PERKINS+WILL

# Research Journal

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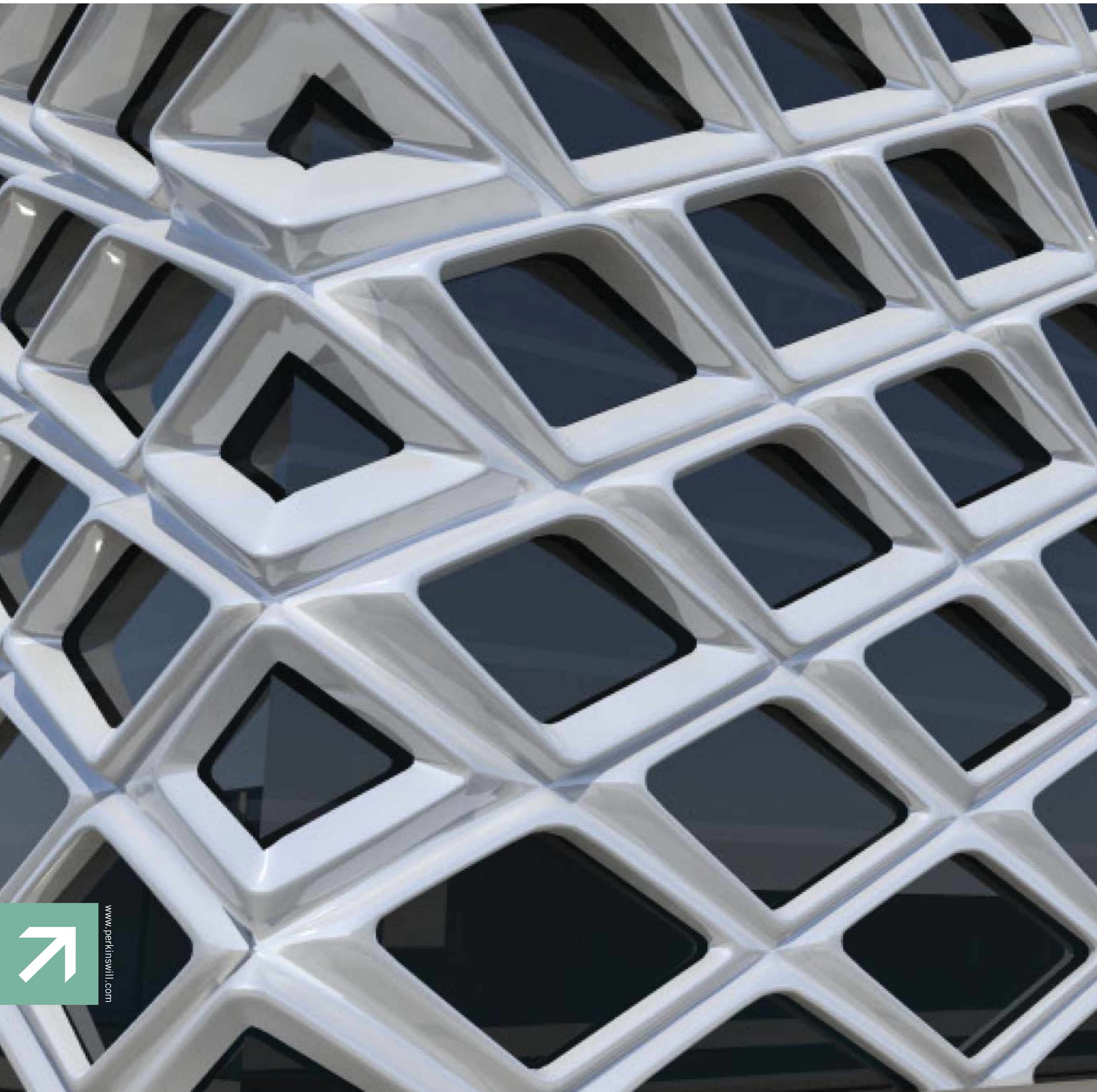

**Editors:** **Ajla Aksamija, Ph.D., LEED AP BD+C, CDT** and **Kalpana Kuttaiah, Associate AIA, LEED AP BD+C**

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*We would like to extend our* **VERY SPECIAL THANKS** *to: Emily Gartland.*

Perkins+Will is an interdisciplinary design practice offering services in the areas of Architecture, Interior Design, Branded Environments, Planning + Strategies and Urban Design.

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## JOURNAL OVERVIEW

The Perkins+Will Research Journal documents research relating to architectural and design practice. Architectural design requires immense amounts of information for inspiration, creation and construction of buildings. Considerations for sustainability, innovation and high-performance designs lead the way of our practice where research is an integral part of the process. The themes included in this journal illustrate types of projects and inquiries undertaken at Perkins+Will and capture research questions, methodologies and results of these inquiries.

The Perkins+Will Research Journal is a peer-reviewed research journal dedicated to documenting and presenting practice-related research associated with buildings and their environments. Original research articles, case studies and guidelines have been incorporated into this publication. The unique aspect of this journal is that it conveys practice-oriented research aimed at supporting our teams.

This is the seventh issue of the Perkins+Will Research Journal. We welcome contributions for future issues.

### RESEARCH AT PERKINS+WILL

Research is systematic investigation into existing knowledge in order to discover or revise facts or add to knowledge about a certain topic. In architectural design, we take an existing condition and improve upon it with our design solutions. During the design process we constantly gather and evaluate information from different sources and apply it in novel ways to solve our design problems, thus creating new information and knowledge.

An important part of the research process is documentation and communication. We are sharing combined efforts and findings of Perkins+Will researchers and project teams within this journal.

Perkins+Will engages in the following areas of research:

- Market-sector related research
- Sustainable design
- Strategies for operational efficiency
- Advanced building technology and performance
- Design process benchmarking
- Carbon and energy analysis
- Organizational behavior

# EDITORIAL

This issue of Perkins+Will Research Journal includes five articles that focus on diverse research topics, such as legal aspects in architectural profession; use of performance-based computational design methods and digital fabrication; comparison of different hospital floor plans and walking efficiencies; methods for studying relationships between rail transit and real estate development; and sustainable design strategies and technical design of a healthcare facility.

"Architectural Services During Construction: Duties and Liability" is a literature review that presents architect's responsibilities and obligations under the construction contract. It discusses information obtained from the AIA standard contract documents, white papers and law reviews. Conclusions indicate that architects should be fully cognizant about their responsibilities defined in the contract and limit their work to such expertise.

"Re-Skinning: Performance-Based Design and Fabrication of Building Facade Components: Design Computing, Analytics and Prototyping" discusses a collaborative research project between Perkins+Will and the University of Cincinnati. The objective of the collaboration was to integrate building performance simulations and modeling to drive design decisions, to use parametric design tools for exploration of building skin designs, and to investigate digital fabrication and prototyping methods for building facade components.

"A Simple Model for Comparing Healthcare Staff Walking Efficiencies Across Different Hospital Floor Plan Designs" discusses a methodology for investigating relationships between spatial layout of hospitals and walking patterns of healthcare staff. The study used pedometry step measurements to compare walking energy in double-loaded and racetrack corridor floor plan designs. Research findings indicate that the racetrack corridor floor plan layout minimizes walking workload of healthcare staff.

"Projecting Returns on Transit Investment: A Research Proposal for Analyzing and Evaluating Investments Made In and Around MARTA Stations and Projecting the Returns" presents a research methodology that can be used to study correlations between rail transit stations and real estate developments around them. The article infers that real estate development has been successful around transit stations in some areas, while not in others. The authors propose to investigate developments around Metropolitan Atlanta Rapid Transit Authority (MARTA) stations.

"Sustainable Design Strategies and Technical Design Development: Rush University Medical Center Entry Pavilion" discusses sustainable design strategies that were considered as an approach for meeting the Living Building Challenge and several building performance analyses that were conducted during the different stages of the design. It also discusses technical design development and construction of a glass terrarium, one of the unique design aspects of the entry pavilion.

**Ajla Aksamija, PhD, LEED AP BD+C, CDT**
**Kalpana Kuttaiah, Associate AIA, LEED AP BD+C**

# 01.
# ARCHITECTURAL SERVICES DURING CONSTRUCTION:
*Duties and Liability*

**Helena O'Connor, CAU-RJ, LEED AP BD+C,** *helena.oconnor@perkinswill.com*

ABSTRACT
The objective of this paper is to investigate architect's responsibilities and obligations during construction, resulting in a better understanding of the scope and limits of architects' services and the risk architects face. Understanding of the architect's duties is important to establishing reasonable expectations thus reducing exposure to liability. The paper provides a literature review on this topic discussing information and resources gathered from books, AIA standard form agreements, AIA white papers and law reviews. Conclusions indicate that architects should clearly define their contractual responsibilities and conform their services to such duties.

KEYWORDS: architect duties, breach, negligence, liability

## 1.0 INTRODUCTION
Architects have a legal duty to provide services in accordance with their professional standard of care. Although defined by applicable law, language in an architect's agreement can increase this standard, thus creating risk that is difficult to manage. Likewise, contractually imposed duties beyond standard architectural practice can increase an architect's risk. Architects must follow their legal standard of care and carefully consider contract language to understand and align their duties with their legal and professional obligations. This paper examines architects' duties and responsibilities under an industry standard owner/architect agreement and reviews limitations to architects' authority. After analyzing several court cases involving claims of professional negligence, this paper presents different circumstances in which architects were found negligent and others in which they defended against these claims. Finally, this paper offers ideas on how to limit risk through management and quality control strategies.

## 2.0 ARCHITECTS' DUTIES AND RESPONSIBILITIES

### 2.1 The Law
Although architects' legal responsibilities differ from jurisdiction-to-jurisdiction, in general neither state nor federal law require architects to guarantee, warrant or ensure results, but expects them to use reasonable skill and care when providing professional services.

During their practice, architects are exposed to administrative law, which includes "regulations developed to implement civil statutes"[1]. Public officials follow established regulations when reviewing architects' submitted documents and address adopted code and regulatory requirements specific to each project.

### 2.2 Standard of Care
The standard of care is the level of performing services expected of architects by law. A contractual statement of this legal duty might read: "The Architect shall perform its services consistent with the professional skill and care ordinarily provided by architects practicing in the same or similar locality under the same or similar circumstances. The Architect shall perform its services as expeditiously as is consistent with such professional skill and care and the orderly progress of the Project"[2]. Even though this statement can be modified by contract or conduct, architects should conform their contracts to this standard; otherwise they might increase their exposure to liability. Compliance with this standard is judged based on what a reasonable architect would do, at the same time and circumstances, and is decided on a case-by-case basis in court. The architect who fails to exercise reasonable care may be held liable for professional negligence.

## 2.3 Before Construction - Scope of Architect's Basic Services

The scope of architect's services is defined in the agreement between the architect and the owner. The most common industry standard agreement form is the AIA B101 - 2007 Standard Form of Agreement Between Owner and Architect, developed by the American Institute of Architects (AIA).

The following are the Scope of Architect's Basic Services under AIA B101-2007[3]:

- The Architect's Basic Services include "usual and customary structural, mechanical, and electrical engineering". The Architect may choose to hire consultants outside the Architect's firm to perform these services, and enter into agreements with those parties.
- The Architect will manage his own services, consult with the Owner, research design criteria, attend meetings, communicate with the Project team, report progress of the Work to the Owner, and will submit a schedule of services showing anticipated dates for start of construction and substantial completion.
- The Architect will coordinate his services with the services provided by the Owner and Owner's consultants, and is permitted to rely on the accuracy of these services.
- The Architect is not responsible for changes made by the Owner without the Architect's consent.
- During Schematic Design phase, "the Architect shall prepare a preliminary evaluation of the Owner's program, schedule, budget for the Cost of the Work, Project site, and the proposed procurement or delivery method and other Initial Information, each in terms of the other". The Architect will also make recommendations on environmentally responsible design options available and applicable to the Project and discuss with the Owner the feasibility of incorporating these options. He will also consider materials, building systems and equipment consistent with owner's budget, and schedule.
- The Design Development phase follows the Schematic Design phase, and the Architect submits drawings and specifications showing the development of the design to the Owner, and updates the estimated pricing.
- The Construction Documents phase follows the Design Development phase approved by the Owner, and documentation of the Project continues in a more detailed manner. An updated estimated Cost of the Work is included. These documents will be sent to the Owner, who will forward to various contractors during the Bidding or Negotiation phase.
- The Architect shall assist the Owner during the Bidding or Negotiation phase, and offer substitutions of materials.

## 2.4 During Construction

The architect's role during construction is described in both the AIA B101 – 2007 and in the AIA A201 - 2007 General Conditions of the Contract for Construction. Even though the architect is not a party to the construction contract, he develops the construction documents, including drawings and specifications that the contractor uses to construct the project. Under the AIA B101 and A201 – 2007, during construction the architect provides administration of the contract for construction to, among other things, observe if the work meets the architect's design intent. The architect is the point of communication between the contractor and the owner in matters regarding the contract including changes, acceptance of the work and payments to the contractor.

The following are the Architect's Responsibilities under AIA B101 and A201 – 2007[4]:

- The Architect will provide administration of the Contract for Construction, and, when granted authority, will be the Owner's representative, acting on the Owner's behalf during construction until the final Certificate for Payment is issued.
- The Architect will visit the site at appropriate intervals to become generally familiar with the progress and quality of the Work completed, observing if it complies with the Contract Documents. The Architect is not responsible for the means and methods of construction, or for safety precautions at the job site. These are the Contractor's sole responsibilities.
- The Architect will keep the Owner informed about the progress of the Work and will report deviations, defects and deficiencies. The Architect is not responsible for the Contractor's failure to carry out the Work in accordance with the Contract Documents.
- The Architect will investigate matters regarding site conditions that are different than expected found by the Contractor during the performance of the Work. The Architect will then recommend an adjustment of the Contract Sum and/or Contract Time based on these unanticipated conditions.

- The Architect is the point of communication between the Owner and Contractor, and the Architect's consultants.
- The Architect will review, then accept or reject, the Contractor's Application for Payment. If accepted, the Architect will issue a Certificate of Payment to the Owner, in order to initiate payment to the Contractor. The issuance of this Certificate means that the Architect represents, to the best of his knowledge, information and belief, that the Work has progressed to a certain point and is in accordance with the Contract Documents.
- The Architect has authority to withhold payment if portions of the Work are defective, if third party claims may be or are made against the Owner, if Subcontractors have not been paid, if the Work cannot be completed for the unpaid balance of the Contract Sum or in the remaining Contract Time, if there is damage to the Owner or a separate contractor, or by repeated failure of the Contractor to carry out the Work in accordance to the Contract Documents.
- The Architect has the authority to order inspection or testing of the Work. The Owner may be obligated to pay for these inspections and tests, but if Contractor's work had been done incorrectly, then the Contractor shall be responsible for these costs and the Architect's additional time.
- The Architect will review Shop Drawings, Product Data and Samples submitted by the Contractor for compliance with the design intent only.
- The Architect is not responsible for the means and methods of construction or for safety precautions and will not be responsible for the Contractor's failure to perform the Work in accordance with the Contract Documents.
- The Architect will prepare Change Orders and Construction Change Directives, and may authorize minor changes that do not affect the Contract Sum and/or Contract Time.
- The Architect will inspect the Work to determine the dates of Substantial Completion and Final Completion, check if the Contractor finished his punch list, and if the Work conforms to the Contract Documents.
- The Architect will receive and forward to the Owner all close out requirements, and will issue the final Certificate for Payment.
- The Architect will interpret and decide matters concerning the Contract Documents, decide matters regarding performance, and will respond to contractor's requests for information regarding the Contract Documents.
- The Architect may be the Initial Decision Maker, who will be responsible for providing initial decisions on claims between the Owner and Contractor. The initial decision maker may be another individual, but will be the Architect if no other individual is selected and named in the Construction Contract.

### 2.5 Authority of the Architect and its Limitations

During construction, the architect may perform functions at the job site as an owner's representative and will act on owner's behalf with certain authority. The architect's authority might be actual, implied or apparent.

Actual authority is when the owner expressly gives authority to the architect to represent the owner at the job site. Both the AIA B101 and A201 – 2007 spell out the scope of this authority. For example, the architect may authorize minor changes in the work that are consistent with the intent of the contract documents and do not involve an adjustment in the contract sum or time.

Implied authority allows the architect to exercise authority incidental to his actual authority. Apparent authority is when the owner leads others to believe that the architect has more authority than he really has.

Rejecting contractor's work if work does not conform to the contract documents is a common authority granted to architects by contract. During construction, an architect often makes several site visits in order to become familiar with the progress of the work and generally determine that contractor's work is progressing in accordance to contract documents[5].

## 3.0 LIABILITY

### 3.1 General

An architect is negligent when he fails to perform his duties consistent with the degree of care and competence generally expected of a reasonably skilled member of the profession providing similar services under similar circumstances. Acts of negligence arises out of architect's acts or failure to act and he may be held liable for negligence if all the following have been found to exist: duty, breach, cause and damage. In other words, the architect owed a legal duty to the complaining party; architect failed to perform his duty; that failure is the proximate cause of harm; and an actual harm or damage happened as a result[6].

Depending upon causes of action permitted by applicable law, architects may face a negligence action by the owner, the contractor or third parties. Depending on the claim and type of damages sought, privity of contract may be required to impose liability on architects.

Applicable law and/or contracts may obligate architects to maintain insurance, such as worker's compensation, professional, general and automotive policies. Typically if an owner asks an architect to carry additional insurance and/or limits, the owner reimburses the architect for the corresponding costs. Professional liability insurance protects architects from negligence claims. Most professional liability policies require that the architect notify its professional liability carrier if a claim is made against the architect. The definition of a claim depends upon the architect's policy but in general to be considered a claim, the event must have three elements: injury to a person or property that has been proved; allegation that the architect was the one who caused the damage; and demand for compensation[7].

Professional liability insurance coverage is very specific and "often excludes coverage of claims for a design professional's general negligence in the performance of its duties"[8]. Certain acts are covered, but others are not. If architect execute services outside the policy's covered services, he may not have coverage against claims arising out of these services. Intentional torts acts are usually not covered in these policies.

Statutes of limitations and statutes of repose are two concepts that relate to when a claim can be filed. "Statutes of limitations establish the period of time within which a suit can be filed upon the discovery of the act or omission giving rise to the claim"[9] and "statutes of repose establish an outer time limit beyond which the design professional cannot be held liable for design and construction defects after the completion or substantial completion of a project"[10].

## 3.2 Liability During Construction to the Owner, to the Contractor or to Third Parties

Contractors supervise construction and architects observe the work to determine if it is in accordance with the contract documents. This distinction is critical to accurately reflect industry practice and the contractor's and architect's liability exposure during construction. That is why it is imperative for the architect's role to be clearly and correctly defined in the contract. An architect does not supervise construction, such as in Case #1[11], where contract provisions clarified that the architect was not responsible for workers' safety at the job site. The architect was not liable for worker's injury after the worker fell from a ladder, since the contract documents uniformly and clearly limited architect's responsibility to design and determination as to design conformance, which do not extend to worker safety. The court agreed that the architect was not in charge of the means and methods of construction or safety precautions.

If it is determined that architect is supervising the work, he can suffer inappropriate legal consequences. "If a design professional has agreed to perform supervisory tasks on a construction project, the contractor on the project may have a right to rely on the competence of that supervision"[12].

In order to receive payment from the owner, a contractor issues an Application for Payment that the architect reviews. After visiting the site and observing the work, the architect issues the owner a Certificate of Payment based on the progress of the work stated by contractor. Owner will pay the contractor based on those certificates issued by the architect and will rely on architect's professional opinion that the work has progressed to the point indicated and that the work is in accordance with contract documents. If architect issues certificates for payment without proper observation of the work, he may be liable to the owner for injury caused by defective work. In Case #2[13], the contractor installed insulation too close to recessed light fixtures, which violated the building code and caused a fire. A provision in the contract stated that architect must visit the site at appropriate intervals to become familiar with the quality and progress of the work in order to keep the owner informed. Not paying attention to how the insulation was installed was an omission on part of the architect and that was considered as negligence. "The architect's obligation to issue certificates of payment required him to be familiar with both the quantity and quality of the work", therefore the architect approved payment for defective work, breaching his duties towards the owner. Even though the contract also stated that architect was not responsible for the means and methods of construction, based on Case #3[14] "where liability is predicated on a breach of the duties the architect owes to the owner, the exculpatory language does not absolve an architect from liability for a contractor's failure to carry out the work in accordance with the contract documents." Architect may reject contractor's Application for Payment if the architect finds non-conforming work.

Architect must exercise care when reviewing shop drawings and submittals. Even though the architect is usually not liable to subcontractors when mistakenly approving shop drawings, in certain jurisdictions he may be held liable to the owner if the scope of the work is changed during the review of shop drawings, resulting in built work that is not in accordance with the contract documents. The architect may also be held liable to third parties for injuries resulting from approving shop drawings that have faulty information, and may not be able to receive indemnification from a joint tort-feasor. In Case #4[15], the architect was not relieved from liability when he approved subcontractor's shop drawings that contained incorrect gauge information for the supports of a stair landing. The landing collapsed and two workmen were injured. The architectural firm was ordered to pay the two workmen damages on their lawsuit against the architect, who later brought this action against the contractor and subcontractor for indemnification. The court ruled that "the architectural firm's conduct was an omission, which constituted active negligence" and prevented the architects from receiving indemnification from the contractor and subcontractor. "Each failed to perform an affirmative duty undertaken by contract", so one party would not receive indemnification from the other. The court referred to another lawsuit, Case #5[16], where that court ruled "if a person seeking indemnity personally participates in an affirmative act of negligence or is physically connected with an act of omission by knowledge or acquiescence in it on his part or fails to perform some duty in connection with the omission that he was undertaken, he is deprived of the right of indemnity".

### 3.3 Defenses

There are a variety of defenses that architects have successfully used to defend against negligence claims.

