David or Goliath?
Empowering Architecture through Energy at Scale

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Abstract

The rapid rise and projected growth of solar photovoltaic (PV) energy generation in the United States may be the most physical and visible expression of technology in the American landscape by 2050. Will new PV systems be dominated by Goliath-scale utilities or will David-scale integration with architecture and communities prevail? Determining the future of who controls energy from the Sun will likely be an epic struggle. This paper compares categorical performance characteristics of PV systems at national utility-scale to those at local building-scale, and envisions a future of democratized energy expressed architecturally. This future is illustrated through a design project for existing buildings.

Utility Scale PV (Goliath)

In the last two decades within the United States a conflict has emerged between utility-scale photovoltaic (PV) energy production and production at the scale of individual buildings. Dubbed a “Green Civil War” by the New York Times,[1] the challenge of resolving relationships between land use and renewable energy projects will certainly persist in the coming decades. At a national scale our current electrical utility landscape is densely woven with transmission wires, punctuated with monumental fossil-fuel plants, and now planted with gargantuan solar farm arrays. The dominant industrial-scale, vertically-integrated and centralized-generation system of delivering electricity to the United States has been in place since the early 20th Century. The freedom and control that electric utility companies currently enjoy has logical origins. When the United States began mass electrification around 1900, it was more practical and politically expedient to promote singular utility companies to control, generate and distribute electricity because they could assume the financing, risk, and logistics required to develop a new technology and large-scale systems. The evolution of technological, financial, and regulatory mechanisms has only strengthened utility control and dominance.[2] Members of the general public, including architects, have not typically been directly involved in development of these utility-scale systems and mechanisms. Our contemporary domestic landscape is quickly and visually transforming with the rapid deployment of very large ground-mounted PV arrays sprouting up in rural, suburban and urban places and planted by utility companies and energy developers often in concert with technology corporations hosting large server farms. A profit-driven economic imperative is primarily responsible for this monopolistic transformation.

Economic and Regulatory Performance

Rapid advances in PV technology and lower costs since 2010 have led PV to become the least expensive source of electricity generation in history,[3] currently “almost one-third less than the cheapest fossil fuel globally.”[4] According to the U.S. Energy Information Agency (EIA) national solar installations are at an historic high. Utilities have adopted PV generation to lower their internal operating costs and expand their capacity and revenue. To finance their expansion of PV which includes land acquisition and related transmission infrastructure costs, utilities have been granted significant rate increases by regulators, effectively passing this cost to retail consumers. According to EIA data the average national retail price of electricity increased by nearly 33% from December 2013 to December 2023 with the market cost of rate increases rising from $2.7 billion to $9 billion during this same time period.[5] Investopedia reports the average net profit margin for large-scale domestic utility corporations in the past decade to be 10.88%.[6] Parallel to increased rates and consistent profit, the National Renewable Energy Laboratory (NREL) reports the median installation cost of utility-scale PV has decreased by 82% since 2010.[7] However, this decrease in cost only reflects the purchase and installation of the PV systems. The regulatory permitting process adds additional expense, in part because of the lengthy time required for review and approvals through local, state and federal levels. The Solar Energy Industries Association (SEIA) reported in 2023 that the permitting process for a utility PV project requires from four to five years to complete, with an average of 300 projects approved annually.[8] They note that in comparison, approximately 3,700 permits to drill for oil and gas are approved annually.

