the building as a BIPV, which has proven to be a difficult strategy to execute, that the we change the typology of the building instead? And what design requirements would come forward from this approach? Haghighi (2022) also concluded that the integration of PV technology into architecture does not depend on the PV products that are used, but whether or not the PV panels are part of the design concept and design process.

What would happen if architects prioritise the integration of solar panels in the way they design their buildings and cities? Is there a way to integrate PV panels in the building design in such a way that it looks like they belong to the building instead of being added?
This integration could also lead to a more sufficient use of the solar panels. If a building would be perfectly orientated towards the sun orbit, designed with the right angles for the solar panels to optimally gain energy, then less solar panels would be needed in order to gain the same amount of energy. This will reduce machinery costs, material use and maintenance.

A counterargument would be that prioritising the integration of PV panels would be at the expense of other design parameters that are essential in a building design. For example, Hestnes (2000) argues that energy conservation technologies always need to be introduced first in the design progress, passive solar technologies second, and active solar and PV technologies third and last. But, later in her research, Hestnes also states that *"it is necessary to consider the building as a system where the different technologies used are integral parts of the whole"*. As previously discussed, most PV panels are not yet a integral part of the overall design of a building. It is therefore important to find a way in which this could be achieved. When it becomes more clear for architects how to integrate PV panels into their design and as they gain more knowledge of the techniques through which this can be achieved, they will also be more likely to incorporate PV panels into their designs. The greater use of integrated PV panels will lead to more wholesome final building designs wherein the PV panels are accepted instead of being called 'ugly' and 'eyesores'.

This leads to the following main question for this research:

To what extent can PV solar panels be integrated into the architectural design?

How can this integration be optimized and what would be the consequences for the building typology?

Figure 1: No architectural connection between the building typology and the solar panels, Ballygally View Images, Copyright 2021 Peter Steele

Figure 2: Solar panels placed around windows and obstacles, creating a chaotic and incoherent design, iStock/MarioGuti

METHODOLOGY

How to achieve the optimal integration of PV solar panels in an architectural design? Haghighi (2022, p.57) created an overview of different approaches for this integration. The research of Hagemann was the only one that created a definition for the integration of PV panels into an architectural design. During the 12th European photovoltaic solar energy conference in 1996 he stated that:

"for achieving technically and architecturally integrated, attractive and high-value PV applications on buildings, it is necessary that the PV system becomes, on all levels of design and construction, an integral part of an overall concept of a building."

As a result of his research, Haghighi tried to find a universal meaning for 'integration' in the context of photovoltaics (PV) and architecture. He suggested that integration could be seen in the context of *"combining two or more things in order to become more effective."*. He further explained that integration can be described as the process of adding a new aspect to a building system in order to improve the system's performance.

Combining Haghighi his statement together with the introduced concept of PV solar integration by Hagemann it can be said solar PV panels and the architectural design function through a way of synergy. When perfectly integrated, the PV panels would provide an added value to the overall concept of the building while the building design increases the PV panel system's performance. This form of solar-building synergy is visualised in Figure 3.

