Architecture Center for Responsive Enclosures: Towards an Interdisciplinary Research Model

This paper will trace the evolution of a nine month research project granted by a new initiative from Pratt Institute's provost. The Innovation Fund was created as seed money to incubate research centers in an art and design institution that has very little history conducting research. Proposals ultimately had to demonstrate the ability to secure government or private foundation funding for continuation of the work and meet the goals of the Institute's strategic plan. The analysis and types of data collection employed, the design work that was produced, and the partnerships that were fostered, will be discussed within the larger objective to build a model to conduct architectural research.

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Obstacles and opportunities within our institution played a critical role in development of our proposal, and this creates a context from which to reflect on our approach as a case study for further investigation. Most importantly this paper will document how unique interdisciplinary collaborations (engineering, manufacturing, geographic information visualization) were formed to produce knowledge that addresses a larger cultural context outside of the typical architectural design problem.

Over the past six years, New York City has promoted energy efficiency policies – including 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 research investigates the important environmental design opportunities that exist within building envelopes, particularly in large commercial and residential structures that are responsible for most of the greenhouse gas emissions and power consumption. Following the current and former Mayoral administration's plans to increase the energy performance of the New York City's buildings, our work targets innovative façade strategies that generate on-site renewable energy, are highly energy efficient, and produce a new vocabulary for sustainable construction.

BACKGROUND

For the last year, we have begun to explore the feasibility of Building Integrated Solar Thermal (BIST) applications for New York City's mid- to high-rise buildings.[1] Solar thermal energy, an existing technology used to harness sunlight to produce heat, can be collected and stored for space heating, to cool buildings through thermally powered chillers, and to produce domestic hot water (DHW). Historically used on rooftops, the technology has evolved for vertical applications and is being widely adopted in Europe with proven results. By addressing the design and engineering barriers that hinder the adoption of solar thermal technology in the US, we plan to investigate, prototype, and test a large scale building component in collaboration with industry and engineering partners. This research presents opportunities for innovation by creating environmentally responsive and resilient buildings by integrating and extending current solar thermal technologies for the predominantly vertical infrastructure of New York City.

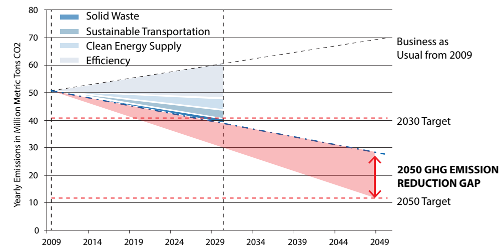
Although solar thermal is a mature technology, it has yet to play a substantive role is reducing fossil fuel consumption. "The generally low architectural quality characterizing existing building integrations pinpoints the lack of design as one major reason for the low spread of the technology".[2] The example of photovoltaic applications has demonstrated that well designed building integrated systems can increase the use of solar thermal systems even more than price reductions and technical advances. This is an argument not only for the value of design but particularly as it bears on the acceptance of new technologies by the general public and the implementation by building owners in particular.

Being that we had less than a year with $20,000 in seed money to conduct research and produce documentation to build an argument, our strategy was to develop a preliminary proof of concept supported by data from a range of sources and disciplines This content would then be used to apply for a larger government grant to flesh out the investigation with the future goal to produce a prototype for testing and data collection. We started with investigating New York's energy use, solar thermal initiatives, policies and barriers, and current available solar thermal technologies. The following is a summary of our findings that form a context for the analysis and design thinking of our proposal.

ENERGY CONSUMPTION AND EMISSIONS

In New York State, buildings represent over 60% of energy consumption by end-use sector.[3] In New York City 45% of that energy is used for space heating and DHW with nearly all of this energy produced by burning oil and natural gas in basement boilers.[4] The Bloomberg administration's PlaNYC 2030 identified the potential impact of global climate change as one of three major challenges toward improving the physical environment of NYC and created an inventory identifying GHG emissions emitted by sector and source. Building heat and domestic hot water contributed the largest share at 43.4% – the equivalent of over 23 million metric tons of CO2 per year or the amount of carbon sequestered annually by a pine forest larger than New Jersey.[5]