Architect can assert that he should not be liable to contractors and subcontractors, since they are not in privity of contract and the architect does not owe a duty to them, especially when the architect does not have a job site supervisory duty under his agreement with the owner. In Case #6[17], the architect had advised the owner in good faith not to accept subcontractor's request to substitute suppliers without using the stricter substitution standard procedures required under the construction contract. That caused delays to the project and the subcontractor claimed that he lost money. Then, the contractor brought a tort action against the architect for negligent interpretation of contract provisions, but architect was not considered the proximate cause of subcontractor's monetary damages. It is necessary "that supervisory duties exist in order to allow a case to be tried under a tort theory where the plaintiff lacks privity or status as an intended third-party beneficiary".

Architect may not be considered negligent if he can prove that his plans were not used accordingly. In Case #7[18], contractor used trenching technique to remove brick from the front of the building, resulting in the removal of all support for a parapet causing it to collapse, along with a part of the building. Since trenching was a deviation from the architect's drawings, the architect was not held liable for the fall of the building or for the injuries that resulted from that collapse. "The plans and designs of a professional are not the proximate cause of an injury if the work was not constructed or performed according to the plans."

Architect may avoid liability if he proves that he was not responsible for supervising construction activities at the job site. In Case #8[19], under the contract with the owner, the architect clearly defined his limited role during construction to provide supervision only for compliance with the plans and specifications. The architect was supposed to check the progress of the work in terms of the design intent and not regarding means and methods or safety measures, which were both the contractor's responsibility. "In the absence of any contractual right to supervise and control the construction work as well as site safety, the architect cannot be held liable in negligence for plaintiff's injuries"[20]. Before a party is required to provide a safe workplace, it must "have the authority to control the activity bringing about the injury to enable it to avoid or correct an unsafe condition"[21].

## 4.0 PREVENTING AND LIMITING LIABILITY

### 4.1 Risk Assessment

Architects should set goals for their practice, assess the risks involved with potential projects and clients, and plan to manage those risks. Architects must understand what they can and cannot do and avoid engagements where they cannot practice in accordance with the legal standard of care. They should not worry that the client will be offended; being honest will earn architect credibility with those clients who will be able to rely on that architect for specific types of projects.

When assessing risks, architects should pay attention to the scope of the project and its requirements, firm's experience, client attributes, influences on project delivery, compensation for design services, the project budget and schedule, attitude of the community and government to new projects, the overall political situation, local laws, rules and regulations. After analyzing all the potential risks, the architect should evaluate if it is possible to provide design services and still satisfy the client and the architect's internal company policies. "The best way to handle risk management is to identify potential risks and plan for them ahead of time"[22].

### 4.2 Quality Control

The following items can lead to professional liability claims. Architects should carefully pay attention to these problem areas and try to address them during quality control activities in their practice[23]:

- Inadequate supervision of inexperienced employees – Design errors are caused mainly by inexperienced architects who did not receive enough supervision and direction during the performance of the work.
- Inadequate project coordination – Poor communication and the separation of tasks within the design team cause each team member to understand very little about the project as a whole causing coordination problems within the design documents.
- Inadequate communication between architects and consultants is a major problem.
- Inadequate design quality control – Sometimes architects are requested to make lots of changes within unreasonable time frame, affecting the ability to revise drawings adequately to check and coordinate all the changes.
- Inadequately worded contract documents – Using non-standard contract documents can cause problems if an architect does not understand his duties and responsibilities listed in these documents.

### 4.3 Signs of Potential Claims

Not all claims can be anticipated, but if an architect wants to try to avoid claims he should try to find out if either the owner or the contractor is under financial difficulties and carefully pay attention to owner's litigation history and unexpected site conditions[24].

## 5.0 CONCLUSION

It is important to note that architects provide services, not products. Even when exercising his reasonable professional judgment, an architect might be mistaken unfortunately buildings cannot be pre-tested and guaranteed they will work as planned. Architects are liable for negligent services, but will not be liable for errors or omissions that a reasonable practitioner might have also made under similar circumstances. An architect will be held liable for its negligence when he fails to exercise reasonable professional judgment, resulting in harm to persons or properties. Architects should be very careful when preparing contracts to clearly define their role for all phases of the project and while exercising their duties before and during construction. Courts consist of people with their own opinions and interpretations of the law, which explains why almost identical cases have had opposite outcomes. Architects play a pivotal role in a highly complex industry where "interpretation" is a continuous activity exercised by all project participants, each paying attention to their own interests, even though the success of a project's construction should be the ultimate goal.

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# 02.
# RE-SKINNING: PERFORMANCE-BASED DESIGN AND FABRICATION OF BUILDING FACADE COMPONENTS:
## *Design Computing, Analytics and Prototyping*

**Ajla Aksamija, PhD, LEED AP BD+C, CDT,** *ajla.aksamija@perkinswill.com*
**Todd Snapp, AIA, LEED AP,** *todd.snapp@perkinswill.com*
**Michael Hodge, MARCH, AAIA, ACADIA,** *m.aaron.hodge@gmail.com*
**Ming Tang, LEED AP BD+C,** *tangmg@ucmail.uc.edu*

ABSTRACT
This article discusses a research/teaching collaboration between Perkins+Will and the University of Cincinnati and a unique design studio that was initiated as part of this collaboration. The studio investigated the relationships between performance-driven design, computational design techniques, integration of analysis tools with the design process and digital fabrication for a building facade retrofit. The studio project was an existing cold storage facility, which is being converted into a commercial office building. The objective of this collaboration was to integrate building performance simulations and modeling to drive design decisions, to use parametric design tools for exploration of building skin design and to investigate fabrication/prototyping methods for testing constructability and material choices. We discuss the design process as well as the results of this collaboration. We also conclude with final remarks regarding the best practices for collaborative research efforts between design practice and academic research institutions.

KEYWORDS: simulations, computation, parametric design, fabrication, building skin

## 1.0 INTRODUCTION

### 1.1 Background and Motivation
Developments in computational design and simulation applications are providing methods to improve current design practices, since the uncertainties about various design elements can be simulated and studied from the design inception. Building performance simulations aid in investigating design options and the overall building performance and are an integral part of the design process for energy efficient and high-performance buildings[1,2].

At the same time, computer-aided manufacturing (CAM) and digital fabrication are increasingly being used for design prototyping, because they are useful for testing constructability, material properties, form and geometric properties. By combining computational design tools with rapid prototyping techniques in the design process, designers and architects have real-time capabilities to generate multiple design options, iterate design approaches and end with scaled artifacts to study, review and critique the design solutions[3].

What exactly is parametric design? Parametric design relies on control of 3D modeled components through modification of certain parameters of a building model. These modifications are driven by mathematical formulas, data values, numbers or specific computer algorithms rather than manual changes of the model properties. Parametric design also requires use of specialized computer modeling software tools. A key advantage of a parametric design process is efficiency, allowing designers to be able to quickly adapt the characteristics of a model based on certain rules without having to recreate a separate model for each iteration or study. In a parametric design process, the rules governing the parametric controls and association of model elements may represent structural loads, environmental data (such as solar radiation, solar angles, wind velocity) or simply a change in dimensions.

These processes and tools are relatively new to the A/E/C design community. The benefits of parametric design tools in practice have been acclaimed, while also acknowledged as increasing in complexity and time required for certain design tasks[4]. There are case studies where parametric design methods have been used to determine building geometry and curvature of the cladding design for stadium buildings[5]. Other examples include parametric generation of tall building forms[6]. Computational tools such as Maya, Rhino and Grasshopper, CATIA, Solid Works, Inventor and Bentley's Generative Components are all examples of platforms that allow parametric control of model geometry based on rules and constraints. There are also examples of algorithms and computer code that can be used for parametric control of model geometry[7]. Also, custom plug-ins for existing design applications, which allow import of analytical data into BIM applications for parametric control of Revit families have been created and tested at Perkins+Will[8].

### 1.2 Project Objectives

In this professional and academic collaboration, topics such as parametric design, building performance analysis, simulations and fabrication were introduced with the objective to design and fabricate building facade components. A course named "Re-skinning: Performance Driven Design & Parametric Correlation" was developed at the University of Cincinnati School of Architecture and Interior Design during the fall of 2011. This course heavily relied on involvement of practitioners during the course. Co-taught by Ming Tang, Dr. Ajla Aksamija, Todd Snapp and Mike Hodge, the course covered parametric modeling techniques associated with performance-based design and digital fabrication.

The students were introduced to a real adaptive re-use project, where a 10-story, 400,000 SF (37,000 SM) cold storage facility constructed during the 1910's is being converted into a commercial office building. The independently structured exterior facade of this building will be removed and replaced. Therefore, the purpose of the collaboration was to design a new building skin for this project using digital design methods and performance analysis and to construct physical prototypes using digital fabrication methods.

These three primary objectives were investigated during the collaboration:

- Integration of performance analysis to drive design decisions
- Use of parametric tools to explore building skin design
- Fabrication and prototyping methods to test constructability, material choices and form.

The central feature of this collaboration was to examine new, emerging digital technologies and their applications for facade designs. The benefits for the design practice are that emerging design approaches, technologies and computational design methods were explored in relation to a real project. We addressed several questions during this process:

- Which tools are appropriate for the performance-based design approach? How do they relate to different design stages?
- What is the relationship between digital models and fabrication? What are the appropriate approaches for using design models to fabricate actual components?
- What are the best tools and practices for the translation of a digital design model to the physical prototype?

The collaboration offered us a route to investigate innovative design methods, observe the design and development, document results and applications and share the outcomes and insights into the changing nature of design affected by the emerging computational design methods. This article reviews the design process, collaboration and the results and provides recommendations for best practices for collaborative research efforts between design practice and academic research institutions.

## 2.0 PROJECT OVERVIEW AND COLLABORATION

### 2.1 Fulton Redevelopment

Fulton Redevelopment project is located in Chicago, Illinois, and is currently used as a cold storage facility. It was designed and built in the 1910's and consists of

400,000 SF (37,000 SM) of space. This 10-story building is located in the traditional food distribution part of Chicago. Over the last ten years, the surrounding area around the site has undergone drastic changes and redevelopment. For example, new multi-family residential construction, commercial developments as well as adaptation of the existing building stock into residential or commercial buildings have turned this area into a mixed-use neighborhood.

The building's immediate site was rezoned from industrial to commercial use. This building is one of the tallest buildings in the immediate area and has an excellent connection to the existing transportation infrastructure for public and vehicular transportation, as seen in Figure 1. A new elevated train stop is located in close proximity to the site.

The building's primary structural system consists of reinforced concrete slab and columns with drop panels. The existing independently structured exterior walls consist of brick masonry and original cork insulation, whose primary function was to isolate the interior cold storage facility from the exterior environment. The vertical piers and cross beams are thermally isolated from the main structure with cork infill. Since the building's current function is being converted into a commercial space, the primary existing structure will be retained, while the exterior facade will be removed and replaced with a new building skin. The objective is to open up the interior space, provide sufficient daylight and design a high-performing building envelope that minimizes energy consumption.

Figure 1: Fulton Redevelopment project and site.

## 2.2 Collaboration Process

This collaboration was based on a close working relationship between a design practice and an academic institution. The focus of the project was to redesign the building facade for Fulton Redevelopment using building performance analysis software to guide design decisions as well as emerging computational tools for parametric design and fabrication. The practitioners provided all of the background information about the project and presented and instructed students on the best methods for integration of building performance analysis tools into the design process. Remote video conferencing, podcasts and online collaboration tools were used effectively to monitor the progress of the course and to provide guidance for further development of design solutions and fabrication of prototypes (Figure 2). Also, meetings were scheduled to review and critique design development.

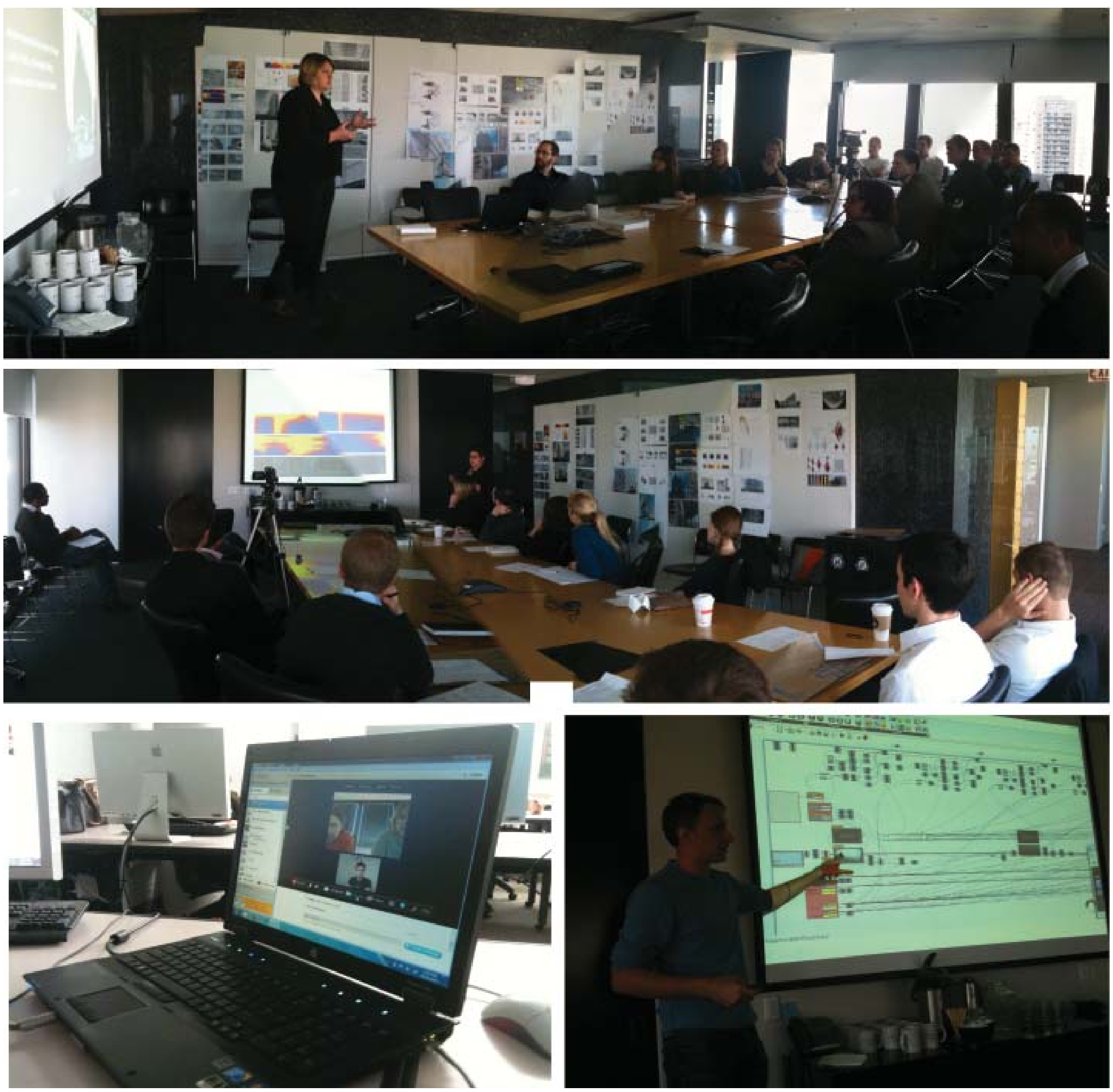

Figure 2: Collaboration.

Digital production processes that were used during the course allowed for distinct design and fabrication phases (Figure 3). Initially, information about the site and its characteristics were compiled and assembled from GIS application as well as existing building conditions from the original construction documents and BIM model. Different software programs were used to develop design concepts, such as Revit, Maya, Rhino and 3D Max. During the design phase, simulation and performance analysis tools were introduced, such as Ecotect, Vasari and custom spreadsheets. Results of the analysis process, such as solar radiation along the different facade orientations, were used to drive design decisions and design optimal facade solutions. Parametric modeling tools, such as Grasshopper, Maya MEL scripts and customized plug-in for Revit, were used to size and position building skin components and determine appropriate forms and geometry based on analysis results. The design phase required the use of simulations and parametric modeling techniques for the design of forms and components based on performance data. The digital fabrication phase introduced different techniques, such as laser cutting, CNC milling and 3D printing, which allowed design solutions to be physically studied and examined. The end results were physical prototypes of building skin components.

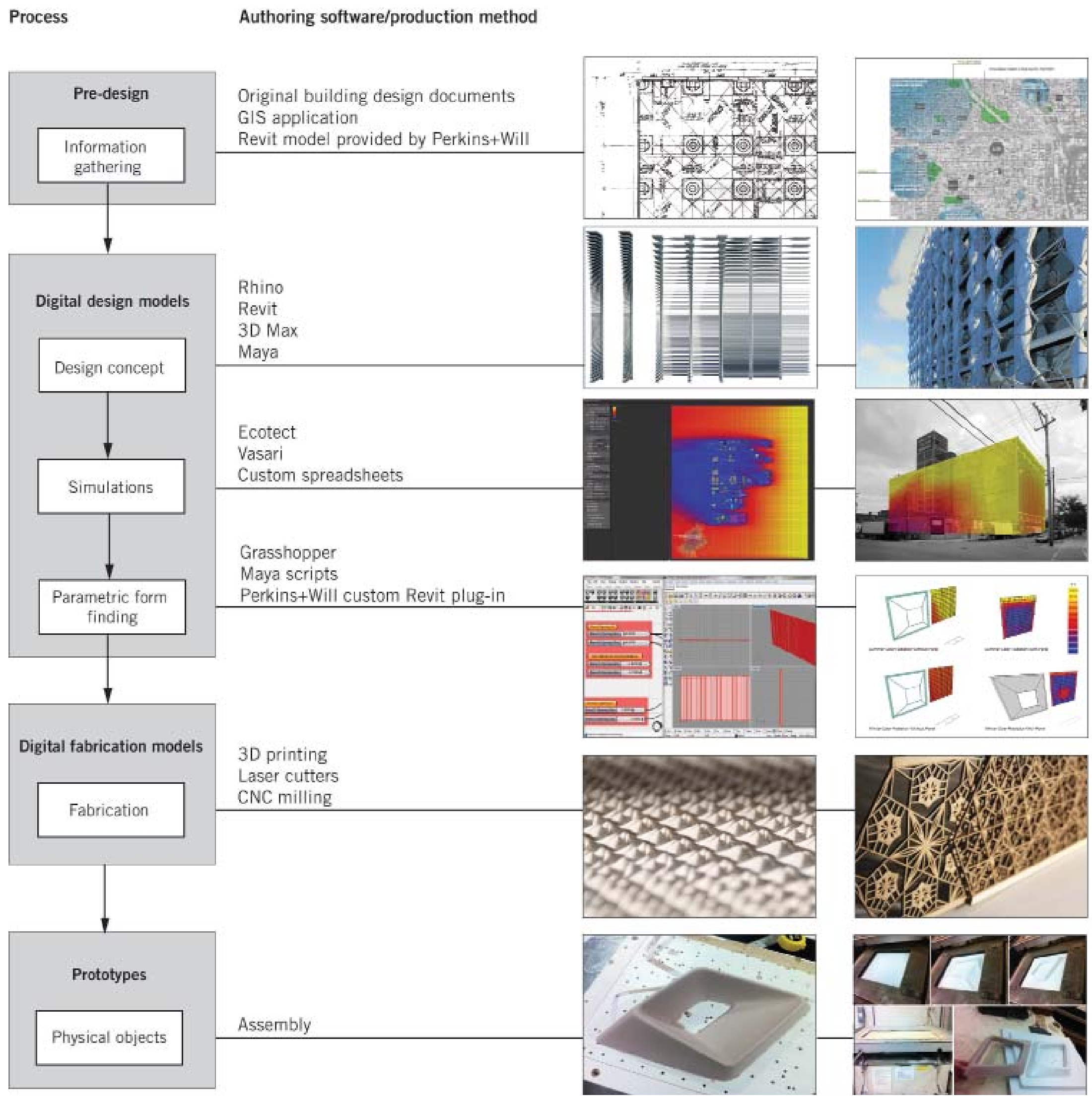


Figure 3: Building skin digital design and fabrication process.

## 3.0 PERFORMATIVE DESIGN AND DIGITAL FABRICATION

Emerging digital processes are beginning to impact the profession of architecture in a manner similar to what has occurred in other creative/design disciplines providing new methods to evolve the practice of architectural design.

Traditionally, building performance is considered as an evaluative process. As such, the traditional design typically uses analysis and simulation tools at set destination points in a linear design process. However, performance driven design processes provide computational means to evaluate solutions at any stage and preferably, from the onset of early design to maximize the potential of an integrated design/performance feedback loop. The non-linear parametric model associations, connected to the input from analysis and simulation software, can provide a design feedback loop between geometry and performance/environmental data. In this relationship, parametric geometry associated with analytical data can represent building massing, envelope/wall system shading components or bay spacing in a column grid tied to an external envelope/skin module. In a performance driven design approach, the performance results can become the input for parametric control of geometric model elements, as seen in Figure 4.

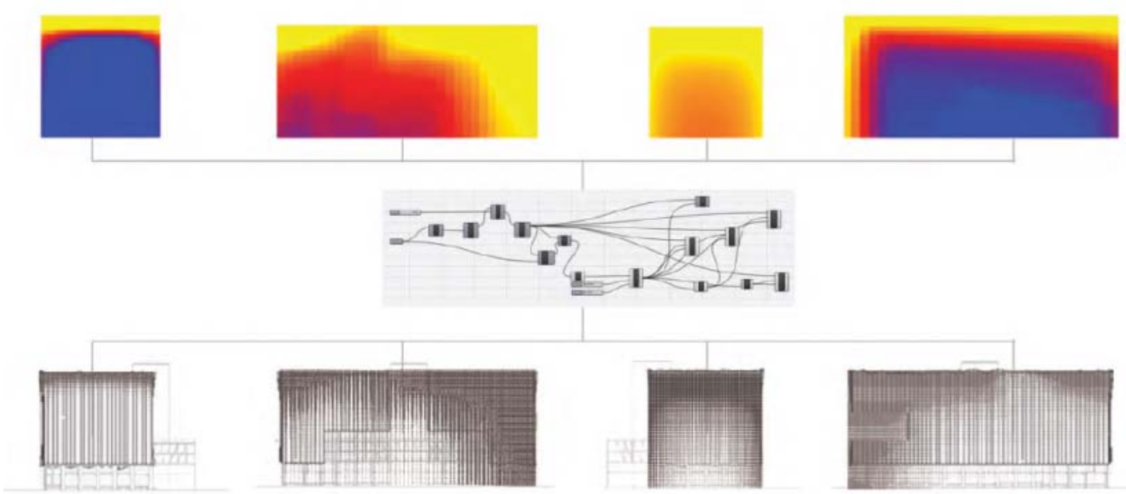

Figure 4: Translation of performance analysis data, such as solar radiation, to form generation via parametric design tools.