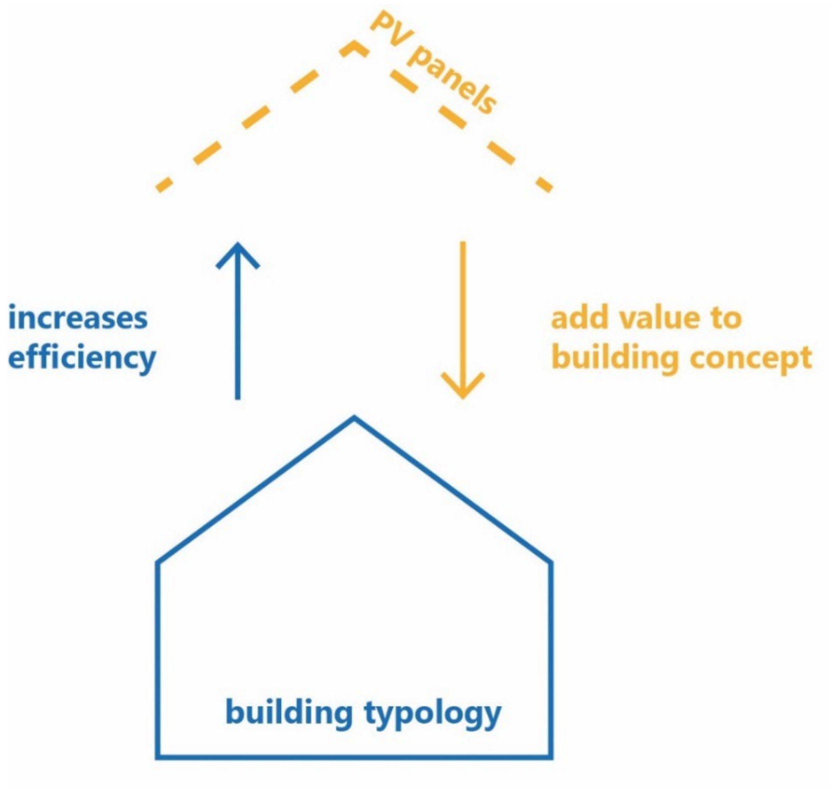

Figure 3: Concept of the synergy between PV panels and building typology in a design, own work

This research will focus on the integration of PV solar panels by means of adapting the architectural form of the building, wherein both parts of the solar-building synergy are represented. This will lead to the development of a solar building typology that will form the basis of a solar panel focussed architectural design.

Design requirements

The first step in this research is mapping out the design requirements for the sufficient placement of solar PV panels on the rooftop of a building. To what extent can the building typology increase the PV panel system's performance? In order to integrate PV solar panels into an architectural design, the solar panels need to function correctly and not be limited by the building design. If a sun panel performs at its best, it will converse its maximum amount of sun energy into usable electricity. Manufacturers call this amount of conversion 'the solar panel efficiency' (Enel X, 2023). At the moment, in 2023, residential solar panels have an efficiency rate of around 15-20%.

The question is raised how the building typology can contribute to this efficiency rate. What changes can be made in the building typology in order for the solar panels to perform well?

In their book 'Designing for the Climate Emergency' Pelsmakers et al. (2022) map out a design strategy for architecture students to create an integrated sustainable design. In chapter 4.5.2 Energy systems, they have mapped out their key recommendations for architects to design their building for solar energy capture systems, see Figure 4.