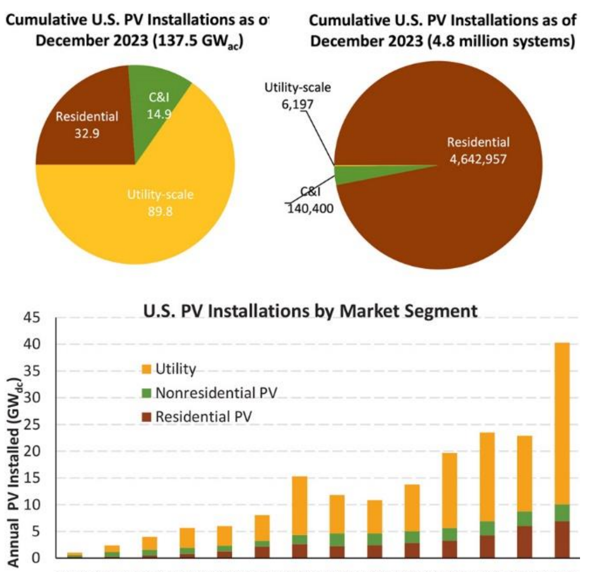

Fig. 1. Growth and Share of U.S. P.V. Installations. Source: EIA

The EIA reports that utility PV installations have doubled since 2020, adding 30.2 GW in 2023 (Figure 1) in 399 installations, an increase of 114% from 2022. This accounts for 4.2% of all national PV installations and translates to more than 60 million PV modules added annually to the national landscape, an average of more than 150,000 modules at each new utility installation.

Functional and Experiential Performance

As of 2023, the EIA reports that 65% of nationally installed PV capacity is dominated by utility-scale arrays yet they only comprise a small percentage of total installations. Electric utility corporations control the vast majority of these arrays functioning to directly serve their retail customer base and the majority are sited on purchased or leased land. In recent years power developers have joined with large tech giants to form power purchase agreements (PPA) in which the developer provides the PV array and electricity through contract with a sole corporate user who exclusively buys the power for a fixed price over a fixed period of time. This single function and transaction primarily benefit the seller and buyer.

Fig. 2. Amazon Baldy Mesa 150MW Array. Source: Amazon

According to Bloomberg NEF the national corporate leader in PPA is Amazon which secured 74 individual PPA in 2023 alone, adding in comparison nearly 6 GW of PV generated power equivalent to 7% of all utility-scale installations added nationally in that year.[9] The land that typically serves the singular function of hosting these colossal PV arrays are frequently surrounded by security fencing or sited in remote areas. The 150 MW Baldy Mesa PV array completed in 2024 in the Mojave Desert through a PPA exclusively serves Amazon AI, according to an Amazon press release.

More than 83% of these vast arrays displace former range and agricultural land and currently cover over 2.5 million acres, and are projected to cover 7 million acres by 2040.[10] The U.S. Bureau of Land Management announced plans in 2024 to develop solar on 31 million acres of public land. Will this dramatic and singular function of land use by utility companies continue to be accepted by the American public? How will this affect future public experiential perceptions of the transforming domestic landscape? The perceived qualities of utility-scale PV can range from sublime to ignoble.

Some insight on public perception of the experiential and aesthetic qualities of utility-scale PV are revealed through information provided by the Ohio Power Siting Board (OPSB), an official state board that addresses energy policy, siting review for energy facilities, and the protection of environment and land use in Ohio. From 2019 to 2021 the OPSB approved 26 applications for utility-scale PV projects with no denials. From 2022 to 2024 they approved 14 applications with 5 denied or withdrawn. Reasons cited for the 46% decrease in approvals included a dramatic rise in public objections to the reduction of agricultural and rural character, ecological disruption, and general aesthetics of the environment all threatened by utility-scale PV and framed as “public interest” denials based on strong local opposition. By 2024 in Ohio, 26 of 88 counties had passed bans and exclusion zones on large scale PV.[11]

It is fair to note that some utility-scale PV development has recently included efforts to address some perceived environmental improvements such as planting trees at the perimeter of array fields or allowing continued animal grazing practices on the occupied land. The Amazon website features a story about a Kentucky sheep rancher who leases land to the solar developer Silicon Ranch, and sheep are allowed to graze under the PV array. The story notes that the rancher sells meat to a distributer who supplies to Whole Foods Market, owned by Amazon.

Building Scale PV (David)

At the local level, our neighborhoods and communities have seen a dramatic rise in PV installations. It is now common to see parking lots, houses, commercial buildings, and institutional buildings hosting PV arrays. Small-scale PV installations have doubled since 2020, adding 10.1 gigawatts in 2023 in 880,000 residential installations and 13,000 non-residential installations, an increase of 15% from 2022.[12] The magnitude of this physical change is evidently normalizing public perception and acceptance of PV. However, architects are rarely involved in the design of these installations.