As an example, the core of performance-driven design process can be environmental performance data based on simulation results used directly as an input to the parametric building model. The data can be transferred to the model via a spreadsheet or software application plug-in to drive element/component optimization in the model.

Computer-aided Manufacturing (CAM) tools have also yielded a significant leap for designers providing new digital fabrication means of exploring material limits and form. By combining parametric design tools with rapid prototyping techniques into design process, designers and architects have opportunities to generate multiple design options, iterate conceptual approaches and end with scaled artifacts to study, review and critique the design solutions.

These strategies were introduced to students as a series of projects through scaled models, simulated construction and material experimentation. Digital representation (immaterial process) and fabrication (material process) are considered hybrid activities. Digitally generated design solutions were used for digital fabrication, such as 3D printing, CNC milling or laser cutting methods. Several different strategies were used that investigate building representation (immaterial process) and fabrication (material) process, summarized into two distinct paths:

- *Physical representation:* end product as scaled model for physically realizing immaterial form
- *Physical prototyping:* material and form-driven design process.

Part of the challenge, when using digital fabrication in the design process, is the ability to realize the conceptual idea within size limitations and allowances of the current fabrication tools. For example, one of the challenges is how to break down complex forms, which are generated from performance-driven design process, as simplified components that can be manufactured by fabrication and assembling. This can be solved by the slicing and tessellation method, where a complex form is divided into a large quantity of two dimensional contours or patterns, which are fabricated individually and assembled to construct the original form.

The workflow from performance data, such as solar radiation, to the pattern of building skin, to the fabrication stage provided many interesting approaches for building skin designs, which are discussed in the next sections.

## 4.0 RESULTS

### 4.1 Adaptable Building Skin

This approach developed a design scenario for adaptable building skin components, which would be able to respond to daily or seasonal environmental changes (Figure 5). The design solution includes two facade systems: 1) standard curtain wall as the primary facade; and 2) secondary movable panels that respond to the changes in environmental conditions by opening and closing. The movable panels consist of channel glass with aerogel insulation and a track system attached to the building's primary facade. These secondary panels would provide improved thermal insulation for the building envelope when this is needed and would reduce building's energy consumption. For example, they would be able to close during nighttime hours when the building is unoccupied, therefore reducing the heat loss between the interior and exterior environment. Parametric design tools have been used to control the positioning of the movable panels along each facade.

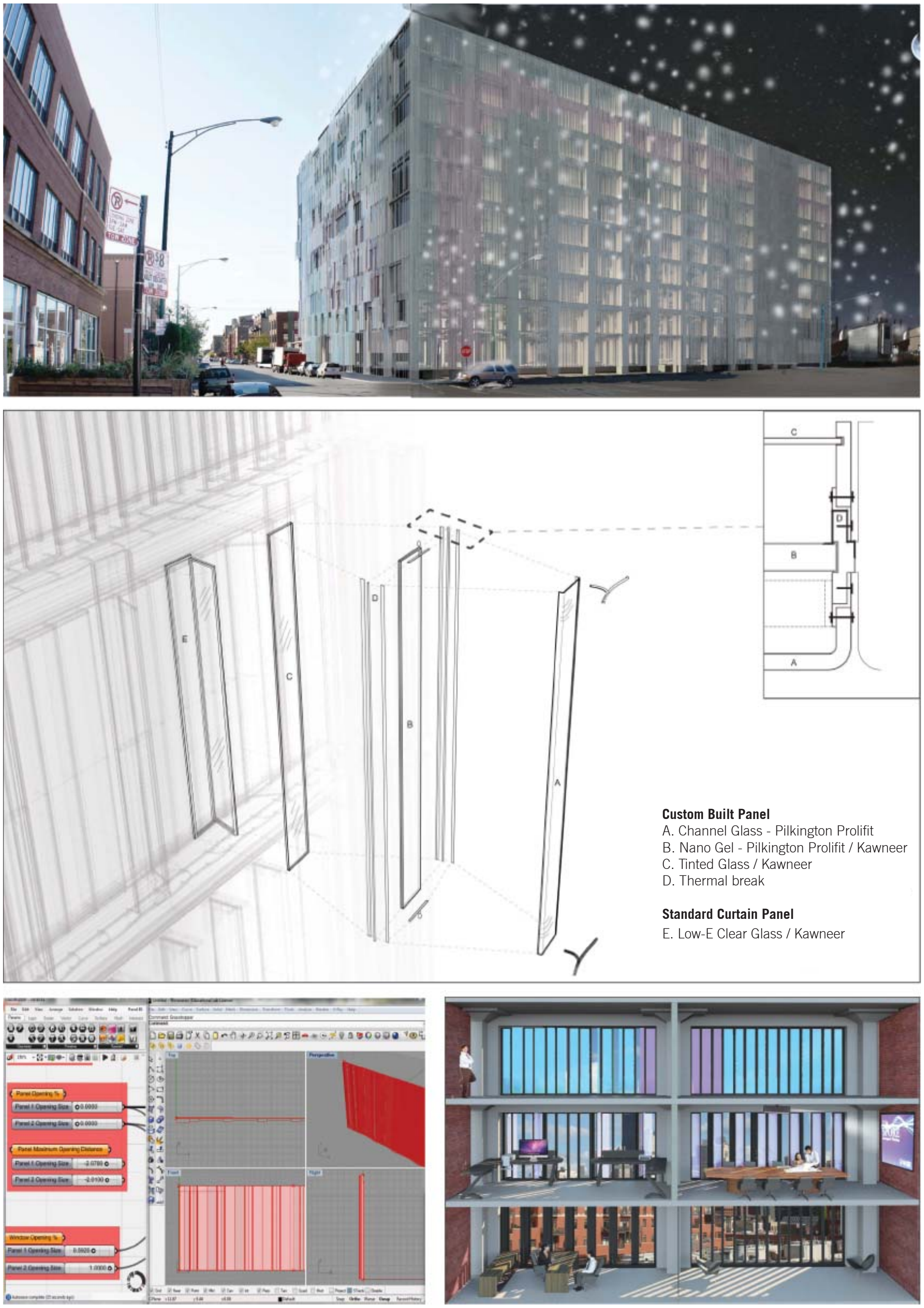


Figure 5: Adaptable building skin. By John Fricano.

### 4.2 Double Skin with Kinetic Shading System

This approach developed a design scenario with glazed double skin building envelope, where an integrated shading system would be used to block solar heat gain and reduce energy consumption (Figure 6). The interlocking shading system would be positioned within the double skin cavity. It consists of horizontal louvers, which are able to rotate and change positions using a pivoting system. At least three levels of shading would be possible. Also, different facade orientations would be treated differently, varying the percentage of shading, number and positioning of louvers as well as the angle of rotation of some of the shading elements. Parametric design tools have been used to control the geometry of interlocking shading system, while digital fabrication and laser cutting have been used to develop low-fidelity physical models of the shading system.

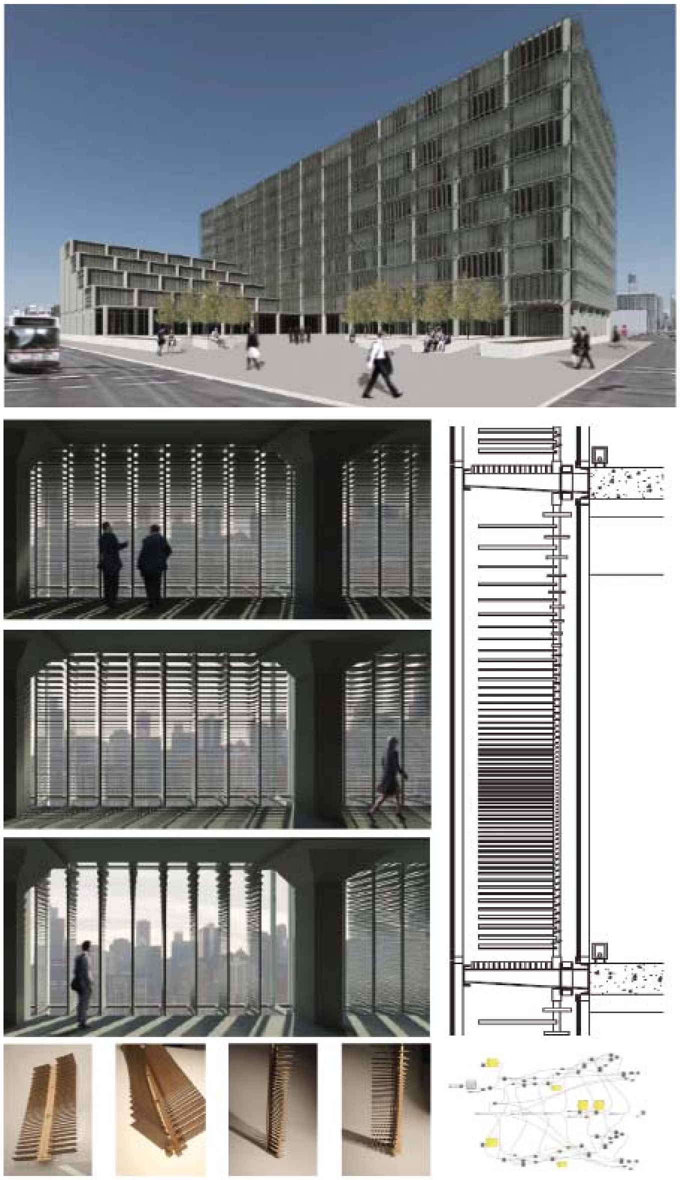

Figure 6: Double skin and kinetic shading system. By Joshua Kuffner.

### 4.3 External Shading System

This approach developed a design scenario where a sliding shading system consisting of several layers of intricately designed patterns would be able to provide different shading percentage for the facade, seen in Figures 7 and 8. The primary building's facade would consist of a curtain wall with glazing and the secondary external shading system would be able to adjust patterned layers to allow control of shading gradients. Parametric design tools have been used to translate the images of incident solar radiation analysis results along each facade to a shading percentage gradient, which determined the amount of shading necessary for each orientation. Digital fabrication and laser cutters have been used to develop low-fidelity prototypes of the shading layers.

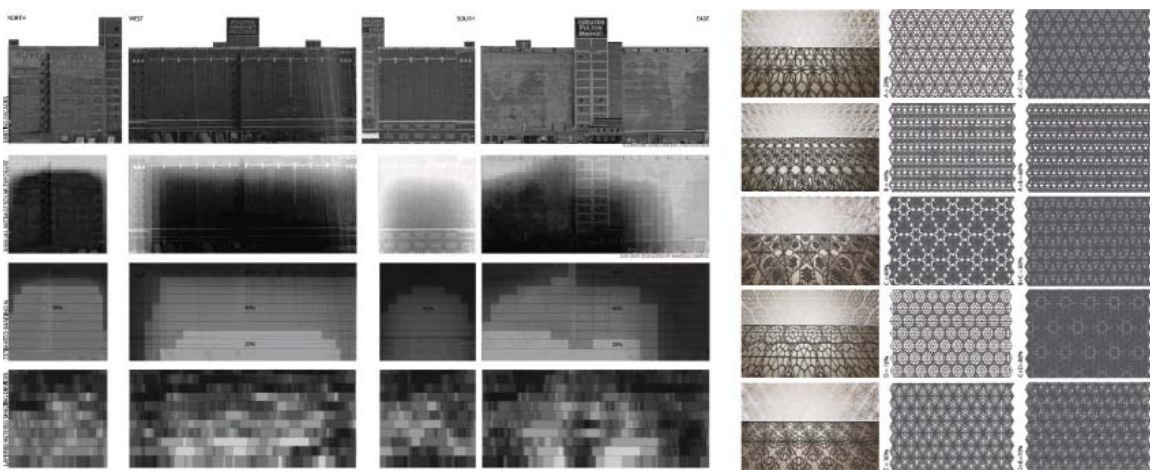

Figure 7: Solar radiation analysis and shading percentage gradient for each facade orientation. By Suncica Milosevic.

Figure 8: Exterior shading system and intricate pattern. By Suncica Milosevic.

## 4.4 Tectonic Building Form

This approach developed a design scenario where the geometry of three-dimensional shading elements was varied in response to solar radiation along the different facade orientations (Figure 9). Dimensions, depth and the percentage of glazing were varied to reduce solar heat gain for critical areas of the facade with highest solar exposures, while balancing access to daylight. Parametric tools were used to size and position shading elements, which would be constructed from glass fiber reinforced polymer (GFRP) material. Digital fabrication process for this design solution used CNC milling to create molds for shading elements and low-fidelity prototypes were constructed from vacuum molding process with plastic material, as seen in Figure 10. Early study models were executed using 3D powder printing.

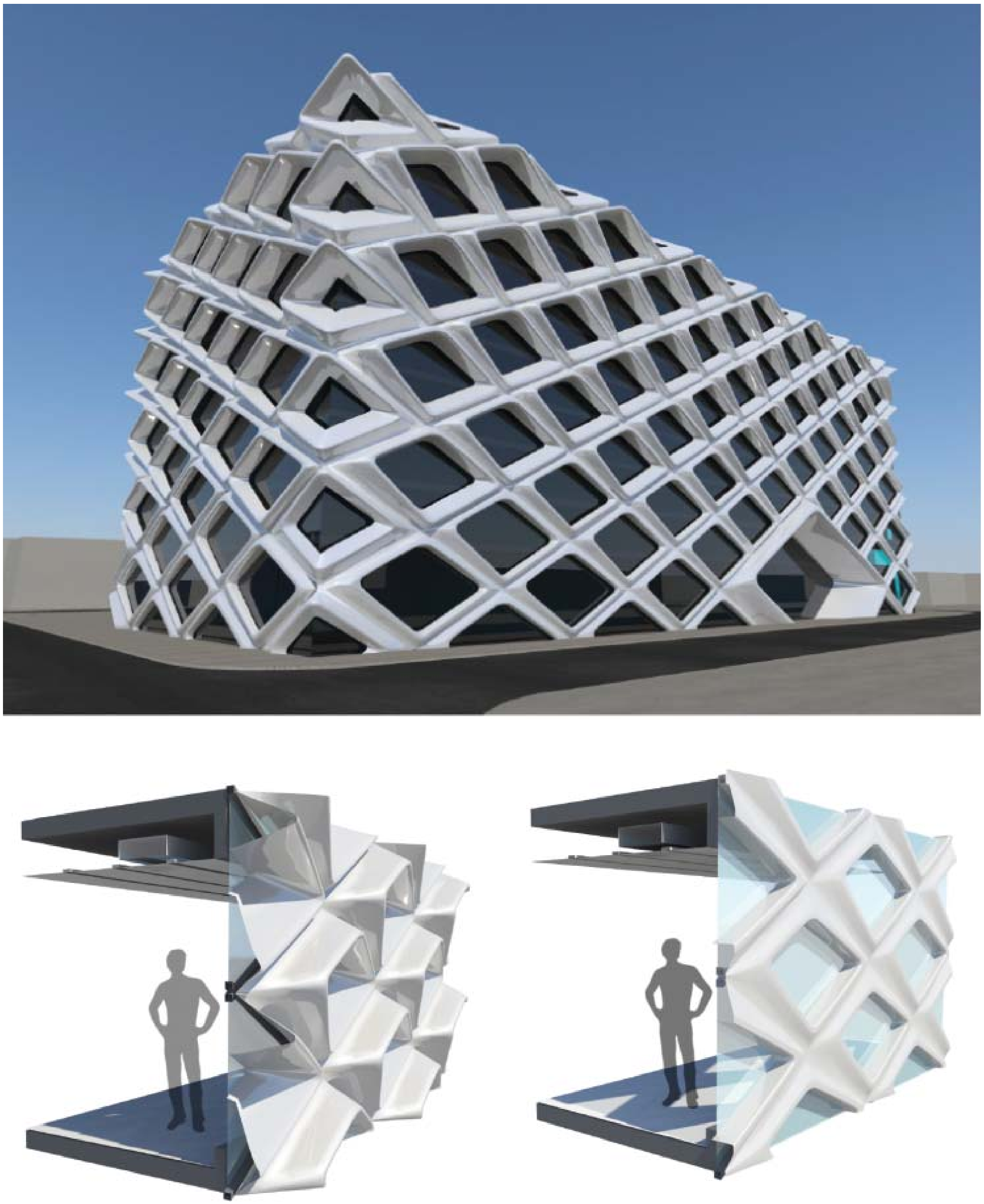

Figure 9: Tectonic building form. By Andrew Newman.

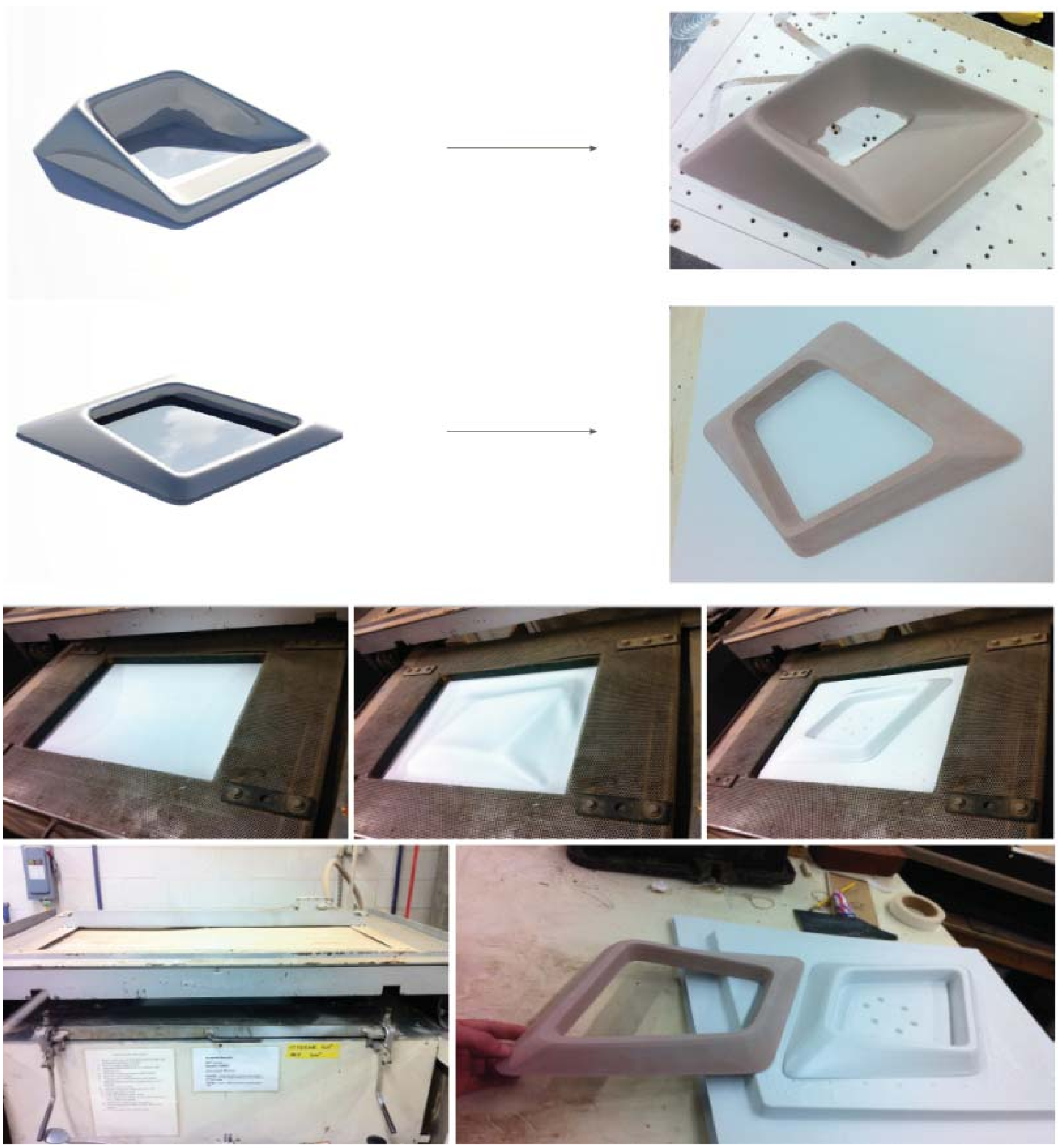

Figure 10: Fabrication.

## 5.0 CONCLUSION

New developments in advanced computational tools and methods are offering unprecedented ways for design exploration and evaluations. Performance-based design that integrates simulations and environmental analysis in the design process has an advantage over traditional design methods, because it allows a certain design iteration to be evaluated against different solutions. Also, digital fabrication techniques allow for creation of physical prototypes, which can be used to evaluate constructability, material behavior and selection as well as aesthetic qualities.

This mutual effort between design practice and an academic institution can serve as a model for collaborative research activities, since it specifically addressed new ideas and methods for integrating practice, research and education on emerging technologies. The recommendations from this collaboration are:

- Both design practice and academic institutions benefit from engaging in collaborative research
- The benefit for practice is that emerging design approaches, technologies and computational design methods can be explored in relation to a real project
- The benefit for academic institutions is that this type of collaboration bridges the gap between the profession and research/educational institutions and provides an excellent platform for effective learning and connection to the practice.

### Acknowledgments

Authors would like to acknowledge University of Cincinnati graduate students who were involved in the class “Re-skinning: Performance Driven Design & Parametric Correlation” (Marrisa Campos, Melina Carneiro Brandao, Francis D’Andrea, Dylan Fischer, John Fricano, Joshua Kuffner, Mailys Meyer, Suncica Milosevic, Andrew Newman, John Ritter and Daniel Ruberg).