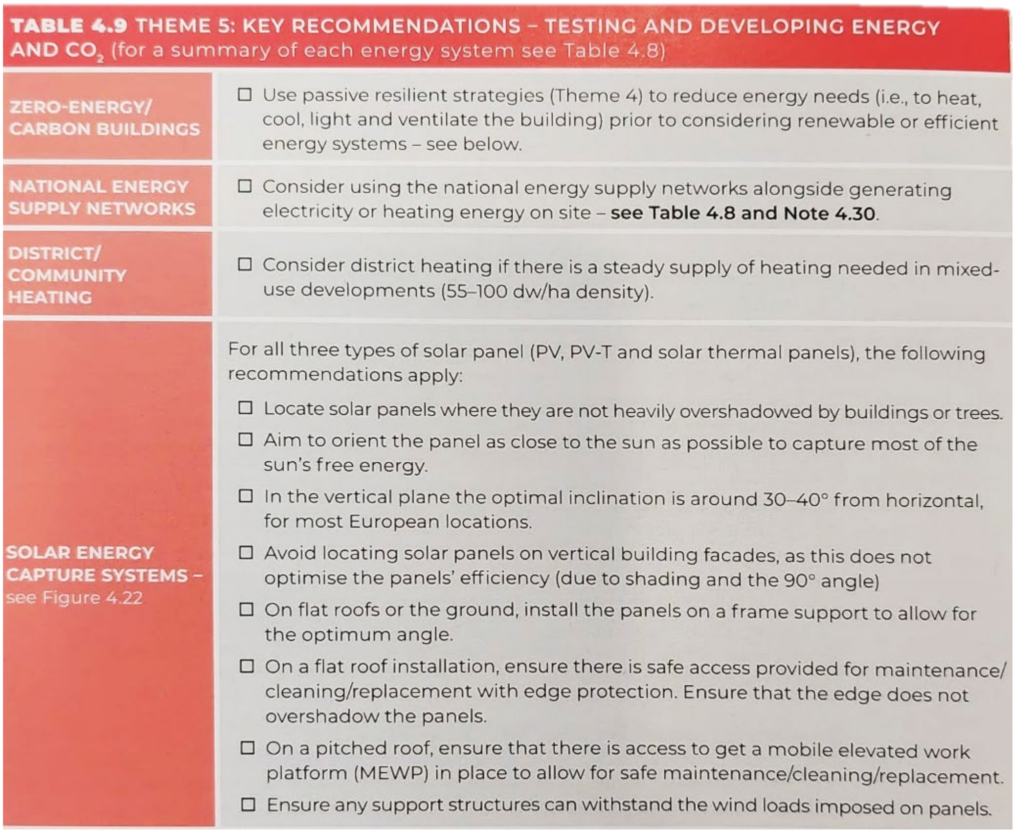

TABLE 4.9 THEME 5: KEY RECOMMENDATIONS – TESTING AND DEVELOPING ENERGY AND CO$_2$ (for a summary of each energy system see Table 4.8)

ZERO-ENERGY/ CARBON BUILDINGS	☐ Use passive resilient strategies (Theme 4) to reduce energy needs (i.e., to heat, cool, light and ventilate the building) prior to considering renewable or efficient energy systems – see below.
NATIONAL ENERGY SUPPLY NETWORKS	☐ Consider using the national energy supply networks alongside generating electricity or heating energy on site – **see Table 4.8 and Note 4.30**.
DISTRICT/ COMMUNITY HEATING	☐ Consider district heating if there is a steady supply of heating needed in mixed-use developments (55–100 dw/ha density).
SOLAR ENERGY CAPTURE SYSTEMS – see Figure 4.22	For all three types of solar panel (PV, PV-T and solar thermal panels), the following recommendations apply: ☐ Locate solar panels where they are not heavily overshadowed by buildings or trees. ☐ Aim to orient the panel as close to the sun as possible to capture most of the sun's free energy. ☐ In the vertical plane the optimal inclination is around 30–40° from horizontal, for most European locations. ☐ Avoid locating solar panels on vertical building facades, as this does not optimise the panels' efficiency (due to shading and the 90° angle) ☐ On flat roofs or the ground, install the panels on a frame support to allow for the optimum angle. ☐ On a flat roof installation, ensure there is safe access provided for maintenance/ cleaning/replacement with edge protection. Ensure that the edge does not overshadow the panels. ☐ On a pitched roof, ensure that there is access to get a mobile elevated work platform (MEWP) in place to allow for safe maintenance/cleaning/replacement. ☐ Ensure any support structures can withstand the wind loads imposed on panels.

Figure 4: Key recommendations for solar energy capture systems (Pelsmakers, 2022, p.176)

This research is focussed on mapping out a building typology that integrates the use of PV panels into the overall design. Therefore, this research will only take the key recommendations in account that could have an effect on the building typology. Those key recommendations are selected and summarized as building requirements below:

- No overshadowing of the panels
- Only panels on the roof
- Orientation as close to the sun as possible
- In the vertical plane an inclination of 30-40 degrees for most European locations

So, how can these design requirements for the use of sun panels be integrated into the architectural typology of a building? Can we adapt the building shape in order to increase the sufficiency of solar panels on its roof?

Building typology experiments will be done that take the previously set design requirements in mind. Is there a way for the PV panels to provide an added value to the building concept? This will lead to a discussion on how PV solar panels can be integrated into the architectural design. How far can architects go in order to integrate solar PV panels in their designs? What architectural expression will come forward? And what impact will this have on our city typology and way of living?

INTEGRATION INTO ARCHITECTURAL DESIGN

This chapter will discuss what building typology comes forward when the design of a building would be integrated and optimized for the use of solar panels.