The United States is presently challenged with an increasing demand for electrical energy and the U.S. Department of Energy predicts demand increases of up to 20% by 2035 and doubling by 2050 when the nationwide goal of reaching net-zero emissions is targeted and renewable energy sources are projected to dominate electrical generation. PV systems integrated with buildings can make a vital contribution to meet this demand, especially for existing commercial buildings.

Numerous local communities experience a persistent challenge in how to upgrade their aging existing commercial building stock. According to a 2024 study at the University of Michigan, the majority of existing commercial buildings typically lack energy efficient HVAC and envelope technologies and consumed a disproportionately high 17% of all energy in the U.S. in 2024.[13] A 2019 report by the American Institute of Architects indicated that nearly half of all U.S. architectural billings were from work on existing buildings, citing this work as “one of our greatest opportunities” with the potential to “improve the energy efficiency of

America's building stock and unlock social and economic benefits."[14] America's commercial building stock is currently comprised of nearly six million buildings of more than 97 billion ft^2. Another AIA report argues that architects should shift their attention to a more "mature practice area" of deep-energy retrofits of existing buildings, including envelope improvements, updating electric HVAC systems, and implementing integrated on-site photovoltaic (PV) arrays.[15] For architects, the majority of high-performing building design efforts have focused on producing highly-efficient new buildings, largely due to easier adoption of new technologies in new construction.

Energy efficient design in the existing building stock is a less mature practice area for architects, despite the fact that each year another 5 billion square feet of existing buildings are renovated—equal to the yearly total square footage of new construction according to a 2023 study by The Real Estate Roundtable, a real estate policy think tank. When layered and examined holistically, the confluence of increasing national electrical demand, the necessity of annually renovating existing buildings, the significant quantity of existing buildings, and the potential for architects to more enthusiastically engage deep-energy retrofits of existing buildings all make a compelling argument for exploring ways in which large PV arrays can be integrated with existing commercial buildings to achieve their own net-positive on-site energy production without combustion. A 2016 study by NREL outlines this potential for commercial buildings in a range of local communities.[16]

This study defines the technical potential of rooftop solar photovoltaics through detailed data-driven analysis utilizing light detection and ranging (lidar) data, geographic information (GIS) system methods, and PV-generation modeling to determine suitable rooftop area for PV arrays and technical electricity-generation potential. By its stated methodology the NREL study provides accurate in-depth data and predicts that 38.6% of national electricity use can be potentially generated with rooftop solar. The study provides an upper bound on potential rooftop PV deployment and is based on data from 128 cities representing 23% of existing buildings in the United States. The study examines PV hosting potential in small, medium, and large building rooftops. The criteria used in the study to determine the suitability of roof area for hosting PV is based on shading (energy production not less than 70% of an identical unshaded system in the same location), tilt angle (no greater than 60-degree tilt), azimuth angle (not facing north), and contiguous roof area (at least 1000 ft^2 available). The NREL study reveals important data regarding distinctions between small, medium, and large buildings. According to the study only 26% of the total rooftop area on small buildings is suitable for PV deployment yet accounts for 65% of total technical generation potential. Small buildings have a national total suitable rooftop area of 52.96 billion ft^2. More than 99% of the total rooftop area on medium and large buildings are suitable for PV arrays and account for 35% of total technical generation potential nationwide. Medium and large buildings have a national total suitable rooftop area of 34.55 billion ft^2.

The city of Detroit, Michigan created a Detroit Solar Map (Figure 3) using this NREL data to communicate the potential for rooftop PV on buildings within the greater metropolitan boundaries.