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# 03. A SIMPLE MODEL FOR COMPARING HEALTHCARE STAFF WALKING EFFICIENCIES ACROSS DIFFERENT HOSPITAL FLOOR PLAN DESIGNS

**Jeff Tyner, AIA, LEED AP BD+C,** *jeff.tyner@perkinswill.com*
**Sandra S. Dunbar, RN-BC,** *sdunbar@gwinnettmedicalcenter.org*
**Bowman O. Davis, Jr., PhD,** *bodavis@kennesaw.edu*

## ABSTRACT

With healthcare facility design trending toward increasing patient space in new construction, there can be concomitant increases in healthcare staff workloads. This study used simple pedometry step counts to compare staff walking effort in double-loaded and racetrack corridor floor plan designs. It was demonstrated that the racetrack floor plan outperformed the double-loaded corridor in human energy efficiency regardless of staff position or work shift. The racetrack corridor floor plan proved to be the better of the two designs for increasing patient space while minimizing the increase in healthcare staff walking workload.

KEYWORDS: evidence-based design, healthcare staff workloads, double-loaded corridor, racetrack corridor, floor plan design efficiency

## 1.0 INTRODUCTION

Within the major context of evidence-based design (EBD), two major trends in healthcare delivery are prevalent today and are influencing modern hospital design and construction: (1) healthcare delivery is being practiced in a more competitive environment resulting in a trend toward more patient/family-oriented building designs; (2) consideration of the environmental impact of new building design is focusing attention on energy efficiency and the net carbon "footprints" of building designs and construction. In fact, references to building performance and building efficiency deal more with traditional energy efficiency than with "human energy" expenditure and conservation[1].

More "patient friendly" designs require increased room size to facilitate patient comfort as well as that of family and visitors. From a healthcare practice perspective, today's more acutely ill patients require more floor area around beds for medical equipment and in-room procedures. Yet, these patient-centered design trends have paradoxical impacts on hospital constituencies. Patients and their families benefit from more spacious and comfortable rooms, while staff can be negatively impacted by having a larger floor space to cover in daily patient care delivery. It is relatively easy to quantify the physical parameters, such as room size, temperature, humidity, lighting and noise levels that contribute to patient/family comfort and to design new facilities accordingly. It is also possible, through insightful placement of supply storage and other floor plan considerations, to optimize staff work effort. However, no simple means of quantifying the effectiveness of these "staff-centered," work-saving innovations is readily available. In order to have practical utility, such a measurement tool must be simple and inexpensive to employ while having broad applicability across different building designs with different staffing levels. The protocol presented here builds upon the previous work of Shepley[2] and provides a relatively simple technique for comparing staff workloads that should be applicable in differing healthcare delivery scenarios.

In 2009, Gwinnett Medical Center in Lawrenceville, Georgia and Perkins+Will completed the construction of a new North Tower addition, consisting of 155 new patient beds. This building addition provided an opportunity for a prospective study of the comparative staff workloads in two dramatically different hospital floor plans. Although the original South Tower, constructed in 1983, met the codes of its time, the minimum size requirements for patient rooms and the needs for support space have increased substantially over the years. The older South Tower was designed as a double-loaded corridor with a single, centralized nurse station, while the new North Tower employed a racetrack design with duplicate nurse stations and supply storage areas at each end of the unit. To preemptively address staff/patient visualization concerns, satellite charting stations with 12 inches wide windows were situated between each pair of patient rooms to enhance patient observation while moving charting activity closer to patient rooms further reducing walking workload (Figure 1). It was hypothesized that this design would accommodate the desired larger patient spaces while minimizing the increased walking required for staff to cover the larger floor space.

Figure 1: Satellite charting station.

## 2.0 METHODOLOGY

In order to control as many variables as possible between the two different floor plans, a cardiac care unit was selected from the various healthcare specialties housed in the two facilities. This unit proved ideal for study since it would relocate from the old building into the new addition with no change in healthcare tasking and it would retain most of the same staff members.

The older double-loaded corridor unit housed 35 patient beds attended by four patient care technicians (PCTs) and nine registered nurses (RNs) during the day and three PCTs and eight RNs at night. The new racetrack corridor facility accommodated 31 beds attended by three PCTs on all shifts with eight or seven RNs on day and night shifts, respectively. Therefore, the same staff at comparable levels would be performing the same healthcare delivery protocols in both facilities. Differences in staffing levels, differing floor plan designs and daily fluctuations in patient census became the major variables determining staff workloads. All these variables had to be considered in developing a method for quantifying staff walking workloads.

Pedometry was determined to be the simplest and least labor-intensive way to monitor staff workloads. Six Omron, Model HJ-112 pedometers were acquired and a number of volunteer RNs and PCTs were recruited to wear them during their normal work shifts. An effort was made to ensure as many different individuals as possible were involved in the data collection in sufficient numbers to adequately cover all shifts for the two-week study interval in each facility.

Instructions to staff participants emphasized the importance of clearing the pedometer settings before each new wearer and the need to record only in "step mode." Step counting was preferable to avoid having to recalibrate the pedometers for each new participant's stride length. To incentivize participation, the pedometers were raffled off to participating staff at the end of the study. Pedometer measurements were suspended for 90 days pre- and post-relocation until staff had adequate time to acclimate to their new surroundings and to avoid any atypical activity associated with the relocation.

A spreadsheet was provided at each nursing station for study participants to record their first name, pedometer number, date, staff position, shift start time, shift end time and total number of steps at the end of their shift. A section of the spreadsheet was dedicated to "trips off floor" where study participants could record the number of trips off the floor to the cafeteria, lab and other commonly visited sites. This spreadsheet addition was important to ensure that recorded steps were accumulated only in patient care delivery on the floor in question. For the final computation of adjusted patient care Steps, previously measured steps to each "off floor" destination were subtracted from the subjects' recorded totals. The two-week data recording interval generated between 150-175 individual records, which was sufficiently large that a few aberrant data entries, should they occur, would not appreciably skew the means in final analysis. Special cause variations yielding conspicuously "out of range" data points, commonly due to accidental pedometer resets or failures to reset the devices at the beginning of a new shift, could be easily detected by visual inspection and deleted.

Figure 2 shows the calculations used to determine each study participant's relative efficiency. Efficiency calculations were considered "relative" because they were dependent upon floor plan design, staff position, staffing levels and patient census during the study time frame. Mean percent occupancy levels over the study intervals were 92 percent and 100 percent in the double-loaded and racetrack corridors, respectively. Load was determined by simply multiplying the total floor plan square footage by the average percent of maximal occupancy and dividing by the number of staff members of a given position category assigned to cover the floor on each shift. That value, when divided by the calculated effort, provided an approximation of each individual's relative efficiency.

Averaging the relative efficiencies for any staff position on any work shift over the study time interval gave an indication of how each floor plan design was functioning for a particular staff group under normal work conditions. Mean relative efficiencies for each staff group were also compared statistically across the two floor plans using a Mann Whitney Rank Sum nonparametric analysis protocol. Simple efficiency calculations such as these should be applicable to any building design or staffing combination and should allow for simple comparisons across differing healthcare delivery scenarios.

$$\textbf{Relative Efficiency} = \frac{\text{Load}}{\text{Effort}}$$

$$\textbf{Load} = \frac{(\text{Floor plan ft}^2) \times (\text{Mean \% occupancy}/100)}{\text{Staff position number}}$$

$$\textbf{Effort} = \frac{\text{Adjusted patient care steps}}{\text{Hours worked}}$$

Figure 2: Healthcare staff workload (walking) efficiency calculation.

## 3.0 RESULTS

The cardiac care unit selected for this study occupied a floor with 25,405 square feet in the new building, an 82 percent increase over their 13,972 square feet space allocation in the old facility. Typical patient room size increased from 167 square feet to 285 square feet. Since the unit size nearly doubled in the new building, it would not be unreasonable to assume a comparable increase in staff workload, given comparable staffing levels in the two facilities. However, the pedometry data did not support this assumption.

Differences in walking workloads were seen with different staff positions and with the same staff positions when day and night shifts were compared (Table 1). As anticipated, the larger floor plan in the new addition did increase the walking workload of PCTs and RNs on both day and night shifts, but the increases were not as much as expected given the large difference in floor plan areas and the slight reduction in staff levels in the racetrack corridor unit. PCTs, whose job description requires more walking, showed mean step counts per hour of work to increase from 882 to 1010 on day shifts, a 14.5 percent increase. On night shifts, their step counts increased from 735 to 923 per hour of work, a 25.6 percent increase. RN's step counts averaged 536 per hour of work on day shifts in the double-loaded corridor and increased to 631 in the larger, racetrack design, an increase of only 17.7 percent. On night shifts, RN's walking increased from 482 steps per hour to 611, an increase of 26.7 percent. Considering all staff positions and both shifts, walking in the new racetrack design increased within the range of 14.5 to 26.7 percent, considerably less than anticipated given the 82 percent floor plan square footage disparity between the two designs.

Table 1: Comparison of staff walking efficiencies between double-loaded corridor and racetrack floor plan designs.

| Staff Position by Work Shift | Effort | Load | Reletive Efficiency |
|---|---|---|---|
| Patient Care Technicians (PCTs) | | | |
| | Double-Loaded Corridor | | |
| Day Shift | 882 | 3213 | 3.64 |
| Night Shift | 735 | 4284 | 5.83 |
| | Racetrack Corridor | | |
| Day Shift | 1010 | 8468 | 8.38 |
| Night Shift | 923 | 8468 | 9.17 |
| Registered Nurses (RNs) | | | |
| | Double-Loaded Corridor | | |
| Day Shift | 536 | 1428 | 2.66 |
| Night Shift | 482 | 1607 | 3.33 |
| | Racetrack Corridor | | |
| Day Shift | 631 | 3175 | 5.03 |
| Night Shift | 611 | 3629 | 5.94 |

This observation suggested that, even with its larger size, the racetrack design was more efficient in staff effort expenditure, meaning that fewer staff could cover more square footage with fewer steps. To test this assumption, mean relative efficiency values (Table 1) were compared statistically for significant differences between the two floor plan designs. In every comparison of equivalent staff groups and work shifts between the two facility designs, the racetrack corridor efficiencies were significantly higher ($p=<0.001$) than those seen in the double-loaded corridor floor plan.

Night shift PCTs in the racetrack corridor design showed the highest relative efficiency estimate of 9.17. That value represented a 57 percent increase over their efficiency in the double-loaded corridor (Figure 3). However, the best improvement in efficiency was seen with the day shift PCTs. Their efficiency improved 130 percent in the racetrack design. RNs, who typically walk less in performing their duties, also showed dramatic increases in efficiency in the racetrack design ranging from 89 to 78 percent improvements on day and night shifts, respectively.

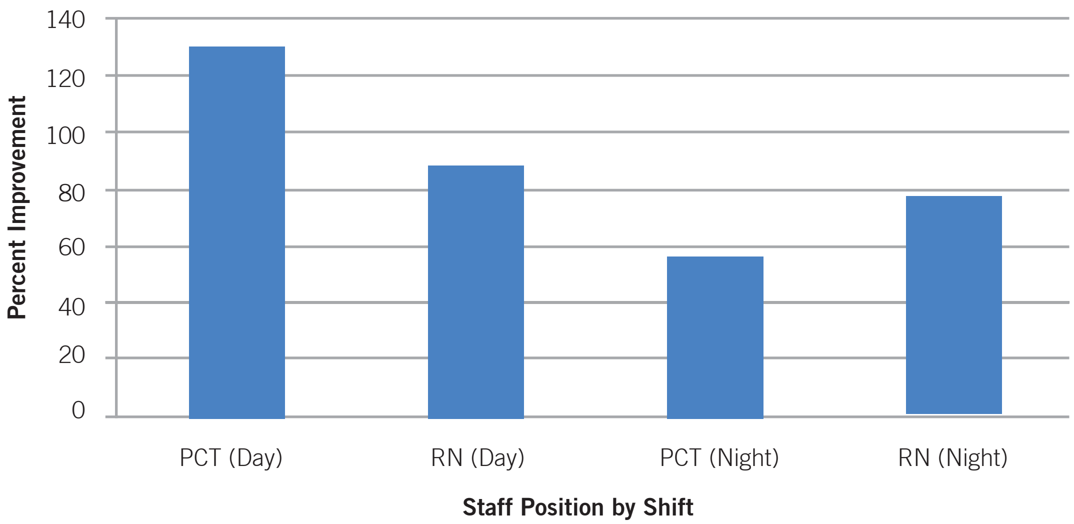
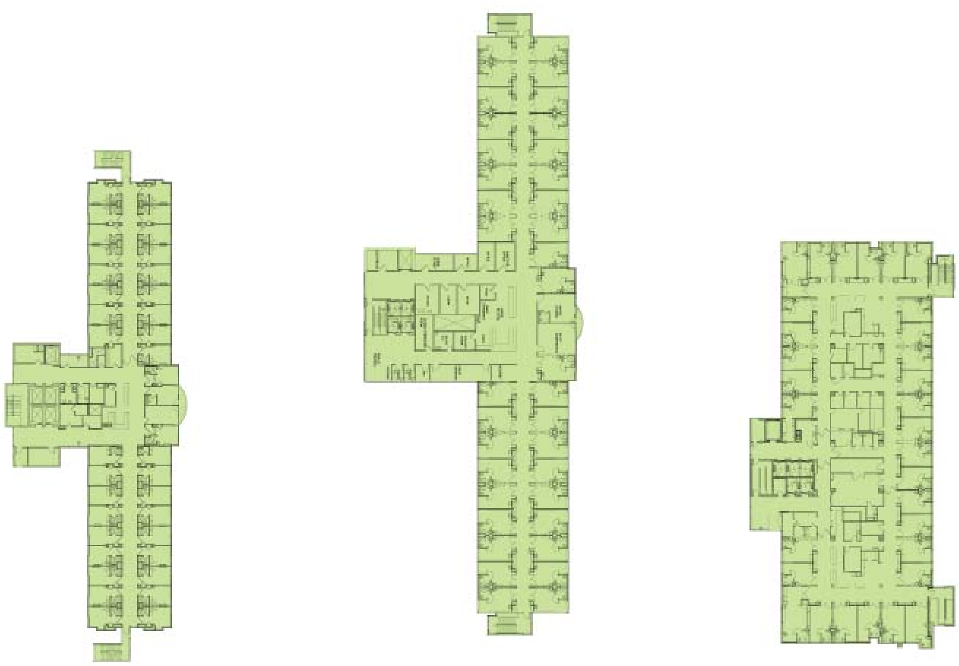



Figure 3: Staff racetrack walking efficiency improvement over double-loaded corridor floor plan.

## 4.0 DISCUSSION

Historically speaking, with the advent of mechanical ventilation, cross-ventilation needs ceased to be a determining factor in healthcare facility design. This innovation allowed designers the freedom to experiment with a variety of new floor plan configurations informed primarily by staff mobility and patient visualization issues. More recently, changing healthcare building codes are further expanding patient spaces in modern hospital designs. Consequently, more spacious floor plans are now required to accommodate a comparable number of patients in these newer facilities and are directing design attention toward mobile staff walking workloads. This is not to imply that human workload has been neglected in the past[3]. For several decades workload has been an integral part of facility planning, being innate to the learned conceptual paradigms for designing navigable configured spaces[4]. Although it did direct attention to the need for centrality in healthcare space configuration and staff assignments, the more complex contemporary paradigm of Space Syntax has proven to be too complex and inconsistently reliable for widespread utility in healthcare design[5]. Given that both floor plan layouts and staff assignments can influence how nurses move through a unit,[6] it is valuable to have comparative measurements of real human workloads across different hospital floor plans.

Figure 4 illustrates the paradoxical impact of accommodating patient expectations with larger, more comfortable rooms while inadvertently increasing the walking workload of healthcare practitioners caring for these patients. Comparing the floor plans in this study demonstrates how large the older, double-loaded corridor design would have to be in order to meet current patient space specifications. Simply building the same design according to current codes would increase the square footage by a factor of 2.1 from 13,354 square feet to 27,568 square feet. With a single, centrally positioned nursing station in that older corridor design, the walking workload of attending staff would increase to burdensome levels.  In fact, simply building a larger facility to meet patient space expectations without considering the increased staff workload could result in the necessity of adding additional staff, which might diminish any financial return realized from the new construction. In contrast, the racetrack corridor design allowed for increased patient space with only modest increases in staff walking.



**1983 South Patient Tower**
13,354 SF
381 SF/Bed

**Per 2010 Codes**
27,568 SF
745 SF/Bed

**2009 North Patient Tower**
24,367 SF
786 SF/Bed

Figure 4: Floor plan comparisons by building code specifications.

This study confirmed how a racetrack corridor design, with its duplicate nursing stations and supply storage areas as well as satellite charting stations, allowed for increased patient space without dramatically increasing staff walking workload. That is not to say that staff walking did not increase in the racetrack design. Different staff constituencies and different work shifts did walk more in the larger facility, with the extent of that increased effort determined by their healthcare delivery responsibilities.

Since most medical procedures and physician's rounds occur on day shifts, this shift should require more walking regardless of building design. Additionally, staff numbers, which influence the "load" calculations for individuals, can vary with employee position. The more people sharing a given workload, the fewer square feet would have to be covered by each individual in carrying out their duties. PCTs typically walk more than RNs in carrying out their responsibilities and there were fewer of them on each shift. Not surprisingly, they showed the largest improvement in efficiency in the new racetrack corridor design. Staff members who walk less in their jobs will not benefit as much by floor plans designed to minimize walking. However, the racetrack corridor design consistently outperformed the double-loaded corridor configuration regardless of staff position or work shift.

In fact, the hospital was able to reduce slightly the number of PCTs and RNs on each shift in the new facility without sacrificing workload efficiency, patient satisfaction or patient care. That patient care did not suffer in the larger unit is evidenced by several indices. Patient falls per patient day decreased from 0.0063 in the old facility to 0.0046 in the new racetrack floor plan, an improvement of 27 percent. Although the racetrack floor plan with its remote charting stations and viewing windows likely played a role in reducing patient falls, this study did not differentiate among the various innovations also employed by staff in the new unit to address this patient care issue. Additionally, average lengths of stay decreased from 5.5 days in the old unit to 4.7 in the new facility with no increase in hospital-acquired infection rate. This reduction in length of stay could be attributed, in part, to the on-site availability of social workers and case managers, spaces for whom were provided in the new racetrack floor plan.

Pedometers, such as those employed here, have historically been used to establish normative data for individuals engaging in walking as aerobic exercise and to monitor general physical activity[7,8] and they proved the simplest and most inexpensive means of monitoring workload activity in this study. However, they are not precision instruments. Tyron et al.[9] subjected pedometers to accuracy tests under controlled laboratory conditions and found their readings in step mode to be off as much as five percent. Variations in gait can yield erroneous step counts with these devices. Since our study protocol employed the same pedometers with the same staff in both facilities being compared, errors should be equally probable in both data samples with no bias in favor of one over the other. Moreover, it was not the purpose of this study to determine definitively and with absolute accuracy the human energy efficiency of different healthcare work environments. Instead, this study required a simple, inexpensive, participant-friendly method of obtaining a general estimation of staff walking effort and workload efficiency that could be reproduced and applied across differing healthcare facility designs. The pedometer proved adequate for that purpose.

## 5.0 CONCLUSIONS

The pedometry experimental protocol employed in this study provided valuable insights into hospital staff energy expenditure in execution of their daily work activities and how their individual workloads were impacted by different building designs. Data confirmed that day shift employees walked more than their night shift cohort and that patient care technicians had a more walking-intensive workload than registered nurses irrespective of building design. More importantly, it was possible to apply employee walking activity measurements to compare the relative design efficiencies of double-loaded corridor and racetrack corridor floor plans. In every aspect of this study, the racetrack corridor floor plan outperformed the double-loaded corridor and proved to be the better of the two designs for expanding patient space while minimizing its impact on attending staff workloads.

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# 04.
# PROJECTING RETURNS ON TRANSIT INVESTMENT:
## *A Research Proposal for Analyzing and Evaluating Investments Made In and Around MARTA Stations and Projecting the Returns*

**Kevin Bacon, AICP, LEED AP BD+C,** *kevin.bacon@perkinswill.com*
**David Green, AIA, LEED AP BD+C,** *david.green@perkinswill.com*

ABSTRACT
It is a commonly held belief that the construction of rail transit systems and more specifically the stations along the system, drives real estate development in the areas they serve. The benefit is seen as a mutual one: high-density development at transit stations and along rail corridors generates the ridership and these systems need to be sustainable and ultimately successful. In practice, however, the success of this concept has not been consistent. The Atlanta region's MARTA (Metropolitan Atlanta Rapid Transit Authority) rapid rail transit system is a perfect example. MARTA offers a range of station types, from central business district to suburban that serve a range of demographics. Several of these station areas are well developed, while others remain surrounded by vacant land or expansive parking lots. This variation drives the core of the research: why has development unfolded at an inconsistent level at the various stations? Is this variation correlated to the investment made at each station and if so, how can the investments and returns be categorized to provide a clear understanding of these issues? The goal of the research is to provide a methodology for analyzing the performance of each station relative to fulfilling development potential and success of the transit system. In addition, it will provide a methodology for determining the broader return on investment that the city and county may realize in relation to the substantial infrastructure investment made at these stations.

KEYWORDS: Metropolitan Atlanta Rapid Transit Authority (MARTA), rail transit, economic development, transit-oriented development (TOD), station area planning, return on investment (ROI)

## 1.0 INTRODUCTION
"Fixed-guideway transit promotes growth and investment," is an axiom in the transportation world. Investment in rail transit has often been touted as a way to spur real estate development through the development of parcels in the vicinity for the transit system stops. On the surface this seems to make a great deal of sense. Rail transit systems represent significant public investment and establish a permanent presence in the areas in which they are located. It is an easy concept to grasp: people using a transit system would also live, work and shop nearby if these amenities were conveniently accessible at a specific station as well as throughout the entire system. In theory, this opportunity lures developers, spurs new development and leads to an increase in surrounding property values. Transit in turn benefits from this. Development appropriately designed and at the right intensities generates ridership for the transit system. High ridership helps sustain the transit system and ultimately makes it more successful.