Considering the design requirements for the use of solar panels on a roof, there are two main aspects that could be integrated into a solar panel based building typology: the prevention of overshadowing and the solar panel orientation. The two aspects raise interesting questions for the creation of a solar panel based building typology: How can the building typology be optimized for the roof to gain maximum access to the sun? To what extent can the building typology be optimized in its orientation towards the sun in order for a maximum sufficiency of the solar panels on its roof? What tools can help an architect to create and design with this building typology?

At first, the building typology will be illustrated that comes forward when the design is fully focused on the accessibility of sunlight. How to change the urban area to give all building access to the sun? What building typology comes forward when a building is designed to never shadow another building around it and gain maximum sunlight during the day, all year long?

Then, the building typology will be illustrated that comes forward when the design is fully focused on the orientation of the building and its solar panels towards the sun. What language would the urban environment carry out when all buildings are oriented towards the sun? How could the optimal orientation and angle for solar panels be integrated in a building design?

SOLAR ACCESS

In 1981, Ralph L. Knowles published his theory on how to design buildings and cities solar access in mind. Knowles stated that society should spend more human energy in designing a framework for urban growth so that in the future less machine energy will be needed to maintain what we build (Knowles, 1981, p. 19). His theory, that he called ‘the sun envelope’, could be a part of this framework.

Knowles describes the sun envelope as ‘a container to regulate development within limits derived from the sun’s motion’ (Knowles, 1981, p7). It is a set of volumetric limits that form a building to the orbit of the sun together with the constraints that prevent the building from shadowing its surroundings, see Figure 5.