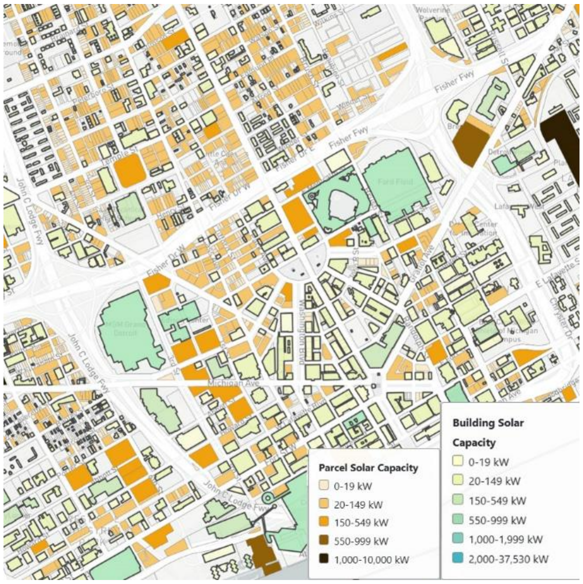

Fig. 3. Detroit Solar Map PV Potential. Source: City of Detroit

The Detroit Solar Map demonstrates significant rooftop PV potential in a city filled with existing commercial buildings. A paper published in 2024 by the Environment America Research and Policy Center outlines the rise of rooftop solar in the last decade and specifically identifies PV potential based on regions and states.[17] The study reveals that the Midwest region currently generates less energy from rooftop PV than any other U.S. region "but not for lack of potential" and the upper Midwest has "prime real estate for solar installations." The EARPC paper highlights the top ten states for rooftop PV potential and the percentage of potential tapped through 2022. Michigan is highlighted with the greatest potential of the top ten states with only 0.43% of rooftop PV potential activated in 2022 and a projected potential of generating 58 TWh/year from rooftop PV alone, within the state. The architectural challenges of integrating large PV arrays with existing buildings can best be addressed in a specific regional and local context. Understanding that 99.57% of building-integrated PV potential is untapped in Michigan provides a compelling rationale for exploring PV application at the scale of existing Detroit commercial buildings.

Detroit is nationally recognized as a locale experiencing a tremendous rebirth of vitality and transformation. The municipal area hosts a significant number of existing commercial buildings that have been renovated in the last decade and a significantly larger number of buildings that have potential to be renovated with electrified HVAC systems and transformed with PV integration. As an automobile-centric city, most existing commercial buildings have a large site area that includes a parking lot. These buildings are relatively simple with few distinguishing architectural features and can easily accommodate large integrated PV arrays based on size, configuration, and available roof area. The context of Detroit inspired this author to envision a design research project to test the potential of integrating large PV arrays with these existing buildings.

Economic and Regulatory Performance

Designing large PV arrays integrated with existing Detroit Buildings presents both opportunities and challenges. It is important to distinguish between the economic and regulatory factor distinctions that guide building-scale PV from those that inform utility-scale systems. From an economic perspective, the direct cost of building-scale PV is more expensive than utility-scale PV primarily due to issues of scale. However, they are not fairly comparable on a levelized cost basis because only building-scale PV delivers power at the point of use. According to a recent report by Wood Mackenzie the cost of a commercial-scale fixed-tilt PV array in 2024 was \$1.44 per watt and the cost of a utility-scale fixed-tilt array was \$0.95 per watt.[18] However, this direct cost comparison does not account for high variability in the cost of transmission infrastructure for utility-scale PV which increases dramatically with the distance between the PV array and point of delivery and can add up to 25% to the total cost. Cost related benefits to building-scale PV include elimination of line losses and distribution maintenance, and reduced risk or service disruption from weather events.

As costs are also a function of implementation time, building-scale PV systems average one year while utility-scale average four to five years. Time of installation is also related to the time in which lower cost PV electricity can reach the grid and supplant fossil fuel generated power. In a direct comparison using PV systems installed in 2023 with data by NREL, for each single utility-scale PV installed with an average capacity of 75.6 MW, an average of thirty-three commercial-scale PV systems can be installed with an average total capacity of 81.2 MW. In another direct comparison made by a Clean Technica report the 550 MW Topaz PV utility-scale array in California took six years to develop and complete during which time over 8,000 MW of small-scale PV were installed nationally. Smaller PV systems produce more power in less time.