As transit projects are planned, however, the development associated with the transit station construction rarely enters into the investment calculus on the part of the transit operators and affected jurisdictions with oversight. The policies and metrics that set goals and provide statistical value for the transit system are framed within narrow scopes. Typically, a transit system looks at construction costs, projected ridership and revenues as well as projected operating costs in a limited set of criteria. In this scenario, the jurisdictions return on investment (ROI) is simply derived from these elements of the project. In a more comprehensive system, the local jurisdictions might consider additional elements that have great impact on the return they realize. Further, it may prove that additional, strategically allocated investments might increase the overall ROI at an attractive rate of return.

It is important to note that this concept conventionally applies to rail or other fixed-guideway transit only. This includes technologies such as commuter rail, rapid (or heavy) rail transit (RRT/HRT), light rail transit (LRT), streetcar and bus rapid transit (BRT) among others. Each of these systems requires physical infrastructure that is permanent in construction. The certainty of station and route locations and service are the development incentive. Conventional buses, local, regional, express or other are susceptible to relocation of stops, route changes and service cuts, thus, not providing the same development incentive.

From Portland, Oregon to Washington, DC there are many examples of development thriving in proximity to transit systems. However, there are also many examples where transit is devoid of development and is disconnected from the cities it serves. The Metropolitan Atlanta Rapid Transit Authority (MARTA) exemplifies this variation in the success of station-associated development. While a number of stations seem to have spurred expansive development, there are other stations along MARTA's rapid rail transit lines that serve as clear examples where development has failed to take hold. Few stations are surrounded by development. If they are, they are not pedestrian friendly, resulting in a poor quality of life. Of those that are, one in particular, Lindbergh Center station, has been heralded as a model for transit-oriented development (TOD). Lindbergh Center seems to be an exception to the otherwise undeveloped stations where underutilized surface and structured parking are the norm. What makes these undeveloped stations different? What causes development to pass them by? Station area plans are produced, transit-oriented guidelines are established and zoning regulations are modified, yet development remains absent. Lack of development in proximity to MARTA is a very real problem for Atlanta, especially as it relates to the investments the city is making in these areas.

The dearth of development at many MARTA stations indicates that there may be less truth to the axiom that investment in rail transit drives proximate real estate development. The reality appears to be that the positive relationship between transit and development may not be as operative in reality as it is in concept. In reality there are many other factors to consider in transit-related development; the presence of rail transit infrastructure is simply the prerequisite. Other conditions, such as market climate, development regulations and institutional requirements like joint development agreements and transit station design play a role. Each of these can either serve to entice development or act as a barrier to it. When these issues have become barriers they must be thoroughly examined, analyzed and understood in order to remove such barriers. This article discusses these conditions and outlines ways in which they may act as barriers. MARTA will serve as a case study throughout the article to illustrate examples where appropriate. While a complete station-by-station analysis is not in the scope of this article, a methodology for further research and understanding of each station in terms of its barriers to development will be framed. It is the expectation that this discussion on development barriers and proposed research framework is the first step of a larger research project.

Underpinning this analysis is the ultimate goal of creating a highly operational analytical framework within which jurisdictions may evaluate the various development parameters in the transit station areas, identify and address development barriers and accurately set investment levels and types to realize the highest levels of return on the jurisdiction's investments.

## 1.1 Development of New MARTA

When the original referendum forming MARTA was passed in 1965, it was intended that Atlanta's transit system would be designed in parallel with land use controls that would promote high density development around transit stations and high ridership on the transit system[1]. Throughout the next decade MARTA would work with the Atlanta Regional Commission (ARC) and the City of Atlanta Planning Department to classify and plan MARTA's stations for development. Zoning regulations were updated and land use plans were amended to ensure that the rail system would have supportive development. Figure 1 is a rendering that illustrates MARTA's original vision for its transit stations.

That original vision has generally been difficult to implement. Today MARTA's rail system has grown to include 38 stations and 48 miles of rail infrastructure funded by more than $6 billion in public investment, but the original goals for the system remain largely unmet in terms of ridership and development potential. Parking, both surface and structured, represents the prevailing development model at transit stations (see Figure 2).

Besides the 1970's, only recently has MARTA's Board taken a serious turn towards system-wide transit-oriented development to help increase ridership and reduce

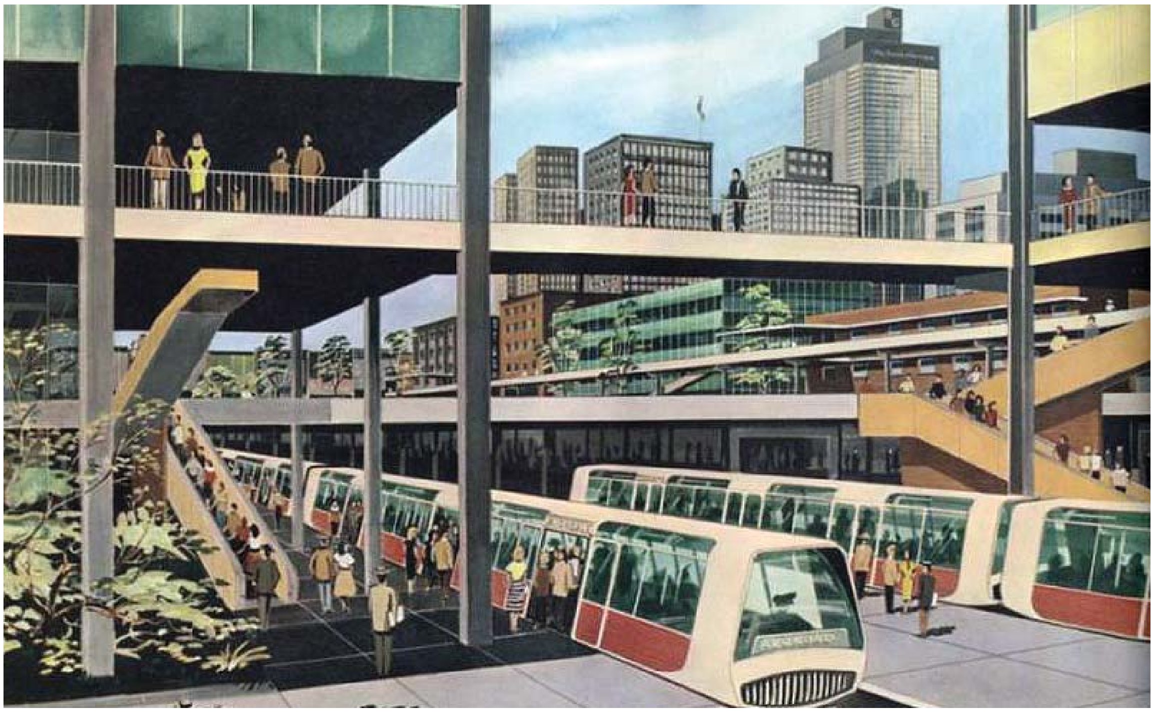


Figure 1: Original vision for MARTA's transit stations (rendering: Walter Hunziker, 1961).

Figure 2: Parking at West End MARTA station (photo: by author).

budget shortfalls with the potential sale of land. For example, in the last decade the Lindbergh Center station has been redeveloped and is now touted as a model of successful transit-oriented development[2]. The 47-acre site is home to a mix of high density office space, multi-family housing, retail and shared structured parking. As of 2011, the station has emerged as the third busiest of the entire system behind the stations at Five Points, Atlanta's transit hub and Hartsfield-Jackson International Airport (see Figure 3)[3]. In addition to Lindbergh's TOD, MARTA has also released its Transit-Oriented Development Guidelines aimed at outlining the agency's development expectations and clarifying its process for joint development[4]. MARTA anticipates that the presence of these guidelines will foster development at other stations in the system. It is too early in the process to determine the success and influences of both of these measures, yet one thing is clear: barriers to development at MARTA stations still persist. As the region seeks an aggressive expansion of rapid rail and streetcar transit over the next ten years, it seems critical that barriers to development are understood and overcome and that an operational system for evaluating the success of the projects aligned with the transit stations is developed.

| CURRENT RANK | STATION NAME | FY 2012 (YTD) | FY 2011 | FY 2010 |
|---|---|---|---|---|
| 1 | FIVE POINTS | 20,956 | 22,188 | 22,769 |
| 2 | AIRPORT | 9,335 | 9,583 | 10,769 |
| 3 | LINDBERGH CENTER | 9,156 | 9,263 | 8,970 |
| 4 | COLLEGE PARK | 9,154 | 9,261 | 9,352 |
| 5 | PEACHTREE CENTER | 7,290 | 7,411 | 7,602 |

Figure 3: MARTA annual weekday ridership for the top five stations (source: MARTA Analysis of Rail Station Entries: Fiscal Year 2012, Third Quarter Update).

## 2.0 BARRIERS TO DEVELOPMENT

Traditionally when barriers to transit-oriented development have been considered, land use and zoning regulations are the elements in the process that first come to mind. Development regulations certainly present barriers to undertaking these complex projects, but they are actually only potential barriers and seem to have become the easiest component to resolve. In addition to development regulations, other barriers that can affect development at transit stations include market conditions, station design and institutional requirements. These are representational, top-level categories. Further, they are framed in terms of conventional understandings of the relationship between each of the categories outlined and typical transit-oriented development.

### 2.1 Development Regulations

Even if the market climate is favorable, regulations on development may keep potential developers away from certain areas. Given the popularity and momentum that station area planning and transit-oriented development have gained over the past two decades, development regulations are not necessarily the major barrier to development that they once might have been[5]. Many cities, even neighborhoods have preemptively undertaken the process of station area planning; putting in place visions for development they deem appropriate. At the end of 2010, MARTA released guidelines for transit-oriented development. These guidelines provide great detail about how development should occur and what it should look like. MARTA is not the only example. BART (Bay Area Rapid Transit), DART (Dallas Area Rapid Transit) and even the State of Florida have similar guiding documents. Still, the presence of TOD guidelines alone does not automatically induce developer interest. While it seems clear that development regulations, in one form or the other, are still posing obstacles to development, it is probably unrealistic to discard regulations altogether in favor of generating new development, but understanding the persisting issues may help to resolve them. Obstacles may be presented when development regulations are unclear, too constricting or, as may be the case in some situations, antiquated and incompatible with transit-supportive development.

First, there are the cases in which existing development regulations discourage development near transit. This can include anything from the policies of a comprehensive plan to the specific parking ratio requirements found in a municipality's zoning ordinance. It is not that these regulations necessarily prohibit development at transit; they cling to outdated ideas of development such as single use projects, often at low densities with substantial minimum parking requirements. This is counter to the types of development that are financially feasible. Projects that support transit often require a mix of uses at higher densities with lower minimum or maximum parking requirements. The parking issues can be especially problematic. Since transit-supportive development conceivably reduces automobile dependence, it will reduce the overall parking requirement while satisfying the requirement through deck parking or shared parking structures. Many development regulations have not caught up with this strategy.

In response, some municipalities and agencies have attempted to update development regulations through zoning overlay districts and design guidelines that address the complexities inherent to transit-supportive development. These can all be useful instruments for changing the regulations themselves, but can also sometimes be problematic. Complex development is not encouraged by complex regulations. As discussed in the previous section, the market climate is highly dynamic. Development criteria change rapidly and in many instances the values associated with particular types of development change. Confining development to a narrow vision of a static solution may lead to a lower level of development. Regulations that are set forth to govern development, transit-oriented or otherwise, might need to be flexible enough to allow for interpretation and innovation in design proposals and thus, incentivize development appropriate to transit station success. As there is often more than one answer to these challenges, it may be that goals should focus on generating activity and ridership through a proactive incentivizing of development in the areas surrounding the stations. These are, most consistently, the properties that will determine the success of development and transit together.

Finally, ambiguity surrounding development regulations may also dissuade developers from taking on a particular project. Unclear zoning ordinances are the first and most obvious problem. Another problem not often considered is uncertainty as to which municipality will ultimately regulate the development. This is especially true of MARTA where the system crosses several municipal boundaries, each with its own set of development regulations. Further compounding the matter is that municipal boundaries in Atlanta are now in a state of flux. Over the past decade Atlanta has seen the incorporation of several new cities. Some of these have had direct influence on development at MARTA stations. For instance, the Sandy Springs station located north of the city was primed for development. However, development plans fell apart in 2005 when Sandy Springs incorporated and it was no longer clear how the new city would regulate the new development. That problem still persists today. The Brookhaven station, on MARTA's northeast line, has long been thought of as a site with high development potential. Now Brookhaven, similar to Sandy Springs, seems destined for incorporation. As uncertainty regarding these changes are apparent, MARTA has remained hesitant to engage developers rather than invest valuable time and resources working towards a project that may become untenable as jurisdictional boundaries change.

## 2.2 Market Climate

As with any development, a developer must recognize transit-oriented development as a lucrative business opportunity in which a substantial return on investment can be realized. It is well established that development near transit commands a higher value than similar development located farther away[6]. In fact, some real estate studies have revealed this "transit premium" to be as much as 150 percent[7]. However, before private development will even consider undertaking a development project the market climate must be right. This does not just apply to transit-related development: a "good" market climate is a fundamental prerequisite to promoting development at any location. If the market is not favorable, there will be no interest in development and addressing any other barriers that exist is moot. But what constitutes a "good" market climate? How can "good" market climates be created? It is a difficult concept to define, however, this section considers four conditions that may contribute to a climate being favorable for development: population, economy, competition and history.

It may seem paradoxical, but a substantial existing population near transit is one favorable sign to a developer. Not only does this existing population produce transit riders it also promises initial patrons for any new development. Larger development projects at transit stations can take many years to come to fruition. Transit-oriented development at MARTA's Lindbergh Center station first gained traction when the Federal Transit Authority (FTA) relaxed its joint development guidelines in 1997 and selected Lindbergh as a pilot project. It would take almost ten years for the project to be completely developed[8]. A built-in population can help offset losses early in development reducing the risk a developer must assume. Several metrics that describe the existing population - population density, job density and area median income for example - can help gauge the characteristics of an existing population and are available from a variety of resources such as US Census Bureau data or market studies.

Another component of the market climate is the overall state of the economy. Since the start of the Great Recession in 2008, development across the country has stalled. Access to funding for new development has become scarce (see more under 2.4 Institutional Requirements) and investors have become increasingly risk-adverse. Though certain federal, state and local funds or low-interest loans may be available to help incentivize development, they often require a certain matching private investment to obtain. In the absences of startup capital, development will not occur.

Competition is another barrier to development near transit. If there is no sense of demand, developers will typically shy away from development projects. Areas that suffer from excesses of certain building types (office space, condominiums anf retail) and high vacancy rates are signs to a developer that the market is not capable of absorbing additional development. Competition with existing development is just one scenario. It is also possible and has been the case with MARTA that development near transit stations struggles when pitted against cheaper, lower-risk opportunities on the urban fringe and in the suburbs. Policies that reinforce this type of market can be responsible for a lack of interest in transit-oriented development. In this scenario, transit investment may require investment in the development process to realize the fullest benefits to the system and to provide a leveling of development opportunities.

Finally, a history of success with a certain development type or a proven model will encourage developers to repeat a similar undertaking. This again speaks to the risk-adverse nature of development. Strip commercial retail, office parks and townhome subdivisions are familiar development models that have a proven success rate and a fairly discernible market. High-density, mixed-use, joint public-private development near transit has the potential for higher returns, but the sample size for successful completion is too small to be convincing to developers. This is a local and regional issue. Though Portland has realized great success with transit-oriented development, developers in other cities may cite local differences in population demographics and market characteristics as reasons why the model may not be completely reproducible in Atlanta[9]. This is a difficult barrier to overcome: if TOD is not being built, how will there ever be enough successful models to encourage additional development?

## 2.3 Station Design

A critical condition that impacts development at transit stations is the transit station itself. Specifically, it is the station design and configuration of its site – how the station connects with and engages its immediate surroundings – that may encourage or discourage development. This point is often disregarded for its simplicity, but can actually play a very important role.

First, consider the configuration of a station site. Odd site geometries and extreme grade changes often encountered at transit stations can make a site difficult to build on or unattractive to development. As an example, a considerable amount of empty land surrounds the MARTA station at Dunwoody. Upon closer observation it is apparent that the land on which the station is located sits far below street level and actually serves as a stormwater retention facility. Its ownership by MARTA, notwithstanding the physical characteristics of this site, present a design challenge to even the most entrepreneurial developer.

Connectivity is also a major issue: do clear vehicular and pedestrian connections exist? Some stations, such as the MARTA station in Midtown Atlanta, have entrances on multiple streets and is easily accessible by car (drop-off only) as well as by bicycle and by foot. However, some stations (or the streets around them), such as the H.E. Holmes MARTA station, do not provide clear connections and accessing a station directly can be a challenge or even dangerous for pedestrians and bicyclists. The Vine City MARTA station has great potential for ridership with its proximity to the Atlanta University Center. However, its entrances are oriented away from the campus and a lack of connections to them make access problematic.

This leads to another consideration in station design: the number of entry points. Even if connections to station entrances exist, they may not be designed in a way that is capable of interfacing with future development. These stations would require significant investments to re-design and re-construct if they are to truly ever become part of a transit-oriented development. The North Springs MARTA station serves as an excellent example. Designed primarily as a park-and-ride facility, the station's primary points of access are via the parking decks that abut the station. Any other connection is an afterthought as the station was never truly conceived as a pedestrian-oriented station. A townhome development immediately south of the station was forced to create a pedestrian bridge just so residents would have some means of accessing the station.

Station amenities are also a design consideration. This can be as simple as the provision of restroom facilities, bicycle parking or bus transfer service that elevate the status of a station over others. A bolder approach is to allow vending or other commercial activities within the stations themselves. This immediately gives a transit station multiple purposes beyond transit access, creating a constant stream of patrons and activities. Recall the earlier discussion that an existing population or activity base can be a good sign to developers: expanded station activities can aid in this incentive in addition to make the experience of transit better for all users. People attract other people; activities attract other activities. MARTA offers us no examples of this principle in practice. The transit authority currently does not allow for vendor opportunities within its stations.

## 2.4 Institutional Requirements

Ultimately, institutional requirements may present the most critical set of challenges to the development process. This category can encompass barriers at the federal, state and local levels in addition to other private development requirement. Barriers in state and local requirements can vary widely from transit system to transit system. However, perhaps the biggest obstacle to enticing transit authorities to address real estate development is that these agencies are focused primarily on the expansion of transit and its operations and maintenance. While trying to keep operations of the system successful, real estate development may be a very low priority. As a result, many agencies lack the funds or have little or no personnel with the qualifications and experience to promote, coordinate or handle real estate and land development matters on a daily basis. Instead, the transit agency's legal department reviews and responds as they can along with their regular legal workload. This situation creates an atmosphere in which expanding the potential returns for the particular institutions is difficult.

In the state of Georgia, the Atlanta Regional Commission and Georgia Regional Transportation Authority also require oversight and review of large projects. FTA's joint development process is required for any TOD on federally purchased property. The Joint Development Agreements require very specific documentation and proof of well-conceived commitments from the developer, transit operator, governments and the public. All of these well-intentioned reviews and requirements add a significant amount of time to the development process. Few developers and their funders are able or interested in pursuing abnormally long projects unless they are significantly sized and lucrative.

One layer of institutional requirements that applies evenly to all transit systems are those set forth by the Federal Transit Administration (FTA). FTA guidelines for joint development were first released in 1997[10]. These guidelines apply to all transit stations where federal funds have been used to acquire land and give transit authorities the flexibility to undertake investment.

MARTA's Lindbergh station was a pilot TOD project under these revised FTA guidelines. It was further incentivized by the fact that any revenue obtained through development was not required to be used for future capital investments in the system, but could rather be channeled to the operations budget. Since transit systems almost always operate at a loss, this potentially unrestricted operations income stream was a huge benefit for transit systems to pursue development. Given that the FTA has seemingly relaxed its restrictions on development of land in which it has a vested interest and has even offered incentives to transit agencies, it is possible that most of the intuitional barriers to development still lie with the transit agencies themselves.

Furthermore, the region and state's priority on funding vehicular capacity leaves very little money for transit projects and is contrary to the goals and efforts to focus development concentrated in-town areas. This continues to create more sprawl and congestion, which in-turn keeps the public demand high for automobile transportation projects. Federal funding of transit is diminishing at the same time, creating more pressure on local governments to identify funding sources. Since regional and state sources are minimal, suburban congestion dominates the development community's focus.

## 3.0 RESEARCH PROPOSAL

The primary purpose of this article is to open the discussion on potential barriers to development at transit stations, to create a method for addressing these barriers and ultimately, to produce an analytical framework within which decisions are made and tracked relative to the investments made at each station and the returns realized as a result of these investments.

The next step in this process will be to identify representative stations in the MARTA system and then analyze and test these stations based on the criteria that are outlined through the process. While the research conducted for this article does not yet include the deep analysis required to determine specific outcomes, this section does focus on framing a methodology for conducting such an analysis. The research project will be conducted in five parts: establish station typologies, establish metrics to test for each criterion, analyze each station, compare with other transit systems and finally, make recommendations for realizing development at under-developed stations. The next sections detail the steps for the proposed research project.

### 3.1 Establish Typology

No transit stations are exactly alike. The design and configuration of stations and their sites impact development. The same holds true for the larger area in which a station is located. A station's context matters. The functions, operations and needs of a transit station located in a dense urban corridor are very different from one located in a suburban area. Well-established urban stations, much like the MARTA station in Decatur, eschew public parking in favor of denser, pedestrian-oriented development. At the Decatur station, few opportunities exist for new development. Suburban stations, on the other hand, may be located in sparsely developed areas and serve as a park-and-ride facility. The North Springs MARTA station is one such example. Its immediate neighbors are two structured parking decks surrounded by vacant land and a few townhome developments. The examples of the Decatur and North Springs stations represent extreme ends of a spectrum. Several types of stations are likely to exist. MARTA's TOD Guidelines suggest that there are seven station types: urban core, town center, commuter town center, neighborhood, arterial corridor, collector corridor and special regional destination. Other typologies may be used for the extended research effort. Since these types were created specifically for the MARTA system, it is very likely that other types exist. A clear and comprehensible typology of stations should be applicable to stations in virtually all transit systems. Classifying and organizing stations in this manner is a key first step in understanding how particular stations work and how barriers to development might be removed and incentives created to increase the city's return on transit infrastructure investment.