PlaNYC 2030 set an ambitious target to reduce citywide GHG emissions by 30% by the year 2030 and by 80% by 2050. New York City will need to deploy a range of initiatives such as energy efficiency, clean energy, sustainable transportation, and waste management to achieve its emissions reduction goals. To date, however, NYC has not developed a comprehensive initiative focusing on renewable energy technologies to serve heating and cooling loads. A study by Meister Consultant Group found that if GHG emission reductions continue at currently projected rates, NYC could face a 15.7 million ton annual shortfall in GHG emission reductions by 2050, represented as "the missing wedge" in a graph



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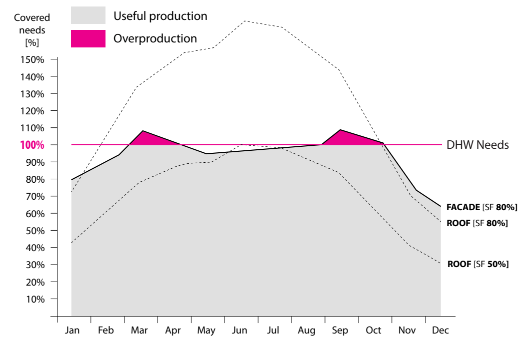

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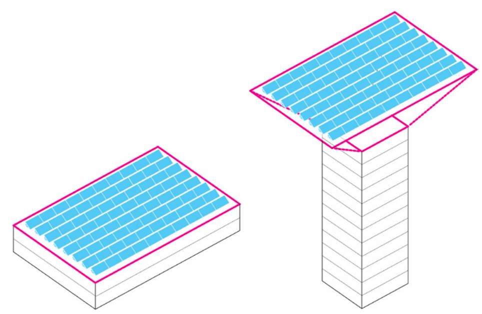

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Figure 1: *The Missing Wedge, GHGe Reduction Strategies (NYC Solar Water Heating Roadmap - CUNY)*

Figure 2: *Roof vs Facade Applications (Architectural Integration and Design of Solar Thermal Systems - Probst & Roecker)*

Figure 3: *Roof Surface Area to Floor Area Ratio: Low Rise vs. High Rise (Blough & Giostra)*

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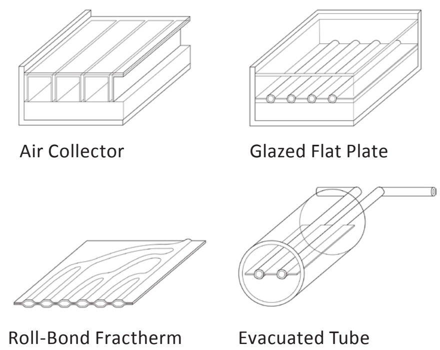

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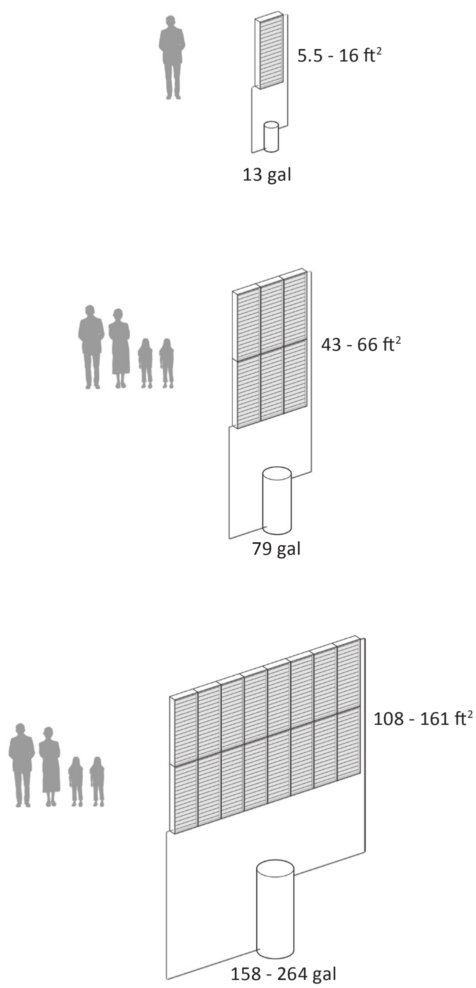

Figure 4: *Current Technologies* (Solar ArchitectureSchittich)
Figure 5: *Collector and Storage Sizing; Top: Large Collective Comsumers - DHW; Middle: One Family Home -DHW; Bottom: One Family - Combi* (Blough & Giostra)

mapping the data.[6] Solar thermal is a key technology that can fill this gap to meet emission reduction targets (Figure 1).