Compared to the generally predictable regulatory factors that govern implementation of utility-scale PV, the factors influencing building-scale PV include more variables and vary widely between regions and states. As of 2024 only a small number of states have regulatory policies that strongly support development of building-scale PV. This is illustrated vividly in a graphic scorecard produced by the Institute for Local Self-Reliance evaluating state policies on local clean energy action.[19]

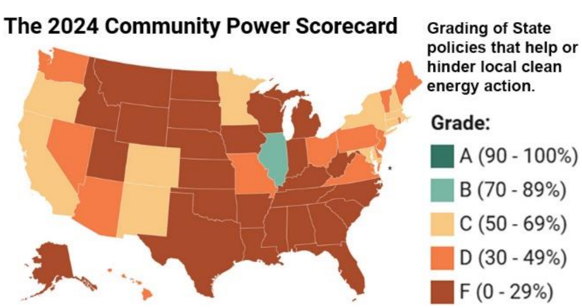

Fig. 4. Regulatory Policy Performance Grades. Source: ILSR

Illinois was rated as the state most supportive of PV net-metering policy, third party ownership, interconnection, hosting capacity analysis, community solar, community energy choice, franchise authority, renewable energy portfolio standard, and integrated resource plan approval. Massachusetts is another state that significantly improved support for building-scale PV in 2024 when the Massachusetts Department of Public Utilities issued an order improving the state's net metering program. A 2024 article in PV Magazine highlighted the most important provision that exempts facilities that serve on-site load from net metering caps if they are less than or equal to 2MW for private buildings or 10MW for public buildings.[20] This range covers most existing commercial building and site capacity to host a large building-scale PV system. The article also notes that Massachusetts has already met 10.8% of its building-scale rooftop PV generation potential, compared to Michigan's 0.43% as noted previously. Unfortunately, a significant number of States were graded as F relative to these types of positive building-scale PV policies, including Michigan.

Functional and Experiential Performance

Even within a tolerable or unfavorable regulatory context, the functional and experiential characteristics of building-scale PV are positive and differ significantly from utility-scale PV systems. Perhaps the most important function is that building and site integrated PV deliver power directly at the point of use. Depending on available area and building use-type, building-scale PV can directly produce 100% or more of a building's annual electrical consumption. When considered on an individual existing building basis, each building retrofit can assume an upgraded envelope and all-electric HVAC system to significantly reduce energy use intensity and include a battery back-up system to allow the building to function independently from an energy perspective. A key point is to recognize the under-utilized or singular functions of existing buildings and sites, and also recognize the energy transformation potential through building renovation and retrofit. Building-scale PV can be deployed in a variety of functional positions including on rooftops, terraces, facades, shading devices, courtyards, entry canopies, towers, and parking lots. In this way, they extend the range of functions provided by an existing building and site.

These functional transformations are related to potential changes in the experiential and aesthetic dimensions of existing buildings. With the assumption that the majority of existing commercial buildings, especially those in Detroit, are rather plain and simple, large building-scale integrated PV systems have the potential to be employed in the service of transforming the aesthetic expression and character of each building. Considering PV modules to be elements of artistic potential directly infers they can be used to modify scale, size, proportion, translucency, transparency, opacity, and color for positive experiential effect. In the context of each unique existing building, PV modules can create new exterior space transitions or extensions, transform the expression of a perceived roof or wall plane, create dynamic light and shadow effects, transform interior light qualities and effects, and complement or radically alter the existing character of building architecture and sites. When integrating a large PV array with an existing building or site the aesthetic opportunities of the mounting armatures are an additional element to consider artistically. A broad range of structural and mounting support morphologies can be introduced with elegant proportions and configurations while strategically integrating with existing building structural systems and form or the metered dimensions of a parking lot.