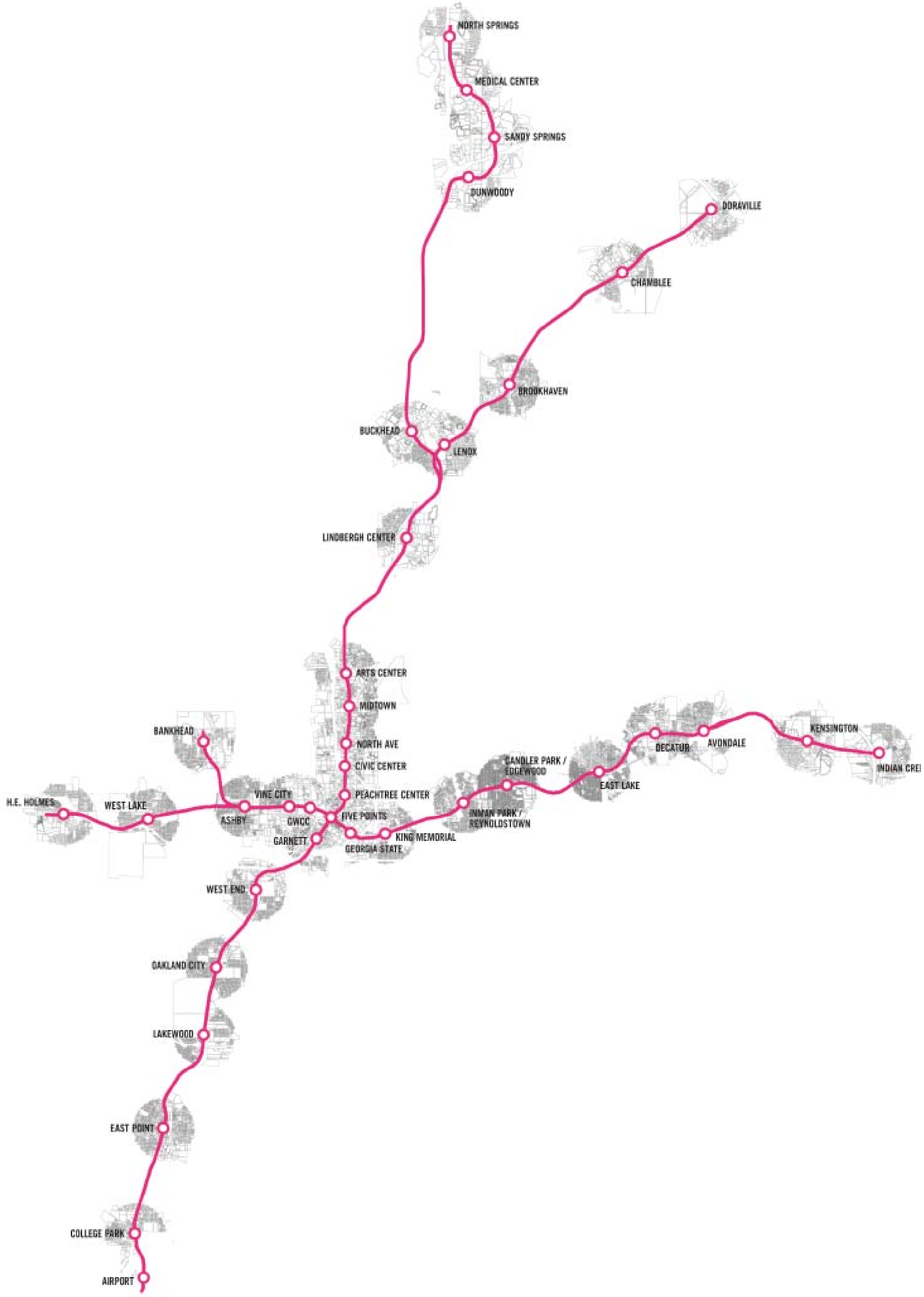



Figure 4: Parcels within ½-mile of MARTA stations.

### 3.2 Develop Metrics

Outlining the four major barriers was the first step in understanding why some stations might be more prone to development than others. Analyzing and testing for these barriers is a more detailed task. The next step of the research project is to develop specific metrics for the analysis of each subject station. The basis for creating metrics lies in the relationship between actions that have measureable inputs and outcomes. These relationships ultimately form the methodology for identifying, projecting and tracking the basic return on investment calculus for each decision in the development process. For instance, in terms of market climate, one might simply review current market conditions including barriers to entry and then determine the subsidies that would be required to incentivize development at a particular station. In a thriving market the investment may be low relative to the predicted return (increased ridership, reduced VMT, increased workforce housing, among others). However, in a more challenging market, the incentive may need to be greater. In this scenario the metrics are critical to determining the ultimate value of the investment for both the transit system and the city. Further, development regulations can be analyzed to ensure that the development levels and patterns that will be required to realize the anticipated returns are structured to incentivize development rather than create additional barriers to development. For instance, if the analysis shows that 100 units per acre yields the highest return and reduces capital barriers to smaller development, while zoning allows only 50 units per acre, then the analysis will reveal the element (the density regulations) that is inhibiting development at a particular station area. Analyzing institutional requirements will depend greatly on transit system location and may require a combination of literature review and interviews with different agencies to establish. However, it is assumed that the intention is such that the station typology will produce immediate data that indicating characteristics that preclude or incentivize development. Entry types, locations, number of connecting streets and adjacent land development may all be valid benchmarks in this category. Ultimately, establishing a clearly defined set of research metrics will make it more effective to compare the relationship between desired outcomes and barriers at the various stations. Once these metrics are created, the returns on individual investments can be determined and action can be taken.

### 3.3 Analyze Stations

Once the stations are organized into categorical typologies and the specific metrics have been established, the next step is to conduct an analysis of each station typology based upon each of the metrics. The result should be a substantially comprehensive matrix that compares metrics for each station, both internal to the individual station and in a comparative structure. The initial stages will include a limited number of stations that represent the various types of stations in the system, however, all stations should ultimately be included in the analysis regardless of surrounding development status. Recording data for stations where development has already occurred will serve as one of several controls for the specific analyses of stations that do not have substantial associated development. A matrix that includes both developed and undeveloped stations will provide relatively conclusive results regarding the nature and number of barriers preventing development in proximity to certain station types and further, act as controls for each of the research criteria.

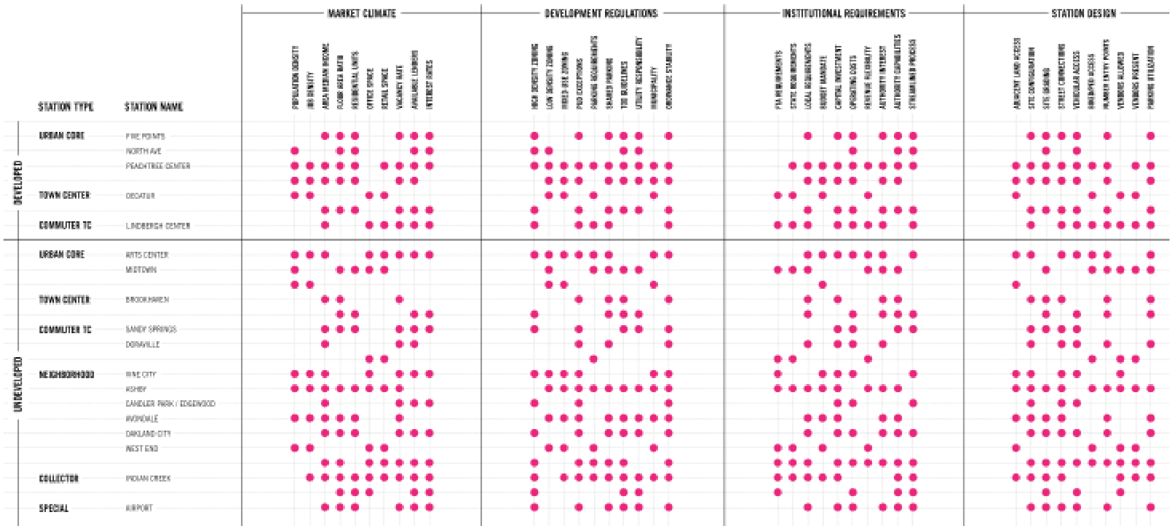
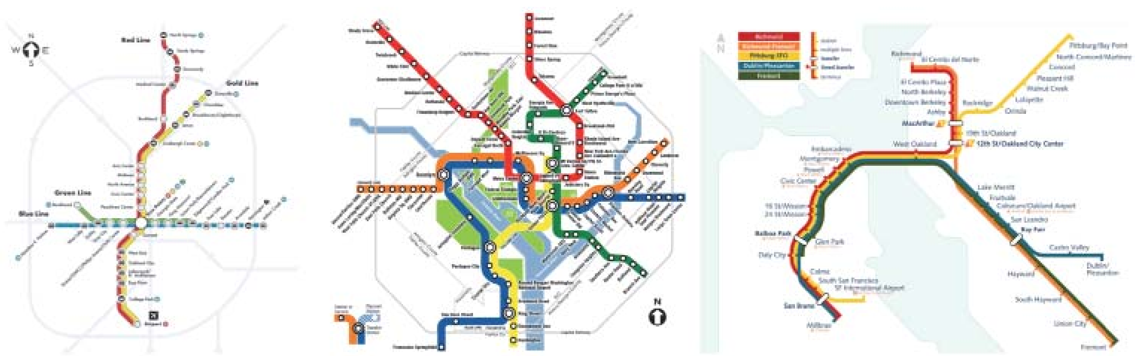



Figure 5: Potential matrix of MARTA system-wide station analysis.

## 3.4 Compare Systems

While section 3.3 provides an analytical comparison at an intra-system level, this next section builds on it by providing a high-level comparison on an inter-system platform. This research will address specific components of systems other than MARTA that have faced similar barriers to development, but have increased development through implementation strategies. Beyond understanding development barriers for stations on one transit system, the broader question remains unanswered: does fixed-guideway transit drive real estate development? By broadening the research to include multiple transit systems, a sufficient sample size can be obtained that might ultimately support a conclusion. The same series of criteria for measuring the efficacy of station area success used in the intra-system analyses will be implemented for the multiple system analyses as well. This should afford consistent preliminary conclusions as to why the conditions for development across multiple stations on multiple transit systems unfold with various levels of success.



MARTA - Atlanta METRO - Washington DC BART - San Francisco

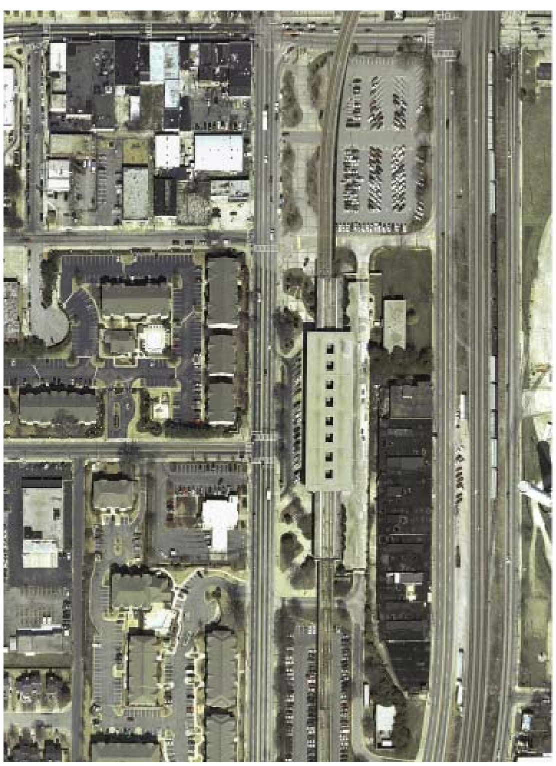
Figure 6: Comparison of transit systems: MARTA (Atlanta), METRO (DC), BART (San Francisco).

## 3.5 Development Recommendations

The previous four sections are intended to yield a clear understanding of how specific types and amounts of investment yield specific returns. This section is intended to take the results from the first four and develop specific recommendations for realizing an increase in development associated with under-performing transit stations. These recommendations will be framed within the relationship between the investments made (the recommendations) and the results of those investments.

A study of the proposed Peachtree Corridor streetcar route conducted by students and faculty at the Georgia Institute of Technology illustrates how such an analysis might inform these recommendations[11]. In 2007 the Peachtree Corridor Task Force unveiled its vision for a 14-mile stretch of Peachtree Street, Atlanta's premier street[12]. The vision included not only streetscape enhancements, but also a streetcar route along the entire corridor. Though the vision's objectives included connecting residents to transit and stimulating development, both real estate and economic, the original alignment for the streetcar appeared to be driven more by a desire to create the perception of a physically continuous corridor. In prioritizing this perception, the proposed alignment often intersected or closely paralleled other major infrastructure elements such as freight rail, interstates and existing transit service all of which had the potential to diminish the transit's influence of development potential. This was particularly true in transit segment number seven in Atlanta's south side. While this area had much to offer in terms of development potential, it was here that the transit alignment abutted the greatest number of physical barriers such as interstate, freight rail and rapid transit infrastructure proximity.

Instead, the Georgia Tech study proposed an alternative alignment that balanced a continuous corridor form with a greater area of potential development capture. This "capture" was defined as the population and properties within ¼-mile and ½-mile radii of the transit alignment. By moving the streetcar alignment away from existing freight and rapid transit rail lines and closer to the neighborhoods it would serve, the streetcar alignment would theoretically realize higher potential gains in terms of developable land area, additional property tax digest, neighborhood access and overall ridership. Figures 7 and 8 illustrate the development vision and analysis for the transit realignment.



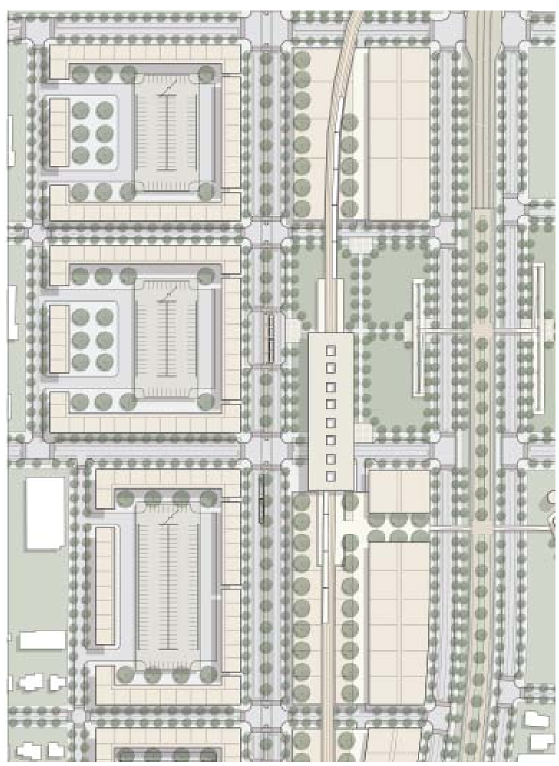
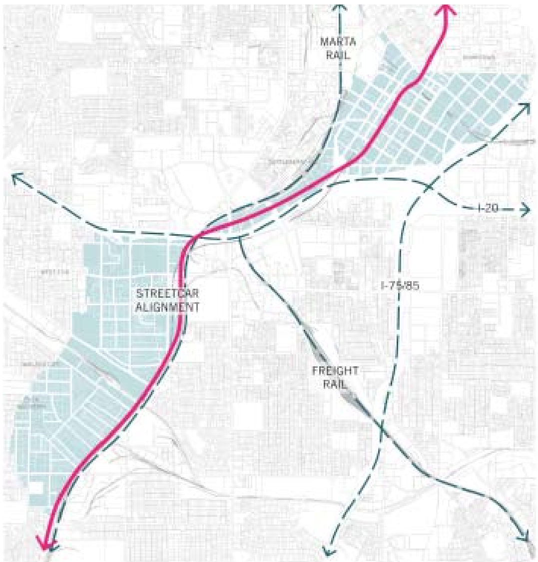
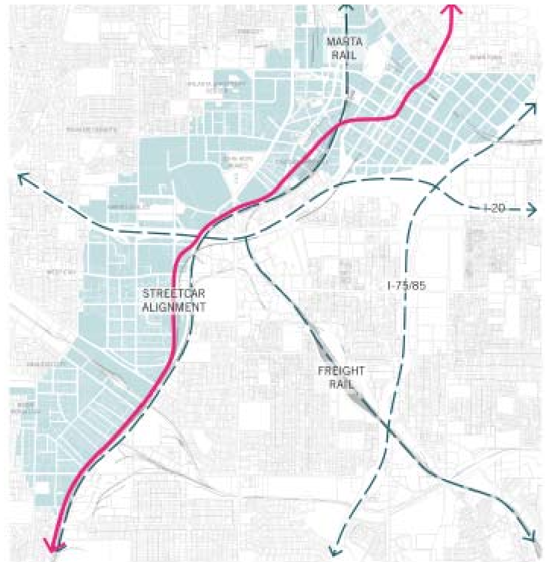


Figure 7: MARTA West End station today (left) and rendering of potential development from proposed alternative streetcar alignment (right).




**ORIGINAL SEGMENT #7 ALIGNMENT**




**PROPOSED REALIGNMENT**

STREETCAR ALIGNMENT
POTENTIAL BARRERS
CAPTURED PARCELS

**DEVELOPMENT POTENTIAL ANALYSIS**

| METRIC | ORIGINAL ALIGNMENT 1/4-MILE RADIUS | ORIGINAL ALIGNMENT 1/2-MILE RADIUS | PROPOSED REALIGNMENT 1/4-MILE RADIUS | PROPOSED REALIGNMENT 1/2-MILE RADIUS | POTENTIAL CHANGE 1/4-MILE RADIUS | POTENTIAL CHANGE 1/2-MILE RADIUS |
|---|---|---|---|---|---|---|
| CAPTURED PARCELS | 1,090 | 1,831 | 1,567 | 2,525 | + 477 | + 694 |
| TOTAL LAND AREA (ACRES) | 416 | 689 | 738 | 1,275 | + 322 | + 586 |
| APPRAISED VALUE | $1.3 B | $1.9 B | $1.4 B | $2.6 B | + $144 M | + $780 M |
| ASSESSED VALUES | $526 M | $757 M | $584 M | $1.0 B | + $57 M | + $312 M |
| NUMBER OF BUILDINGS | 975 | 2,000 | 1,481 | 3,086 | + 506 | + 1,086 |
| BUILDING SQUARE FOOTAGE | 6.3 M | 11.3 M | 7.6 M | 16.0 M | + 1.3 M | + 4.6 M |
| NUMBER OF BLOCKS | 131 | 197 | 222 | 285 | + 91 | + 88 |
| POPULATION (POTENTIAL RIDERSHIP POOL) | 4,619 | 7,297 | 8,367 | 16,978 | + 3,748 | + 9,681 |
| HOUSEHOLDS | 1,090 | 2,152 | 2,458 | 4,807 | + 1,368 | + 2,655 |
| NEIGHBORHOODS SERVED | 4 | 5 | 7 | 10 | + 3 | + 5 |

Figure 8: Comparison of original Peachtree Corridor alignment for Segment #7, Southside (left) and proposed alternative capturing a larger potential development base (right).

## 4.0 CONCLUSION

It is not yet certain that investment in rail transit results in real estate development. Though many have stated this claim, the best affirmation that data and literature review suggest that development near transit commands a premium in value. Empirical evidence is inconsistent: some transit stations have experienced great success, some have had mixed results and others have failed to stimulate development altogether. The evidence suggests that the answer is not a simple causal relationship. Rather it suggests that several conditions factor into whether or not development will be attracted by transit. Market climate, development regulations, institutional requirements and station design all play a role in this respect, however, the relationship between each and the overall extent of impact is not entirely clear. Specific benchmarks must be established and the larger analysis of transit stations and transit systems must be conducted as outlined in this article in order to understand the impact of each of these components on station area development. As rail transit systems continue to be funded and expanded, it is critical to understand which conditions actually contribute to surrounding development. If all of the factors are understood, conditions can be appropriately aligned to ensure the full realization of the development potential of transit, obtain maximum transit ridership and that investments are made that yield the highest returns for the system.

Moving forward, this research aims to provide a highly operational analytical framework for understanding the effects of various types of investment on the outcomes of development of the areas surrounding transit stations as well as the benefits to the larger system. This is intended to be an objective methodology to guide decisions on the allocation of investments in order to render the highest possible returns: returns that are categorized as being highly beneficial to the jurisdictions and citizens within these jurisdictions.

## Acknowledgments

The authors would like to recognize several colleagues in the Atlanta office of Perkins+Will for their contributions. Heather Alhadeff served as a source of knowledge regarding real estate development processes within transit agencies and MARTA operations. Ryan Gravel provided several insights and suggested several MARTA stations where they have served as examples throughout the article. Cassie Branum and Jeff Williams provided clarity on the research concept and contributed to the framework for the research project.

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# 05.
# SUSTAINABLE DESIGN STRATEGIES AND TECHNICAL DESIGN DEVELOPMENT:
*Rush University Medical Center Entry Pavilion*

**Abul Abdullah, AAIA, LEED AP BD+C,** *abul.abdullah@perkinswill.com*
**Ajla Aksamija, PhD, LEED AP BD+C, CDT,** *ajla.aksamija@perkinswill.com*

ABSTRACT
This paper discusses unique design of the Rush University Medical Center Edward A. Brennan Entry Pavilion, specifically focusing on the sustainable strategies considered and investigated during the design as well as the technical aspects. The first part of the article reviews background information about the Rush University Medical Center and its Entry Pavilion, while the second part of the article reviews sustainable design strategies that were considered as an approach for meeting the Living Building Challenge. Building performance analyses that were performed during the different stages of the design process are discussed in detail. The article also reviews obstacles that were encountered with the Living Building Challenge requirements and lessons learned from this process. The last part of the article discusses the design development, technical solutions and construction of a glass terrarium as one of the distinctive aspects of the Edward A. Brennan Entry Pavilion.