The US is woefully behind the EU in solar thermal capacity. The 2008 DOE/EIA Annual Energy review for the US shows solar thermal capacity at 7,600 MWth, which is only .06% or the entire country's energy usage. In the European Union (EU), renewable heating and cooling technologies are considered the energy sector's "sleeping giant", with predictions placing these technolgies as the largest contributor to meeting energy demands by 2050. The solar thermal market increased fourfold in the EU from 2002 to 2008, where over 25% of heat consumed is planned to be generated with renewable energy by 2020 and over half by 2030.[7]

SOLAR THERMAL INITIATIVES

A number of initiatives and feasibility studies for solar thermal in the State and City have recently been carried out by various government, academic, and industry entities such as NYC's Office of Long-term Planning and Sustainability, NYC Economic Development Corporation's Solar Thermal Pilot Program, New York Solar Consortium, and Sustainable CUNY. These studies indicate that creating strong demand for solar heating would allow NYC to lower fossil fuel consumption, reduce GHG emissions and create jobs by deploying proven and cost-effective renewable technologies. NYC is considered one of the most favorable markets in the state for solar heated DHW because of good levels of solar radiation and with fossil fuel costs among the highest in the country.[8] However, although New York State has 25% more available solar energy than Germany, it produces 1000 times less MWth of solar heat per capita.[9] The New York Solar Thermal Roadmap's 2020 target for New York State is an installed capacity of 2000 MWth from the current 6 MWth. Based on combined 70% residential and 30% commercial installations, the Roadmap estimates $2.6 billion in revenue, the creation of 24,000 new jobs, and the reduction of 350,000 tons of C02 yearly. Yet growth in this market has been slow with only 43 known solar thermal installations in the five boroughs since 2003 in a city with over one million buildings. In contrast, over 560 photovoltaic systems have been installed in the City. Why is solar thermal not being aggressively adopted when it can provide up to 60% of DHW needs, is five times more efficient than solar electric and is a more cost-effective technology?

BARRIERS

There is a consensus in the initiatives outlined above identifying barriers to expanding solar thermal in New York State. The goal of our research and design approach is to help mitigate these barriers and foster policy change. Current policy lacks incentives for solar thermal with bias towards displacing electric water heating. Oil and natural gas systems make up almost the entire heating market yet alternatives that offset their use are not currently funded. New York City has high permitting and inspection costs within the residential sector that account for 32% of the total installation costs compared to up 5% in California.[10] High first costs are also due to a learning curve and the need for scalability. The EU has demonstrated that a 50% cost reduction is attainable by doubling the total installed collector capacity over 15 years.[11] If the energy growth rate remains high as in the past decade, most solar energy applications are already cost competitive.

In the 1970s and 80s the public perceived solar thermal to be unreliable with short life spans due to poor system integration and installation. There is also a lack of performance data as solar thermal systems are not commonly metered so the public is unaware of the environmental and cost benefits of the latest technologies. This data is critical for life cycle cost analysis and incentive programs. Finally, limited standardization for components and connections leads to poor installation, maintenance issues and less reliability. Current solar thermal technologies offer a very limited palette of panel size, shape, color and finish. Almost all installations in the US are for rooftops and are add-on applications. Design thinking is required to develop an aesthetic for the technology and create an integrative approach to the architecture and building systems. More technology advancement and development is also needed to fully realize the potential for solar thermal from multi-functional solar facade systems, to thermal storage capacity, to solar assisted cooling using absorption chillers.

CURRENT TECHNOLOGIES

There are two types of active solar thermal systems – air systems and hydraulic systems (Figure 4). Air systems are less expensive but are also less efficient, pre-heating outside air for only space heating using a perforated absorber panel with a plenum behind. The heat is typically used immediately and is not stored on-site. Hydraulic systems produce higher temperatures that can be used for space heating, DHW, or both called a combi system and can potentially power thermal chillers for cooling[12]. Thermal energy can be easily stored in hydraulic systems using a solar heated transfer fluid passing through a hydraulic circuit to a hot water tank usually in the basement (Figure 5). A high performance hot water store in the US will lose 10% or 7ºF over a 24 hours.