To place this experiential potential into perspective it is appropriate to reflect historically on the aesthetic expression of energy in American architecture. In 1776 most buildings in the United States burned wood for energy, especially in cold climates. Buildings literally and physically expressed this energy through prominent integrated fireplaces and proud chimneys. The Industrial Revolution and transition to coal expressed an architecture of furnaces and monumental smokestacks at the scale of individual buildings. With the introduction of methane gas and the advent of new HVAC technologies, buildings began to conceal the expression of energy systems in all buildings throughout the 20th Century. Our contemporary advances in PV technology and rapid adoption demand a new and revealed expression of energy in architecture. This expression explicitly means that buildings will have very large and visible PV systems integrated with the architecture of each existing building and therefore the expression of energy will be dominant in perception of the architecture.

A Test of Location Specific Building PV (Detroit)

To test and demonstrate the potential of integrating large PV arrays with existing buildings a design project was undertaken in the context of Detroit, Michigan and with a process guided by the parameters of building use selection, building site selection, technical performance criteria, and experiential performance criteria.

Specific building use types selected for this design project include a gas station convenience store, a grocery store, a mosque, a high school, a large regional museum, and historic library. The selection includes use-types common to most mid-sized U.S. cities with historic high annual energy use intensity, based on 2024 data from the US Department of Energy and the Energy Star Portfolio Manager Data Explorer. The selections and the results of this design project are therefore transferrable to several million existing buildings throughout the region and nation.

For each of the selected building use types an initial calculated estimate of building area and energy use intensity adjusted for ASHRAE climate Zone 5A is used to determine overall energy used annually. The EUI values are determined using the Energy Star Portfolio Manager Data Explorer.[21] This value is then used to make a preliminary determination of the size of a PV system and subsequently a selection of a finite range of specific PV modules available through U.S. manufacturers. The size of each specific module, and the total quantity of modules required, then determine the overall gross area of coverage required for a PV system. This overall area of coverage is then used to determine specific existing buildings on specific sites in the Detroit metropolitan area that conform to the building use type determined previously and possess the site and building capacity to host the required size of a large PV array. Six specific buildings are located to proceed to the design process.

The design process tests the application of specific technical and experiential performance criteria for a large PV array integrated with each of the individual buildings. The technical performance criteria include PV array design to exceed the annual energy use of each building by 130% in the first year of service and meet 100% in the thirtieth year to maximize system life-span. Each array utilizes high-efficacy PV modules configured and optimized for energy production in the context of site and building configurations, tilt angle, and azimuth orientation verified through PV Watts analysis, the online tool operated by NREL.[22] The designed arrays are very large, with significant experiential impact. The experiential performance criteria include a design for each system to create a new perceived roof form, new transitional exterior space and form, and create dynamic light and shadow effects on exterior and interior spaces. These effects are produced with PV modules and a range of structural support morphologies unique to each building and configured with elegant proportion while connecting directly to the existing structure of each building. The design transformation process proceeds from an existing building, to structural support, to full array, to fully transformed building and experience (Figure 5). The full range of transformations of six Detroit buildings offers a creative demonstration of translating performance criteria into tangible energy expression for existing commercial buildings (Figure 6). This expression foregrounds large PV arrays as essential architectural elements fundamental to positive human perceptions and the direct experience of energy systems at the scale of buildings.

Concluding Assertion (David Over Goliath)

This project asserts the positive potential for a greater democratization of energy in the United States. Compared to the monopolization of utility-scale PV, building-scale PV demonstrates several advantages for making energy accessible to society and for people to understand where energy comes from and how it is made and used. Perhaps the greatest advantage is in the delivery of electrical power directly at the point of use. The cost savings and resiliency benefits include minimization of line distribution losses, distribution maintenance, and reduced risk or service disruption from weather events. Land use benefits of building-scale PV include siting on rooftops, parking lots and other large underutilized and already developed areas serving singular functions. This is in stark contrast to the land area and virgin land types often required for utility-scale PV and the associated distribution pathways. The lengthy and costly implementation time frames for utility PV are no match for the rapid deployment of building-scale PV.

This design project defines an active strategy, one building at a time, for an achievable national transition to renewable energy generation. This transition supports a society where people are able to choose, use and experience energy created directly on the buildings that they own, occupy and appreciate.