KEYWORDS: building performance, sustainability, simulations, building technology

## 1.0 INTRODUCTION

### 1.1 Project Description
Rush University Medical Center (RUMC) is located in Chicago, Illinois. In 2004, RUMC revealed plans to initiate the most comprehensive construction and facilities improvement project in its history, known as the Campus Transformation Project. This plan called for investments in new technologies and facility design that would modernize operations for the 21st century and reorient the campus around the comfort of patients and their families. The guiding principles of the transformation plan were:

- Optimize the patient and family experience
- Conscientiously consider safety of patients and staff
- Organize services around delivery of care
- Use technology on behalf of patients and staff
- Ensure integration of research and education
- Design a comfortable environment to support Rush core values
- Anticipate change through adaptable/flexible best practices
- Embrace the community through design
- Incorporate sustainable design where applicable
- Standardize when possible.

RUMC enlisted Perkins+Will to plan and design parts of the medical campus, which included a new 840,000 square foot state-of-the-art hospital building (Tower), a new medical office building and orthopedics care facility and a centralized power plant/parking garage (Figure 1). The design of this major healthcare facility started in 2006 and the building was completed in early 2012. The existing hospital building is connected to the new Tower with the 10,000 square foot Edward A. Brennan Entry Pavilion.


Figure 1: Rush University Medical Center Transformation Plan and its components (Tower, Entry Pavilion, Orthopedics Ambulatory Care Building, Garage and Centralized Energy Plant).

### 1.2 RUMC Tower

The program for the RUMC Tower included an emergency department, a center for advanced emergency response, non-invasive diagnostics department, interventional platform, women's services and neo-natal critical care units, critical care unit and patient rooms. Figure 2 shows the Tower, Entry Pavilion and the existing Atrium Building on the west side. The Entry Pavilion connects the existing Atrium Building and the Tower and provides an inviting lobby and entry space for the patients, families and the medical staff. A series of bridge connections were also designed and constructed that link the existing Atrium Building to the Tower.

Figure 2: The Tower, view from Harrison Street. Photo credit James Steinkamp © Steinkamp Photography.

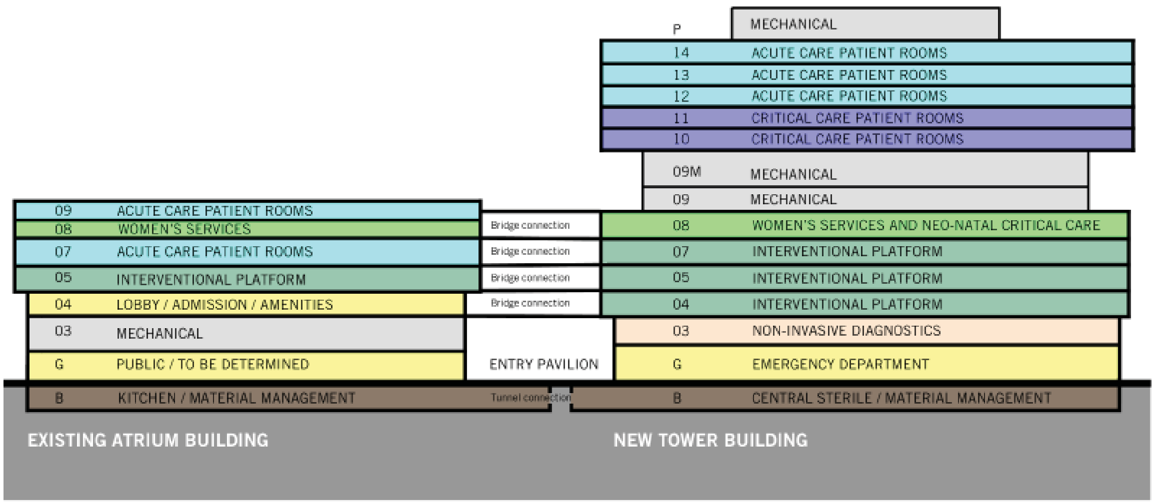



Figure 3: Stacking diagram.

The major formal components of the Tower include the rectilinear base (Levels 1 to 8), mechanical floor (Level 9) and bed tower (Levels 10 to 15), as seen in Figures 3 and 4. The distinctive butterfly shape of the bed tower was directed by the operational and pragmatic requirements with the intention to minimize travel distances between medical staff and patients. The findings of recent research indicates that design layouts and locations of nurses' stations that minimize staff walking increase patient care time and support staff activities, such as communication and collaboration among medical staff[1]. This concept directly correlates to the guiding principles of the project and was a driving factor for the design and layout of the Tower.

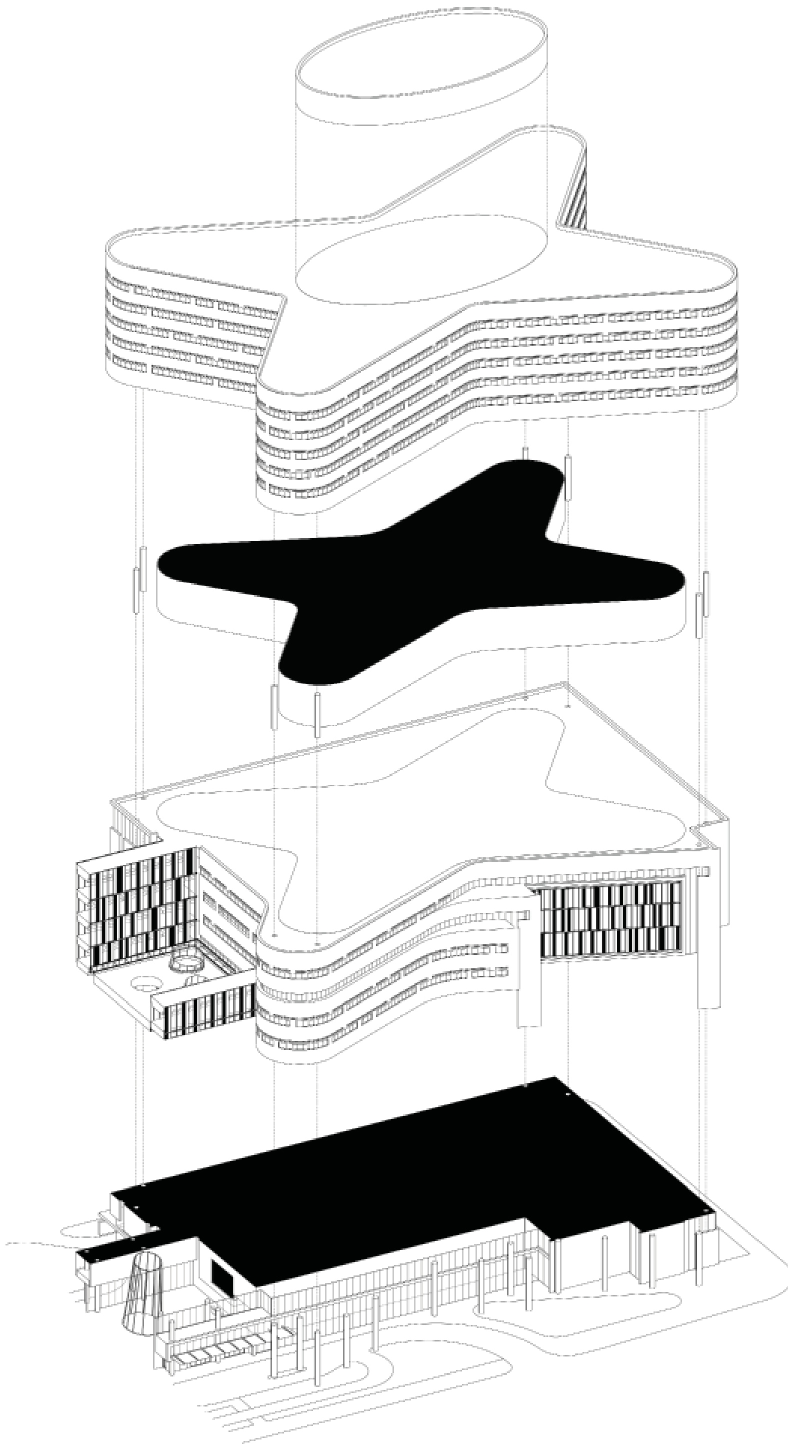


Figure 4: Exploded axonometric view of the Tower.

## 1.3 Entry Pavilion Design

The Entry Pavilion is a grand public entry space connecting the Tower with the Atrium Building. It was designed to address the arrival experience for those coming to the Rush's large, urban campus.

On Level 1, an open-to-above "terrarium" greets incoming guests with trees and a forest floor garden, as seen in Figure 5. A publicly accessible roof garden on Level 4 provides an outdoor space, specifically designed to allow building occupants access to nature, as seen in Figure 6. Also, two large circular skylights provide daylight to the interior space.

Previous research studies have produced strong evidence that hospital gardens can lower stress levels for medical staff and improve their productivity, improve patients' outcomes and can also improve patient and family satisfaction with the overall quality of care[1]. For example, based on post-occupancy evaluations of four hospital gardens, it was concluded that many nurses and other healthcare workers used the gardens for achieving escape and recuperation from stress[2]. Other post-occupancy studies indicated that patients and family members who use hospital gardens report positive mood changes and reduced stress[3]. Therefore, access to nature, roof gardens and terrarium were important design elements. A "staff only" roof garden was specifically designed at Level 9 as respite area for caregivers. Figure 7 shows these major programmatic components in an exploded axonometric view.

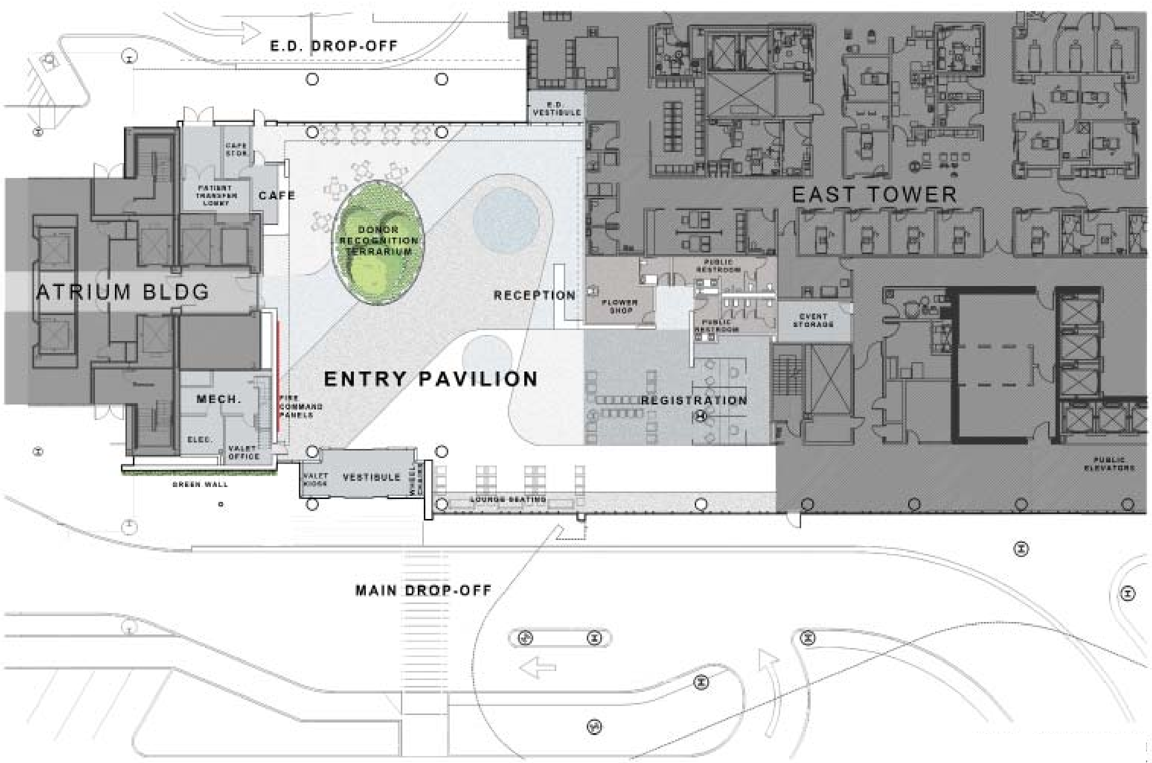



Figure 5: First floor plan of Entry Pavilion.

In the early design stages, the Atrium Building and the Tower were completely connected and aligned since a continuous large floor plate was preferred. The main challenge with this design concept was the existing kitchen, which is located in in the basement directly below the space between the Atrium Building and Tower. This would require that the structural columns would have to be constructed amongst an operational kitchen, which would shut down the hospital. For this reason, the idea of doing the two buildings was too intrusive and costly. The idea of separating the two buildings was then explored and the connections were maintained via bridges. This separation allowed room for an entry pavilion. Therefore, unlike standard design process where an entry is designed at the beginning, the RUMC Entry Pavilion was designed towards the end.

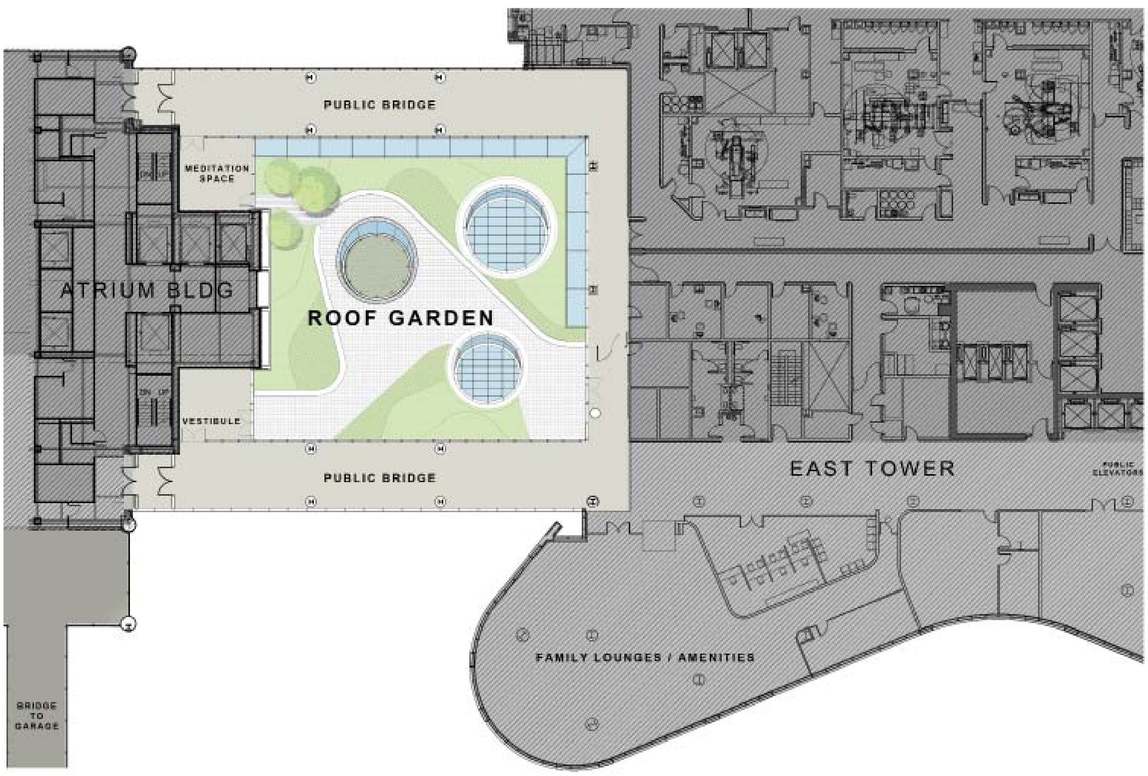



Figure 6: Fourth floor plan indicating roof garden and skylights.

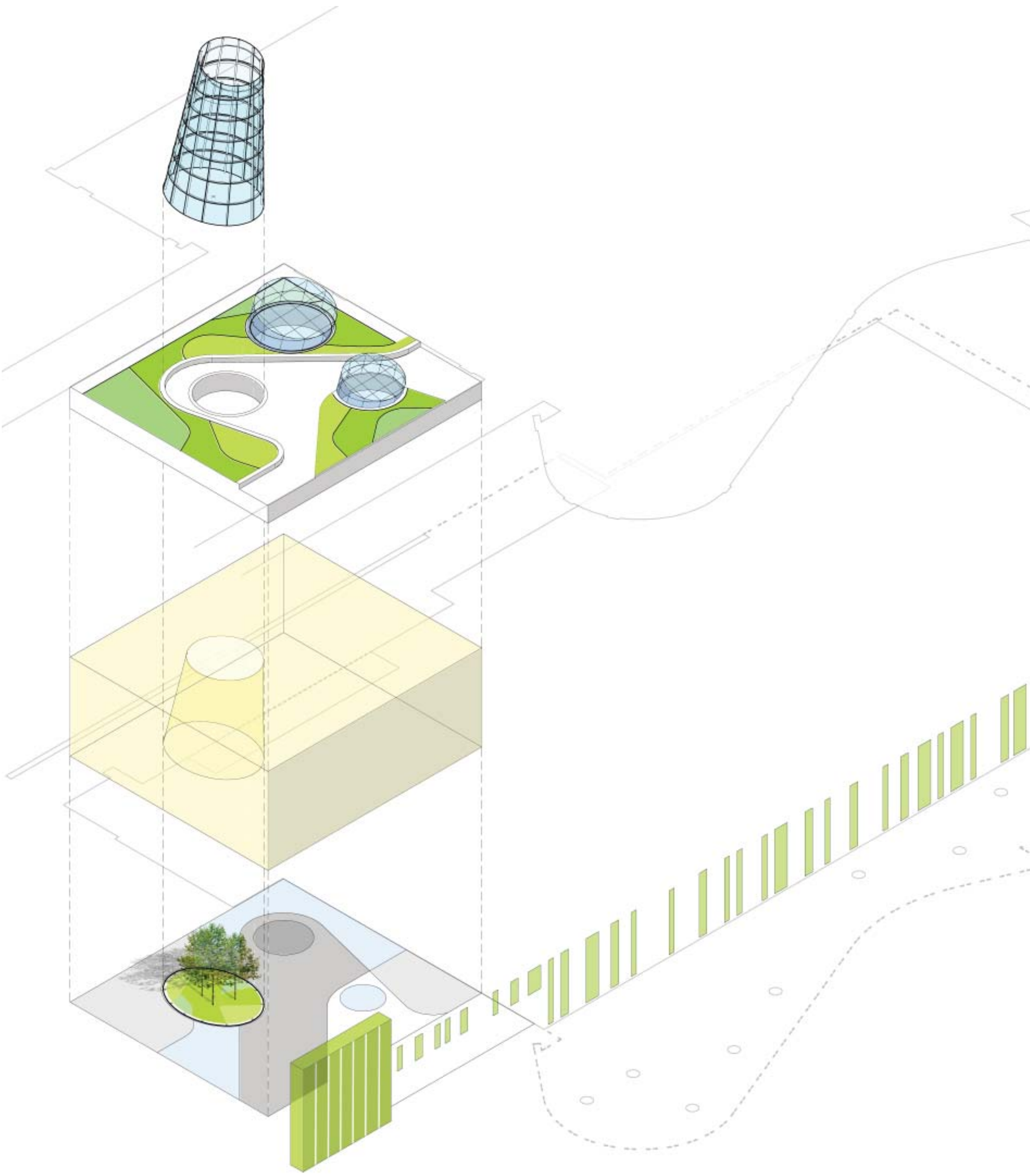


Figure 7: Exploded axonometric view of the Entry Pavilion.

Figure 8: Entry Pavilion interior and terrarium, view from north-east.
Photo credit Steve Hall © Hedrich Blessing Photographers.

Figure 9: Entry Pavilion roof garden after construction, view from south-west.
Photo credit Steve Hall © Hedrich Blessing Photographers.

## 2.0 SUSTAINABLE DESIGN STRATEGIES AND BUILDING PERFORMANCE

### 2.1 Sustainable Design Strategies and the Living Building Challenge

The design of the RUMC Entry Pavilion was started with a goal of achieving the Living Building Challenge[4]. The Living Building Challenge is a certification program that promotes one of the most advanced measurements of sustainability in the built environment today. Living Building Challenge comprises seven performance areas: site, water, energy, health, materials, equity and beauty. These are subdivided into imperatives and can be applied to buildings (new construction and renovation of existing structures), landscape, urban design, community development and infrastructure. This certification program is based on actual performance, which must be measured and verified after the building or development project is completed and occupied. It requires that the building or development is designed and operated as net-zero energy, among the other requirements, where all of the project's energy needs are supplied by on-site renewable energy. It also requires that all of water usage needs come from captured precipitation or closed loop water systems that are appropriately purified without the use of chemicals; and that all occupied spaces have direct access to operable windows and daylight.

The design process the Entry Pavilion considered multiple sustainability strategies for meeting the Living Building Challenge, as seen in Table 1 and Figure 10.