We focused on three hydraulic systems for our proposal because of their efficiency in exchanging heat from the solar absorber to hot water storage and their medium working temperatures required for a range of applications. All have an absorber plate, collecting pipes and a heat carrier medium and include the following technologies: Glazed Flat Plate – cost efficient and widely tested with 122-212ºF working temperatures, Roll-Bond Fractherm – excellent heat transfer and flexible geometry with 248-323ºF working temperatures, and Evacuated Tube – high efficiency in winter with the highest 248-356ºF working temperatures. The formal characteristics of facade applications are highly dependent on the specific solar thermal collector technology. Each has its core components, materials and sizing constraints and provides unique potential for integration.

DESIGN THINKING

Our research addresses not strictly building design per se, but posits that design thinking within the discipline of architecture would encompass by necessity many economies that influence the built environment – from product design and entrepeneurship, to urban design, energy policy, and renewable environmental systems. Instead of problematizing the difference between design and research, the knowledge generation that forms the content and parmeters for the proposal and the design thinking are interwoven, with each acting as engine for the other. The data and findings become material for a generative process of analysis and design to test our hypothesis at three scales: neighborhood, building and component scale. At the neighborhood scale, location and solar exposure, building typology and use will be investigated; at the building integration

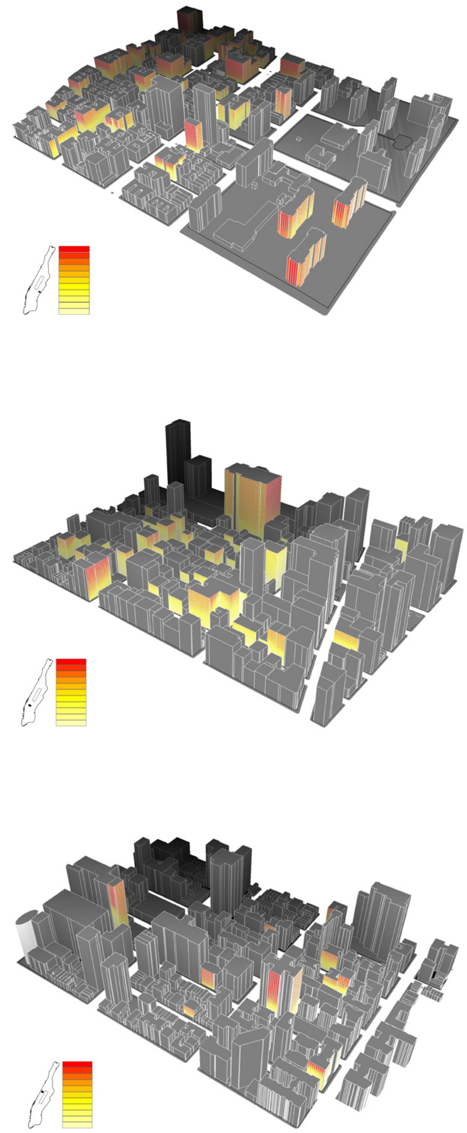

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Figure 6: *NYC Clean Heat Suitability Tests; Top: Upper West Side; Middle: Garment District; Bottom: Turtle Bay (Blough & Giostra)*

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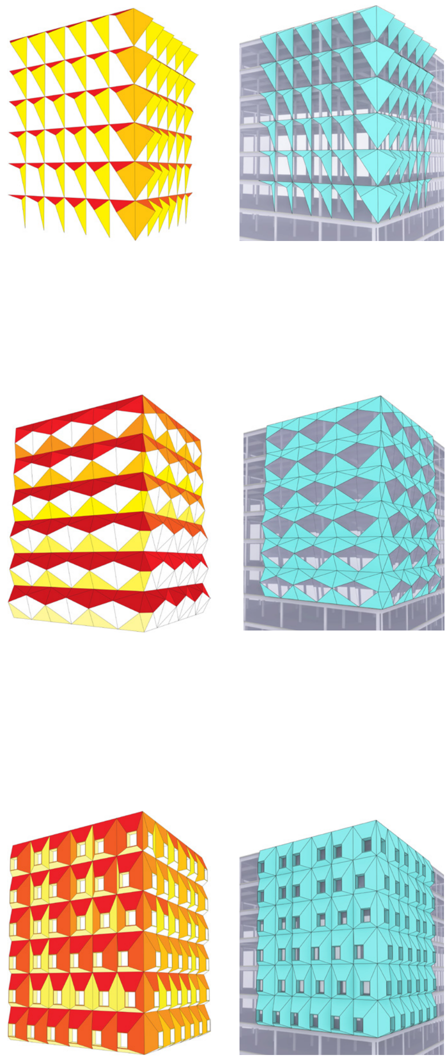