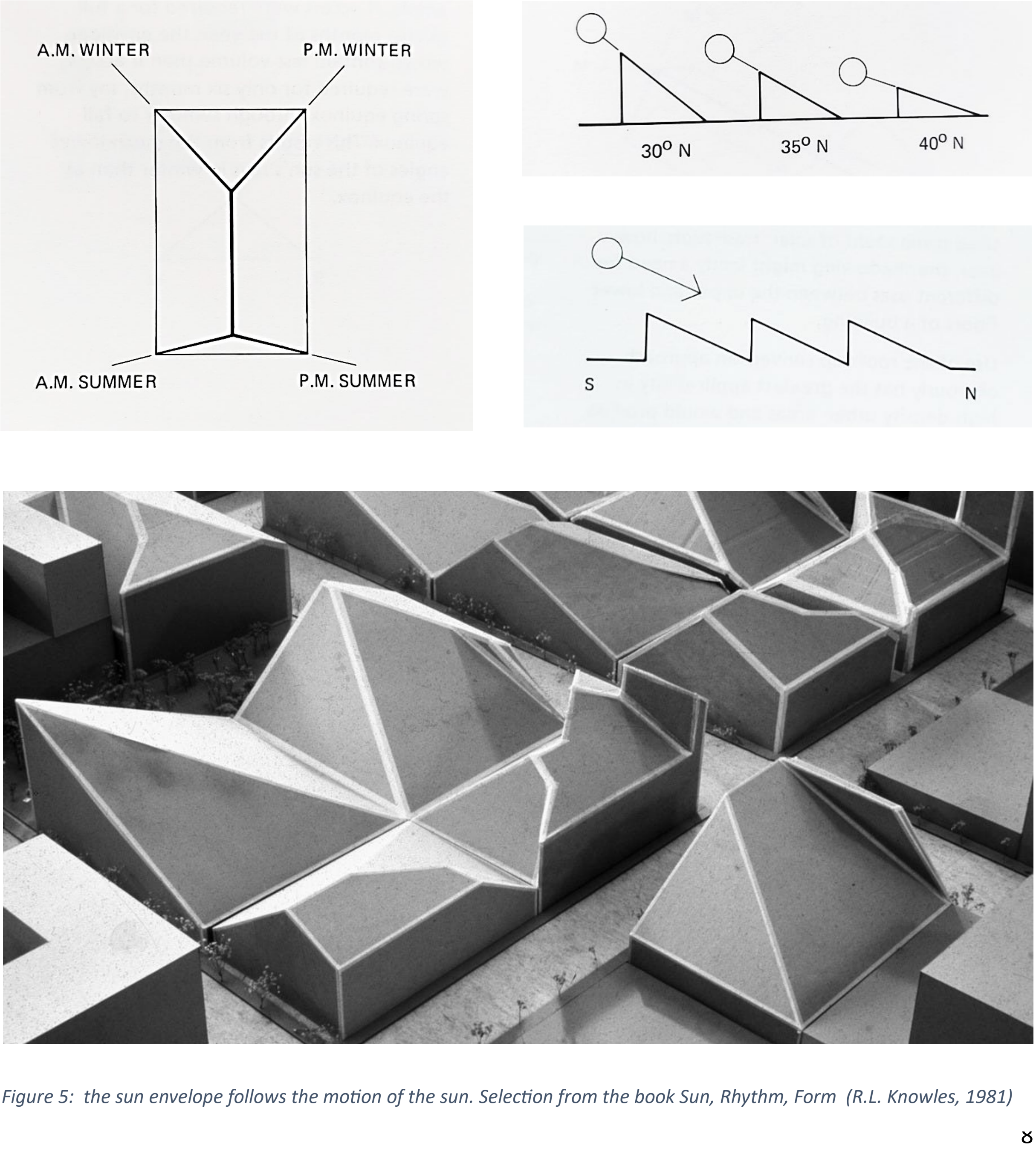

Figure 5: the sun envelope follows the motion of the sun. Selection from the book Sun, Rhythm, Form (R.L. Knowles, 1981)

The sufficiency of PV solar panels most probably will increase when they are applied on a 'sun envelope' building. The placement of the sun panels would also not be limited to the south facing side of the roof, since every part of the roof will have access to the sun at some part of the day. This increases the design freedom and therefore, the design language of solar panels.

Nowadays, Knowles his theory was the starting point of multiple researches that tries to digitalize his sun envelope theory and improve it. Alkadri (2020) presents in his research a comprehensive review of solar envelopes. He focusses on design parameters, digital tools, and the implementation of case studies in various contextual settings. Alkadri does argue that the calculations of solar energy within solar envelopes should take into account the surface characteristics of the surrounding environment. A parameter that isn't taken into account up until today. He also notes that the existing studies on solar envelopes are based primarily on four-season countries:

"The objectives focus on minimizing sun access duration during summer while maximizing it during winter. Accordingly, the concepts and existing parameters of solar envelopes require further adjustments for tropical contexts."

This is an imported note, considering the prognoses for the global warming wherein the world's average temperature will continue to increase. Thus, the adjustments for warmer climates should be taken into consideration.

The remainder of this chapter will further elaborate on the current developments in the solar envelope field and how these could potentially influence the building typology of a solar design.

ORIENTATION

Knowles his theory and even the improved theories by other architects mainly take into account the orbit of the sun. They don't include the 30 to 40 degrees angle of the roof for solar panels to function optimally. This could be desirable, since the solar panels would perform better and less material would be needed for the construction to get the panels to that specific angle.

I have created a small thought experiment wherein I played with various building typologies of an urban landscape of a defined size. What building typologies could be an outcome to catch the sunlight on the roof in a 30 to 40 degree angle and at the same time take the orbit of the sun in consideration as well as not overshadowing the roof of other buildings?

In this chapter there is room for more experimentations like shown in Figures 6, 7 and 8. What other tools, next to Knowles' sun envelope, can architects use to create their own design language together with the sun panels? And what building typologies would follow after that?