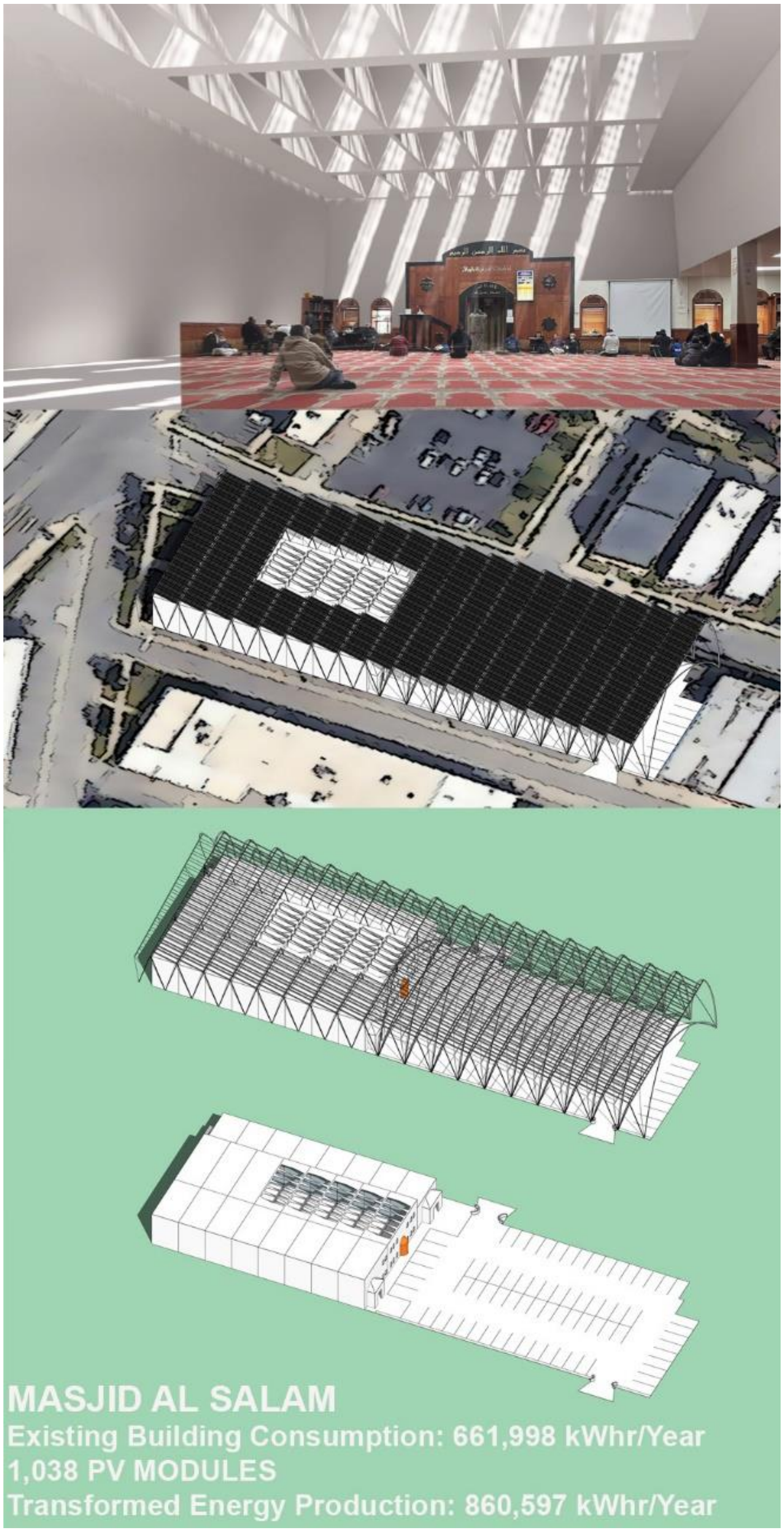

Fig. 5. Transformation Process. Source: Author

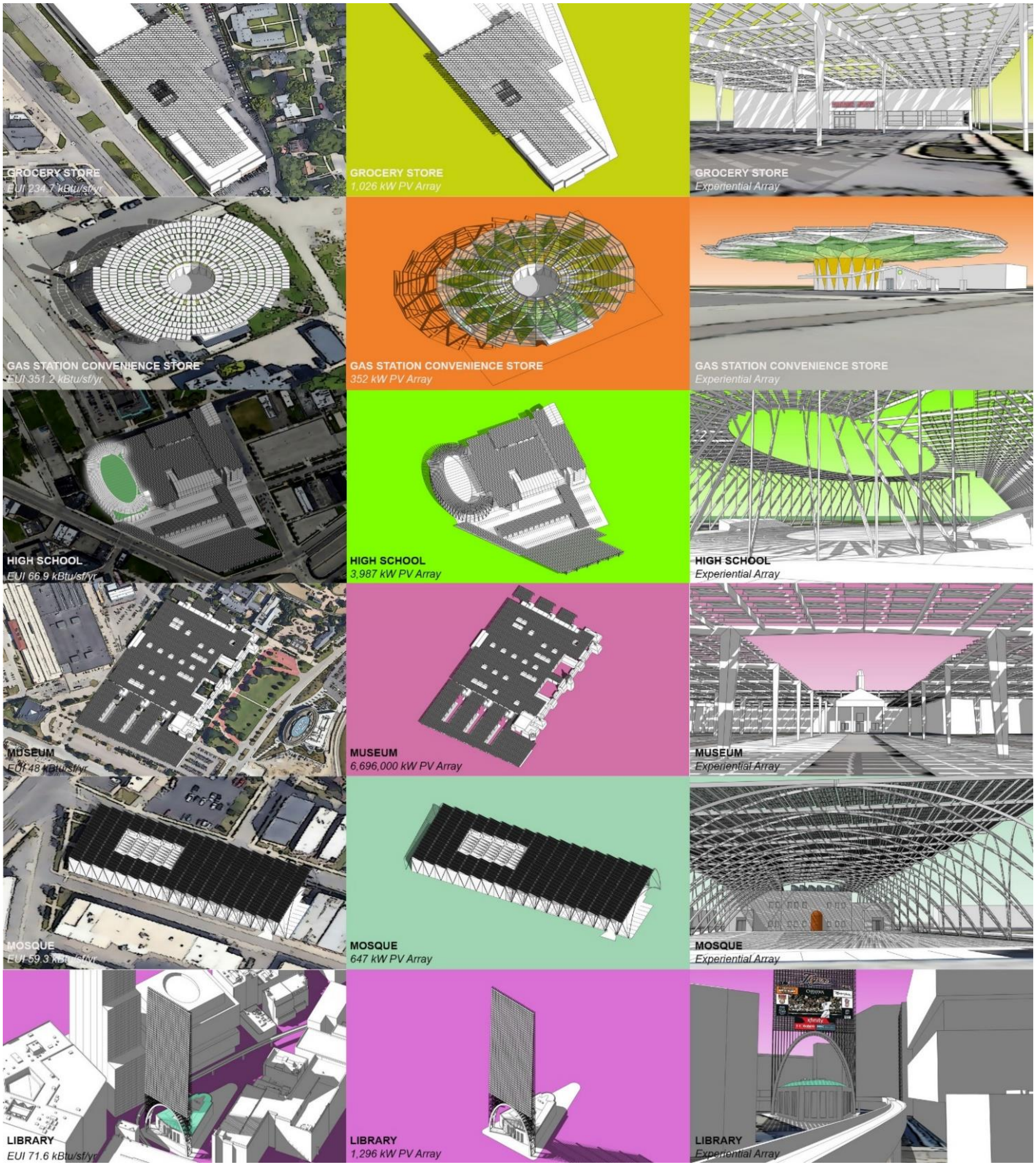

Fig. 6. Six Existing Buildings Transformed with Net-Positive PV Arrays in Detroit, Michigan. Source: Author

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