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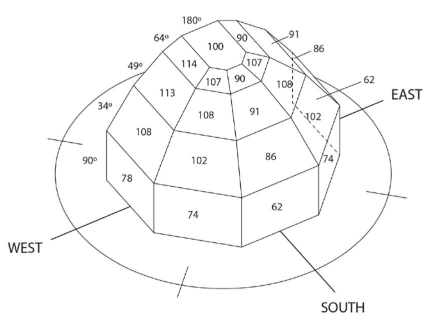


Figure 7: *Form Finding and Environmental Analysis (Blough & Giostra)*

Figure 8: *NYC Solar Irradiation by Surface Orientation (Blough & Giostra)*

scale, emerging technologies, applications and multi-functional facades will be investigated; and at the façade component scale, untized panels and connections, size and appearance will be investigated.

Neighborhood

The first part of the design thinking analyzes urban sites to identify building suitability for vertical applications of solar thermal based on heavy oil heating, location, solar exposure, typology and use. The NYC Clean Heat database identifies 10,000 buildings burning #4 or #6 heating oil. New legislation requires owners to replace boilers burning these heavy oils with cleaner systems – heavy oils account for 86% of building soot pollution in NYC. The New York City Solar Thermal Roadmap considered these buildings the "low-hanging fruit" to reduce GHG emissions but targeted only roof applications for buildings with high DHW use.[13]

We formed a collaboration with the Pratt's Spatial Analysis and Visualization Initiative (SAVI) to use geographic information system (GIS) mapping to form an interactive 3D digital model to test vertical applications based on the coordinates of the buildings in the NYC Clean Heat database. SAVI built the model that included data such as building location, volume, land use and whether it was in a historic district. We then brought the model into Ecotect software to test yearly levels of solar irradiation on south and west facing facades of buildings in three sample neighborhoods (Figure 6). It should be noted that this type of analysis can be done to identify not only existing building stock regardless of boiler type, but also suitability of sites for new construction. Buildings located on wide streets and island edges, plus high rise towers, commercial buildings and New York City Housing Authority (NYCHA) developments (buildings surrounded by open space) are excellent candidates for vertical applications of solar thermal. Space heating and cooling as well DHW should be considered for vertical applications using hydraulic solar thermal systems. The current New York City Solar Map developed by CUNY's Center for Advanced Research of Spatial Information at Hunter College is only for rooftop analysis. From our research, it was determined that a solar map is needed for NYC to analyze building overshadowing and levels of solar irradiation on building façades – ACRE and SAVI plan to pursue this project in the future.

Building Integration

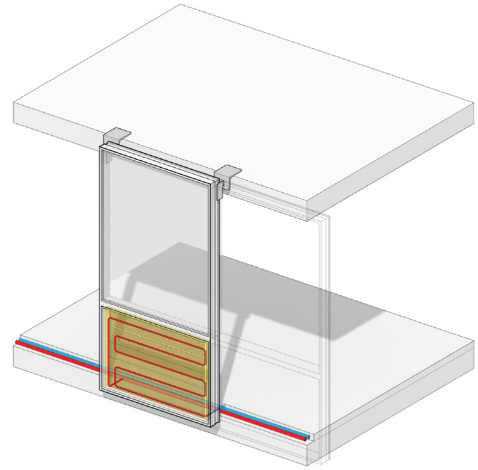
Remarkably all the New York solar thermal feasibility studies we found to date targeted only traditional roof installations. Our research has indicated in NYC where mid- to high-rise building is the prevailing typology, roof applications do not provide enough surface area (Figure 3). An example of an eight story corner loft building with solar thermal panels on the south and west façade provides over three times the usable surface area of the roof. When half of the roof is dedicated to mechanical equipment and overshadowing is considered from neighboring buildings, even a single façade of an infill building provides up to three times the usable surface area. Following new regulations mandating strict energy performance requirements along with a projected steep increase in energy costs, most building facades will need to be retrofitted in the future to increase efficiency. When semi-rigid insulation is integrated into a BIST panel system, it provides the additional benefit of increasing thermal performance of the enclosure with an R-value up to 16. With 85% of the City's building stock to be extant in 2030, BIST systems provide a cost effective means to upgrade NYC's existing infrastructure. In addition to energy cost savings, BIST façade systems will contribute to survivability through on-site energy production creating a more resilient building stock following extreme weather events and disruptions to the grid.