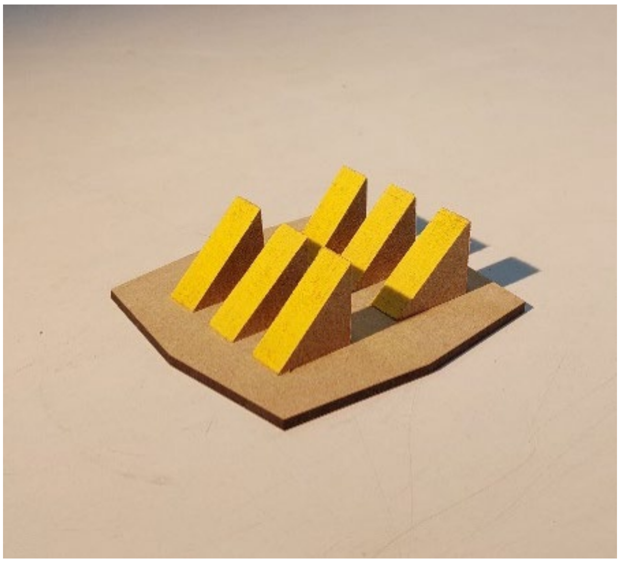

Figure 6: Urban solar typology, experiment 1

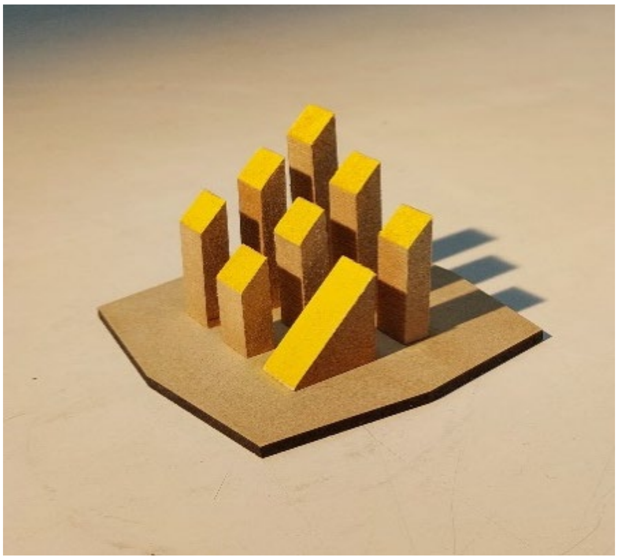

Figure 7: Urban solar typology, experiment 2

Figure 8: Urban solar typology, experiment 3

BIBLIOGRAPHY

Alkadri, M. F., De Luca, F., Turrin, M., & Sarıyıldız, S. (2020). Understanding computational methods for solar envelopes based on design parameters, tools, and case studies: a review. *Energies, 13*, 3302. https://doi.org/10.3390/en13133302

Casey, E. S. (1971). Expression and communication in art. *The Journal of Aesthetics and Art Criticism*, *30*(2), 197. https://doi.org/10.2307/429538

Enel X. (2023). *What is solar panel energy efficiency?* https://corporate.enelx.com/en/question-and-answers/are-solar-panels-energy-efficient

EU. *BIPV Market and Stakeholder Analysis and Needs*; Project Report: R2M, Onyx Solar, Flisom, BEAR-iD, Acciona; EU: Brussels, Belgium, 2016; p. 52

Hagemann, I. (1996). Architectural considerations for building-integrated photovoltaics. *Progress in Photovoltaics, 4*(4), 247–258. https://doi.org/10.1002/(sici)1099-159x(199607/08)4:4

Haghighi, Z. (2022). *Architectural Photovoltaic Application*. BK Books. https://doi.org/10.7480/abe.2022.20

Hestnes, A. G. (1999). Building Integration Of Solar Energy Systems. *Solar Energy*, *67*(4–6), 181–187. https://doi.org/10.1016/s0038-092x(00)00065-7

Knowles, R. L. (1981). *Sun Rhythm Form.* The Massachusetts Institute of Technology.

Palz, W., Vianello, V., & Bonalberti, E. (1984). *First EC Conference on Solar Collectors in Architecture:Integration of Photovoltaic and Thermal Collectors in New and Old Building Structures*. D. Reidel Publishing Company.

Pelsmakers, S., Hoggard, A., Kozminska, U., & Donovan, E. (2022). *Designing for the Climate Emergency: A Guide for Architecture Students*. RIBA Publishing. https://doi.org/10.4324/9781003297246