Roof mounted solar thermal systems produce the most heat in the summer when solar gain is highest and the heat demand is lowest. This results in the potential for overproduction and the risk of overheating which can damage the system (Figure 2). Façade integrated collectors provide an advantage as they reduce production by about 30% in the summer due to the sun angle, while winter and mid-season production are not significantly affected. BIST applications produce a high yearly solar fraction up to 70% and do not require a larger collector area than an optimally oriented roof system covering the same square footage.[14]

A niche market for solar thermal systems integrated in multi-functional façade systems is emerging in the EU and Scandinavia where they are being designed, tested and manufactured. They are proving to be relatively simple and robust with a range of potential configurations. Our proposal targets two different markets for New York based on our findings: 1) advanced multi-functional facades for new construction in the next five to ten years; 2) retrofits for the current building stock using an affordable unitized panel system. The first is speculative and capitalizes on our expertise as designers to employ the latest digital tools pairing environmental analysis with geometric form finding. Factors such as solar irradiation, sun angle and sun shading are parameters that inform novel multi-functional and differential façades (Figure 7, 8). We continued our investigations with Ecotect software and tested specific façade geometry to enhance the performance of the collectors while integrating sun control for vision glass. We also explored the expression of the three different hydraulic technologies and began developing double wall façade construction for potential hot water storage and radiant wall panels (Figure 12). These concept studies begin to address the the future of solar thermal research and development with BIST systems dedicated to specific applications, temperatures, and weather conditions in order to meet the energy goals of 2050.

Component

There are few solar thermal manufacturers and installers in the New York State with Sunmaxx Solar being the largest. During our proof of concept phase, we contacted the CEO Adam Farrell to discuss our research and explore the possibility of SunMaxx acting as our industry partner in the future. Sunmaxx expressed an interest partnering to explore the design and prototyping of a façade panel system as there are virtually no manufacturers of this application in the US. Most of the European products are expensive and complex with limited standadization across applications. For the market targeting retrofits, we concluded that a glazed flat plate system will be investigated because of its simple design, economy, reliability, and integrated thermal insulation (Figure 9). While glazed flat plate is a proven technology for roof applications, opportunities for innovation exist through integrated façade applications including: developing a unitized system for quality and cost control; standardization of hydraulic connections to building plumbing systems for heat transfer efficiency, ease of installation, and maintenance; variation in module dimension and shape for design flexibility; and appearance, including characteristics of color, texture, and reflectivity of glass cover and absorber plate.



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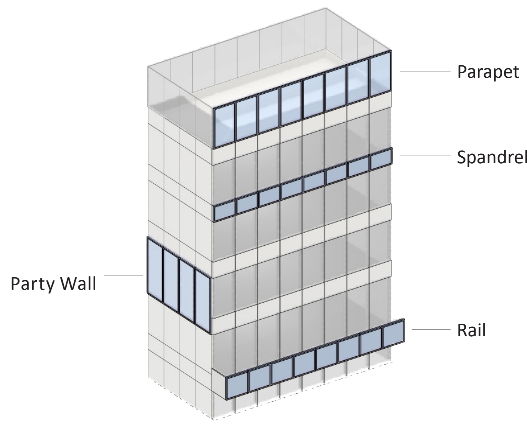

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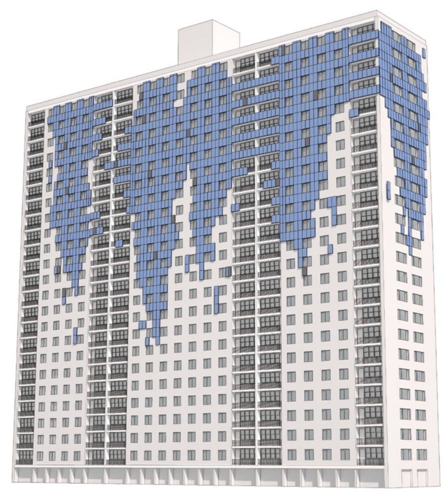

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Figure 9: *Unitized Wall Panel (Blough & Giostra)*
Figure 10: *Curtain Wall Applications (Blough & Giostra)*
Figure 11: *Retrofits NYCHA Housing (Blough & Giostra)*

Our strategy is innovative because it creates a new approach for the application of solar thermal technology to buildings. The BIST façade system is based on the recognition that a majority of today's curtain walls already deploy a high level of geometric modularity and system standardization, making the integration of solar thermal units within the panel the next logical step in the evolution of high-efficiency building envelopes (Figure 10). The proposed system will also integrate all functions pertaining to building enclosures, including waterproofing, pressure equalization, thermal insulation, expansion/contraction and vapor transfer, structural support, and wind load resistance, within one component. This approach avoids redundancies and interferences created by traditional solar panels mounted on pre-existing enclosures, and foresees a new generation of solar thermal collectors available for most building cladding systems, with on-site energy production as an integral part of south and west facing building façades (Figure 11).

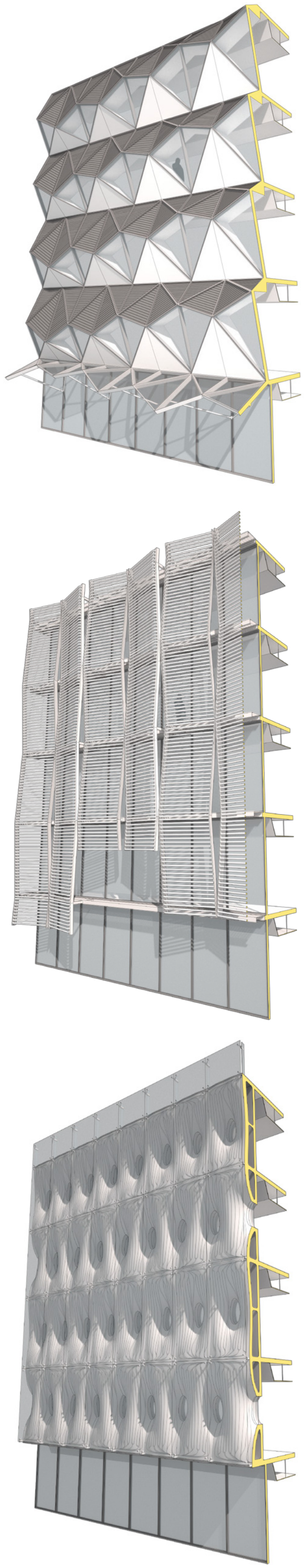

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Figure 12: *Multi-Functional Facades; Top: Thermal Umbrella; Middle: Thermal Vail; Bottom: Thermal Bladder (Blough & Giostra)*

PLANS FOR CONTINUATION

Preliminary research of the BIST system has been completed and we are currently seeking funding for a full proof of concept study. Commercialization is expected in three to five years. In summation, as part of the Innovation Fund research, the project team surveyed existing solar thermal technologies and parameters, solar thermal initiatives in New York, and new trends in energy policy and technology development in the EU, where BIST applications are most advanced. The team performed preliminary analysis of market potential for BIST façade systems in NYC using data based on physical characteristics of existing building infrastructure, typology, energy potential, and cost-saving opportunities for energy customers. Different scale applications for the technology was also schematically designed to envision the architectural consequence of the research. Finally, the team met with stakeholders from the public and private sectors gaining invaluable insight while building a network of partners to collaborate with, several being leading experts on solar thermal technology in New York State.

Our plans for continuation include applying for a New York State Energy Research and Development Authority Advanced Buildings Program for $160,000 in funding. We have built on our collaborations with engineering and industry partners to form a team to fulfill the proposal's research objectives. As Pratt does not having an engineering curriculum, Professor Doug Bohl of Clarkson University will lead the engineering component of the project, providing energy simulations and eventual testing of the prototype. In 2009, Professor Bohl was awarded the National Science Foundation Career grant and has deep experience with grant writing for research funding. As a member of the New York Solar Thermal Consortium Committee, he provided technical analysis and was lead writer for the final report. Adam Farrell, CEO of SunMaxx Solar, will act as the lead industry partner. SunMaxx will provide the expertise for technical feasibility, cost analysis, and commercialization of the system. When the project moves from the NYSERDA Research phase to the Development phase, SunMaxx will produce a working prototype for testing and metering of performance data. SAVI, an in-house collaborator at Pratt, will provide GIS analysis to map building suitability for BIST based on location, typology and use, boiler type and exposure to solar irradiation. The project will also rely on services from two consultants. Buro Happold, one of the leading environmental engineering offices in New York, will provide feasibility analysis for integrating the solar thermal façade with building mechanical, electrical, and plumbing systems. Buro Happold will also aid with environmental analysis of the building façade and mechanical systems to assess heating and cooling performance. ENCLOS, a leading US curtain wall manufacturer, will provide assistance with construction feasibility, cost analysis and design development drawings as it pertains to curtain walls and the proposed unitized solar thermal façade panel.

The team hopes to apply for the Development Category in the Advanced Building Program as we near completion of the Proof of Concept/Research phase. Being that Sunmaxx Solar is the industry partner on this project, we believe that a major curtain wall manufacturer, such as Enclos or Permasteelisa, will be interested in helping to fund the project and bring the technology to market. The team has had preliminary discussions with both manufacturers and there is interest in the technology as the US market is waiting to be tapped. Other state and federal agencies like the US Department of Energy, NYSTAR, and National Science Foundation, who sponsor energy research related to renewables, the reduction of GHG emissions, and resiliency, may have grant opportunities that are a fit for the proposed development project as well. Pratt's Office of Institutional Advancement is supporting fundraising efforts for the work, and is currently investigating opportunities for funding through corporate and private foundations. Grantmakers like the Alfred P. Sloan Foundation, Energy Foundation, New York Community Trust, and Gimbel Foundation that fund research in line with the proposed project may be interested in supporting the work. After meeting officials at the Mayor's Office of Long Term Planning and Sustainability (OLTPS) including Deputy Director Steven Caputo, it was agreed that a BITS prototype would be very useful for metering and collecting performance data. From this information OLTPS could develop a feasibility study with cost comparisons, payback times, incentives, and policy support needed for a NYC program around solar thermal vertical applications. OLTPS discussed applying for NYSERDA funding for such a study in the future.

CONCLUSION

Pratt has had limited experience conducting funded research because it is primarily an art and design institution with an emphasis on teaching. Although this is changing due to new initiatives launched by the School of Architecture like a research lab paired with directed research minors, there are few models for architectural research besides the Pratt Center for Community Development and the Center for Experimental Structures. Both of these groups essentially function as an independent entities with little knowledge sharing regarding research practices outside of their centers. Ultimately, we had to build our own framework for ACRE which forced us to be both self-critical and inventive. A rigorous analysis of the data from a range of sources associated with renewable heating and cooling, created a structure for us to apply design strategies with specific objectives across scales of implementation. Key interdisciplinary collaborations not only allowed us to bolster and verify the content our research but have enabled us to extend the reach or our institution. This approach plays to Pratt's strengths but also acknowledges that if we are to pursue robust research in the future, then we need to partner with other institutions that can provide the expertise to help us get to the next level. Our new relationship with Clarkson is a good example, where their Center for Advanced Materials Processing will provide the engineering and testing expertise and Pratt School of Architecture provides the architectural and design thinking. Being that

Pratt does not have an engineering program and Clarkson does not have an architecture school, the relationship is mutually beneficial. In fact, we are in discussions with Professor Bohl about forming teaching partnerships, where a design research and engineering course focusing on solar thermal envelopes can be created to develop and test concepts collaboratively.

Because the Innovation Fund was initiated by the Provost, we had his full support with the office of Institutional Advancement instructed to give all Innovation Fund grantees priority with help securing funding for continuation. However, a proposal like ours was also new to Institutional Advancement due to its technical nature and disciplinary specificity, so we also produced our own database for possible grants based on our findings. Because of these factors, the School of Architecture would benefit in the future to have its own grant writer as evidenced by the majority of Innovation Fund proposals coming from our department and to build a foundation for future research funding.

ENDNOTES

1. The research team was led by Lawrence Blough and Simone Giostra. Professor Blough coordinates the undergraduate Comprehensive Design sequence with an emphasis on building envelopes, which is taught in collaboration with consulting engineers who practice in the NYC's more innovative offices. He also has extensive experience conducting material research paired with digital fabrication having directed the design and assembly of several full-scale prototypes. Professor Giostra's practice has focused on pushing the boundaries of building performance, particularly in the areas of energy technology and building envelopes. He holds several US Patents including a new integrated system for a sun shading and solar powered media wall developed in partnership with Permasteelisa. For the preliminary proof of concept, the team also included several engineers who teach in the Comprehensive Design sequence. Erik Verboon consulted on façade engineering and David Jones advised on building environmental systems. Student research assistants included Lauren Greer, Gary Lee, and Jiwon Shin.

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