Table 1: Considered design strategies in response to the Living Building Challenge.

| Performance area | Imperatives | Design strategies |
|---|---|---|
| Site design | Responsible site selection<br>Limits to growth<br>Habitat exchange | Habitat preservation on the campus |
| Energy | Net-zero energy | Building-integrated PVs on skylights, south facades of bridges<br>PV panels on Atrium roof<br>Daylighting<br>Stored solar energy for nightime<br>Displacement ventilation<br>Heat recovery systems<br>Double skin facade along the south facade of the bridge<br>Radiant system in the floor<br>Solar hot water system |
| Materials | Materials red list<br>Carbon footprint<br>Responsible industry<br>Appropriate materials radius<br>Construction waste | Alternatives to thin-set epoxy-based terrazo<br>Calculations for carbon footprint<br>Recycled wood<br>Local stone and wood |
| Water | Net zero water<br>Sustainable water discharge | Rainwater use for green roof irrigation<br>Rainwater use for toilettes<br>Rainwater divertion from roofs into cisterns |
| Health | Civilized work<br>Ventilation | Operable windows<br>Daylighting<br>Double skin facade along the south facade of the bridge<br>Exhaust hot air from the atrium via double skin wall cavity |
| Beauty | Design for spirit<br>Inspiration and education | Plant Terrarium<br>Art mural<br>Energy performance LED screen<br>Exposed rainwater retention system<br>Permanent displays explaing building's features |

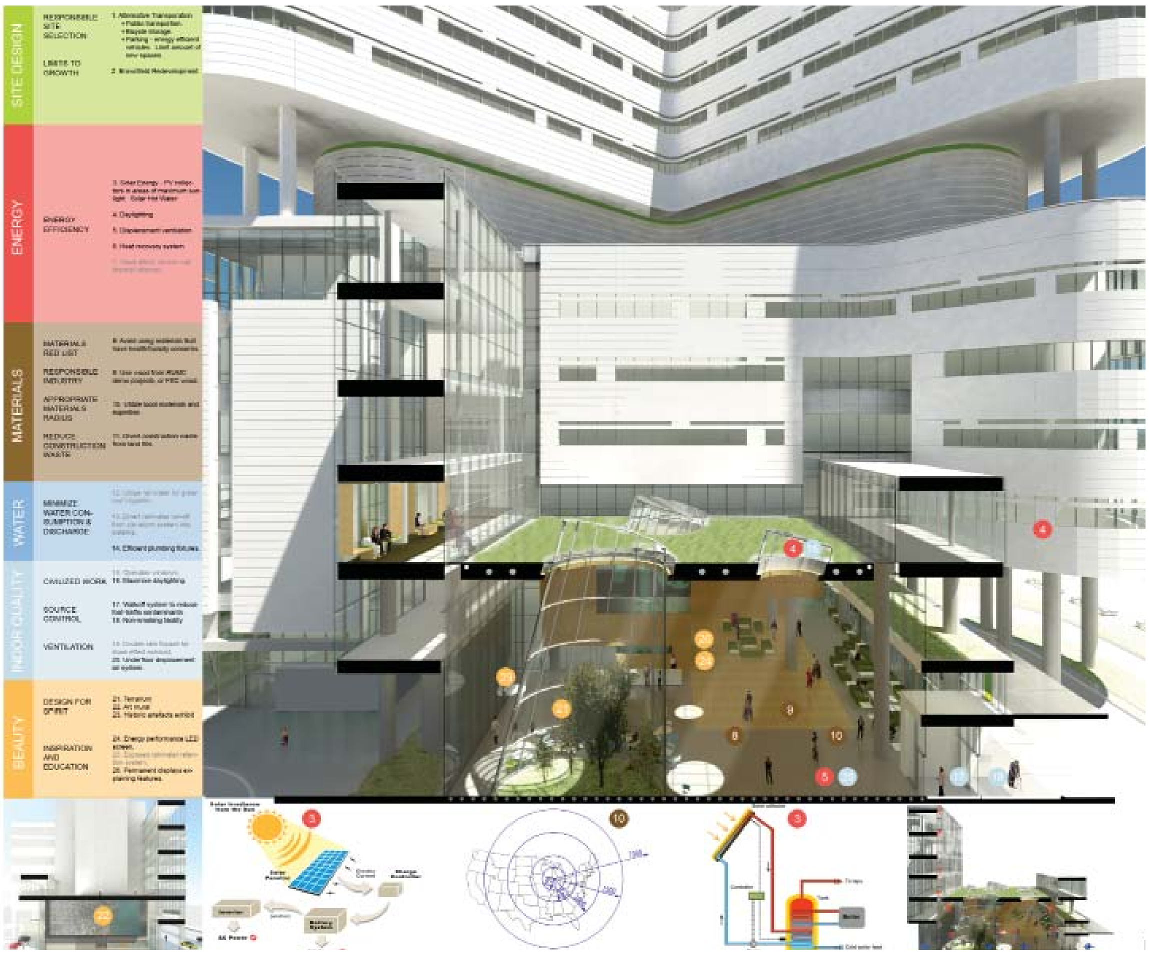



Figure 10: Entry Pavilion section and the considered sustainable design strategies.

Building performance analysis was used to investigate several key aspects during the design, such as solar exposure and shadows for the roof garden, performance of a double skin facade along the bridge corridor, solar access analysis for several facades and daylight analysis. Use of simulations and building performance analysis during the design process improves design decision-making[5,6]. The following sections review the results of various studies and performance analyses conducted for the RUMC Entry Pavilion.

## 2.2 Solar Exposure Studies for Roof Garden

The objective of solar exposure study was to investigate the amount of solar radiation available for the Entry Pavilion roof area. The primary driver was to investigate whether this area will have access to sufficient solar radiation since this portion of the building is used as a roof garden. Figure 11 indicates solar exposure and shading hours for the Entry Pavilion roof area on June 21 and December 20. There are approximately thirteen hours of sunlight available on June 21 and only seven on December 20. Maximum direct solar radiation on June 21 reaches 230 Btu/hr-ft$^2$, while on December 20 reaches 76 Btu/hr-ft$^2$. Diffuse solar radiation was found to be comparable for both dates.

The next step considered hourly shadow ranges for two specific dates during the summer and winter seasons.

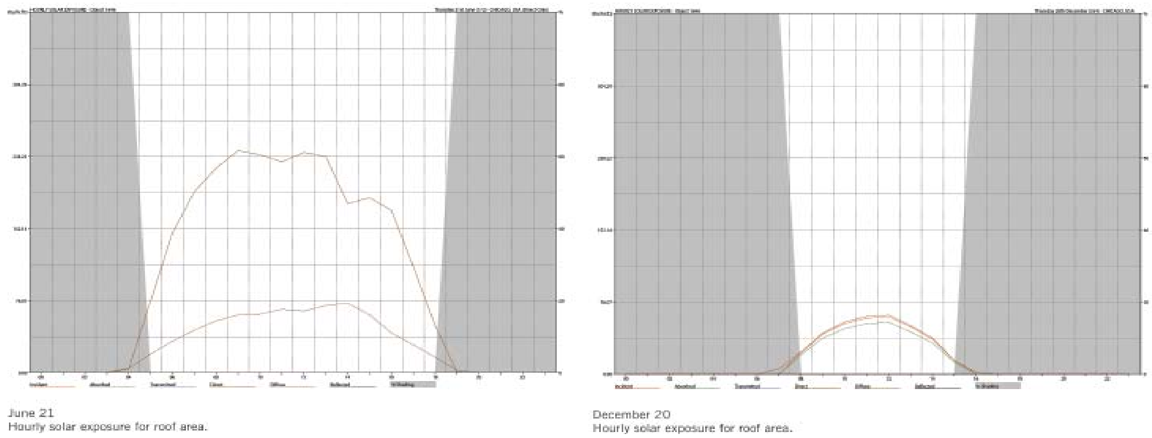



Figure 11: Solar exposure and shading hours study for the Entry Pavilion roof area.

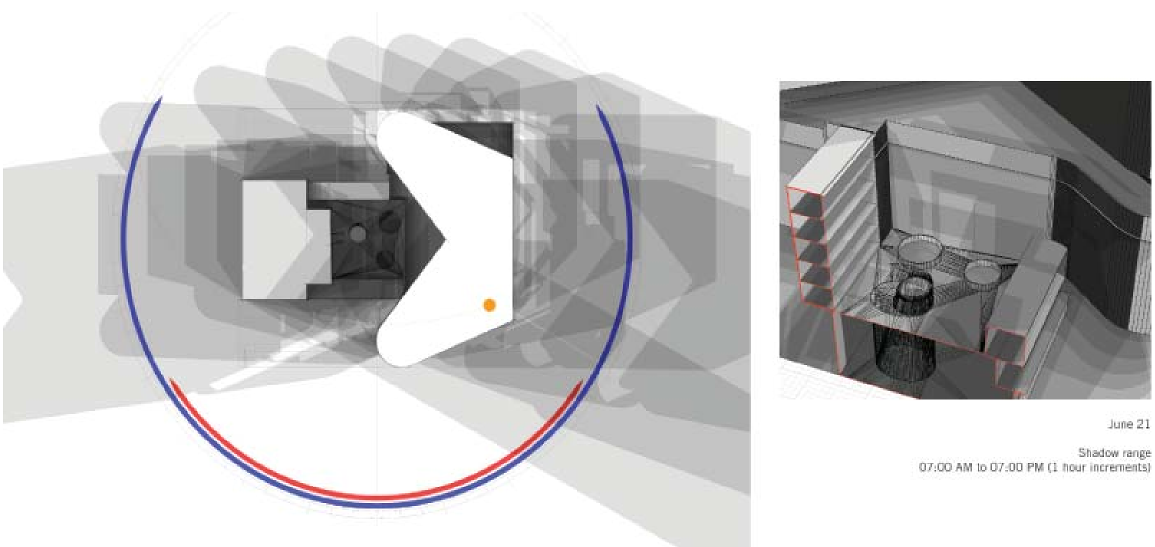



Figure 12: Shadow ranges for June 21 from 7AM to 7PM.

Figure 12 shows shadow ranges for June 21 from 7AM to 7PM. Shadows are displayed in relation to the duration (one hour increments) and darker areas indicate regions of the roof garden that are less exposed to direct solar radiation on this particular day. Figure 13 shows shadow ranges for December 21 from 7AM to 7PM.

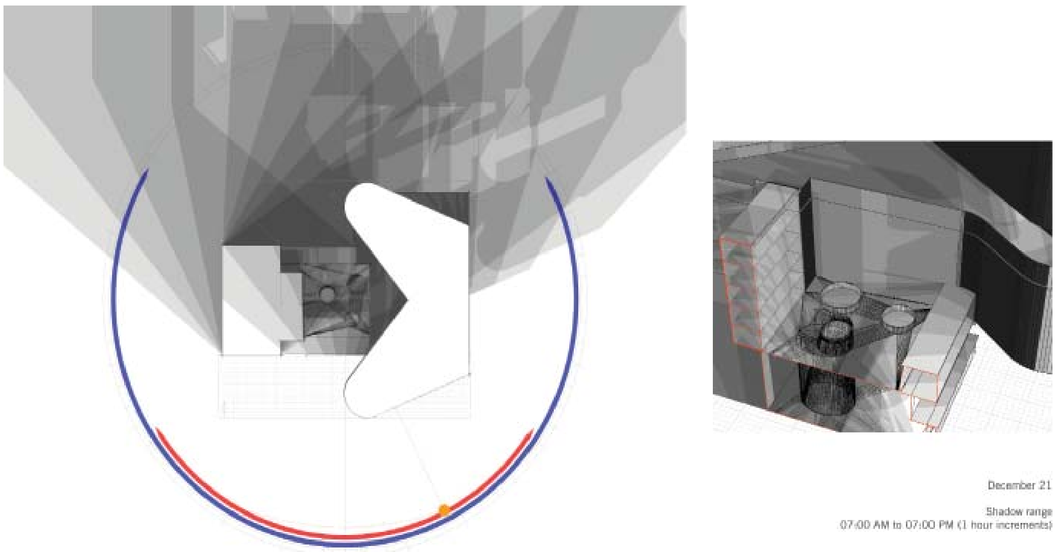



Figure 13: Shadow ranges for December 21 from 7AM to 7PM.

Since this study showed that the Tower and the existing Atrium Building partially shade the roof garden, hourly solar position and shadows were studied to determine how much time the roof garden spends in shade on two specific dates (June 21 and December 21). The diagrams in Figure 14 show hourly sun position and projected shadows on June 21 from 7AM to 6PM. The roof garden is in total shadow from 7 to 9AM as well as from 5PM to sunset. Partial shadows are present from 10 to 11AM and from 2 to 5PM. From noon to 1PM the roof garden is fully exposed to the sun.

The diagrams shown in Figure 15 show hourly sun position and projected shadows on December 21 from 7AM to 6PM. The roof garden is in total shadow from 8 to 10AM. Partial shadows are present during the majority of the day from 10AM to 4PM. Therefore, it was concluded that there is enough solar exposure for plant life and landscaping as well as occupants' comfort.

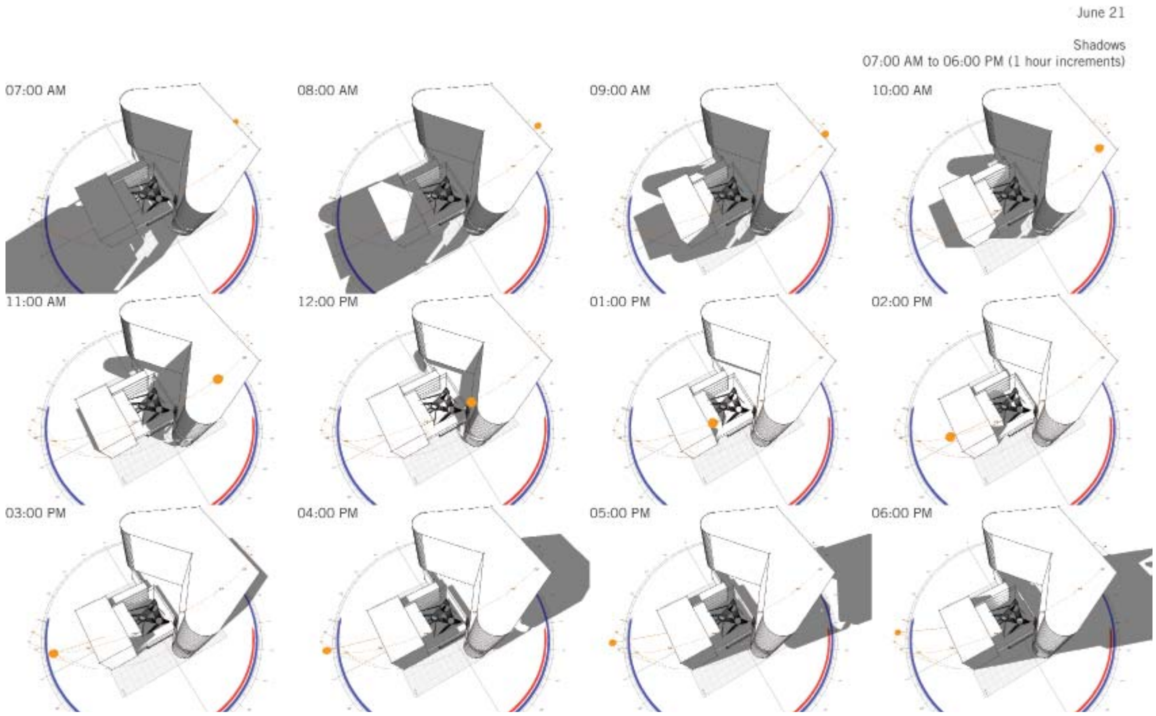



Figure 14: Hourly sun position in relation to the roof garden and projected shadows on June 21 from 7AM to 6PM.

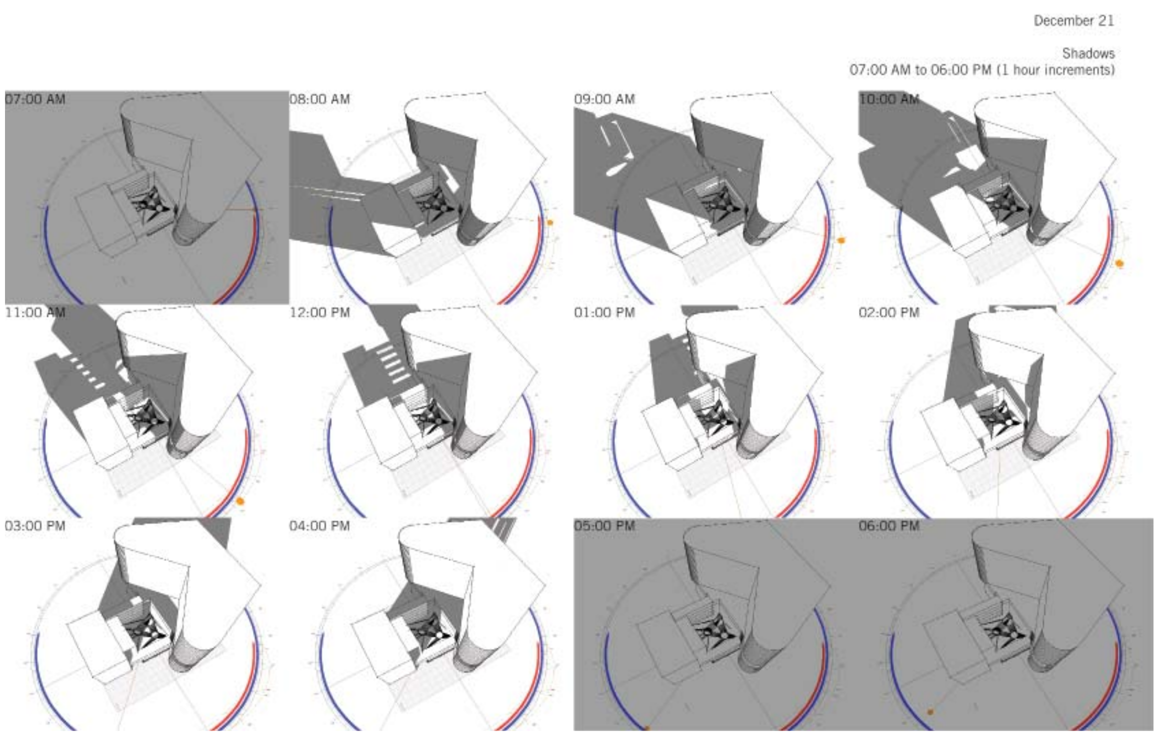



Figure 15: Hourly sun position in relation to the roof garden and projected shadows on December 21 from 7AM to 6PM.

## 2.3 Double Skin Facade Studies

Double skin facade along the south side of the bridge was considered during the schematic design as one of the energy-efficient design methods, shown in Figure 16. Several design parameters and their effects on energy consumption were studied, such as air cavity dimensions between the two skins, location of double air-insulated glazing and the differences in operation during winter and summer months[7].

Constant design parameters for all facade types that were used in the study are shown in Table 2. In order to study the effects of changing air cavity geometry, location of double skin as well as different air flow types, different design scenarios were investigated, shown in Table 3. Base model included single skin facade with low-e glazing, consisting on a curtain wall with double air-insulated low-e glazing unit. For double skin facade options, location of double glazing was varied from the internal to external side as well as cavity depth from 1.5 to 4 feet. Two different types of air flow were investigated, exhaust air during all year as well as combination of exhaust air during summer months and air curtain during winter months. This combined air flow type would allow use of warm air during winter to preheat the air cavity. All double skin scenarios included blinds within the air cavity.

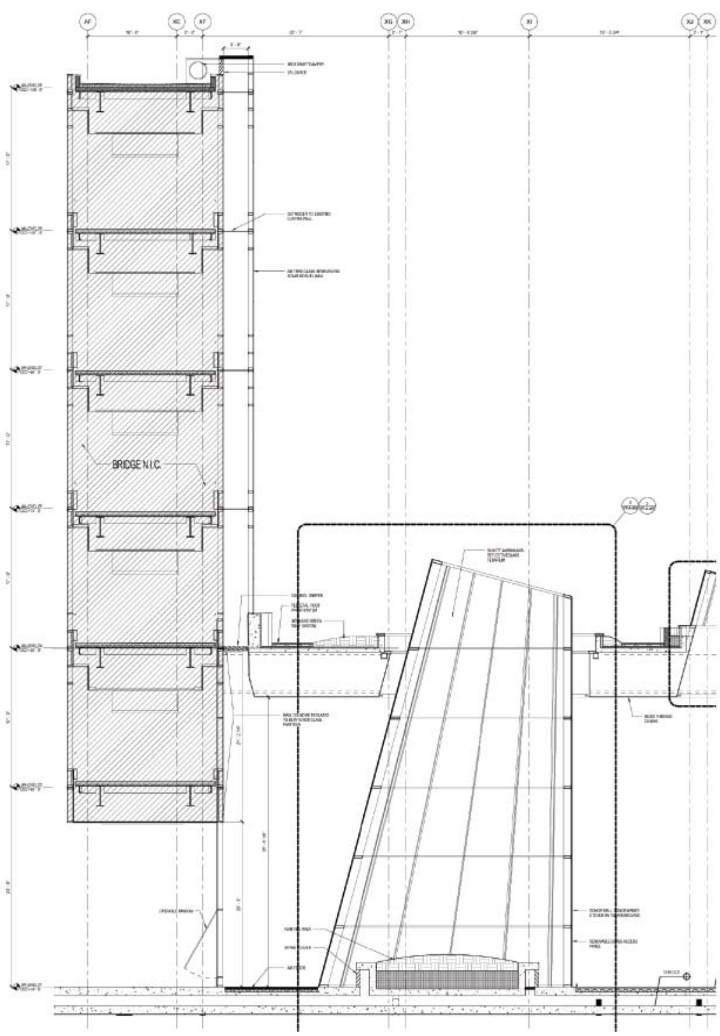



Figure 16: Double skin wall section.

Table 2: Static variables for all facade types.

| All Facade Options | |
|---|---|
| Location | Chicago, IL |
| Orientation | South |
| Temperature Min (deg F) | 68 |
| Temperature Max (deg F) | 79 |
| Humidity Max (%) | 60 |
| Occupancy load (people/SF) | 1.1 |
| Lighting requirements (fc) | 20 |
| Air change rate (AC/hr) | 1.8 |
| Dimensions (ft) | |
| Depth | 18 |
| Width | 70 |
| Height | 60 |
| Glazing type | low-e |
| Window area | 80 |
| **Double Skin Facade** | |
| Type | Multi-story |
| Ventilation mode | Hybrid (natural, assisted by mechanical fans) |
| Shading | Blinds in air cavity that respond to temperature |

Table 3: Dynamic variables for facade types.

| Scenarios | Location of double glazing | Air flow type | Air cavity |
|---|---|---|---|
| Base model | - | - | - |
| Scenario 1 | in | Exhaust air (interior vent supply, exterior vent exhaust) | 1.5 ft |
| Scenario 2 | in | Exhaust air (interior vent supply, exterior vent exhaust) | 2ft |
| Scenario 3 | in | Exhaust air (interior vent supply, exterior vent exhaust) | 3 ft |
| Scenario 4 | in | Exhaust air (interior vent supply, exterior vent exhaust) | 4 ft |
| Scenario 2.1 | out | Combination (exhaust air summer, air curtain winter) | 2ft |
| Scenario 3.1 | out | Combination (exhaust air summer, air curtain winter) | 3 ft |
| Scenario 2.1.1 | out | Combination (exhaust air summer, air curtain winter) | 2 ft |
| Scenario 3.1.1 | out | Combination (exhaust air summer, air curtain winter) | 3ft |

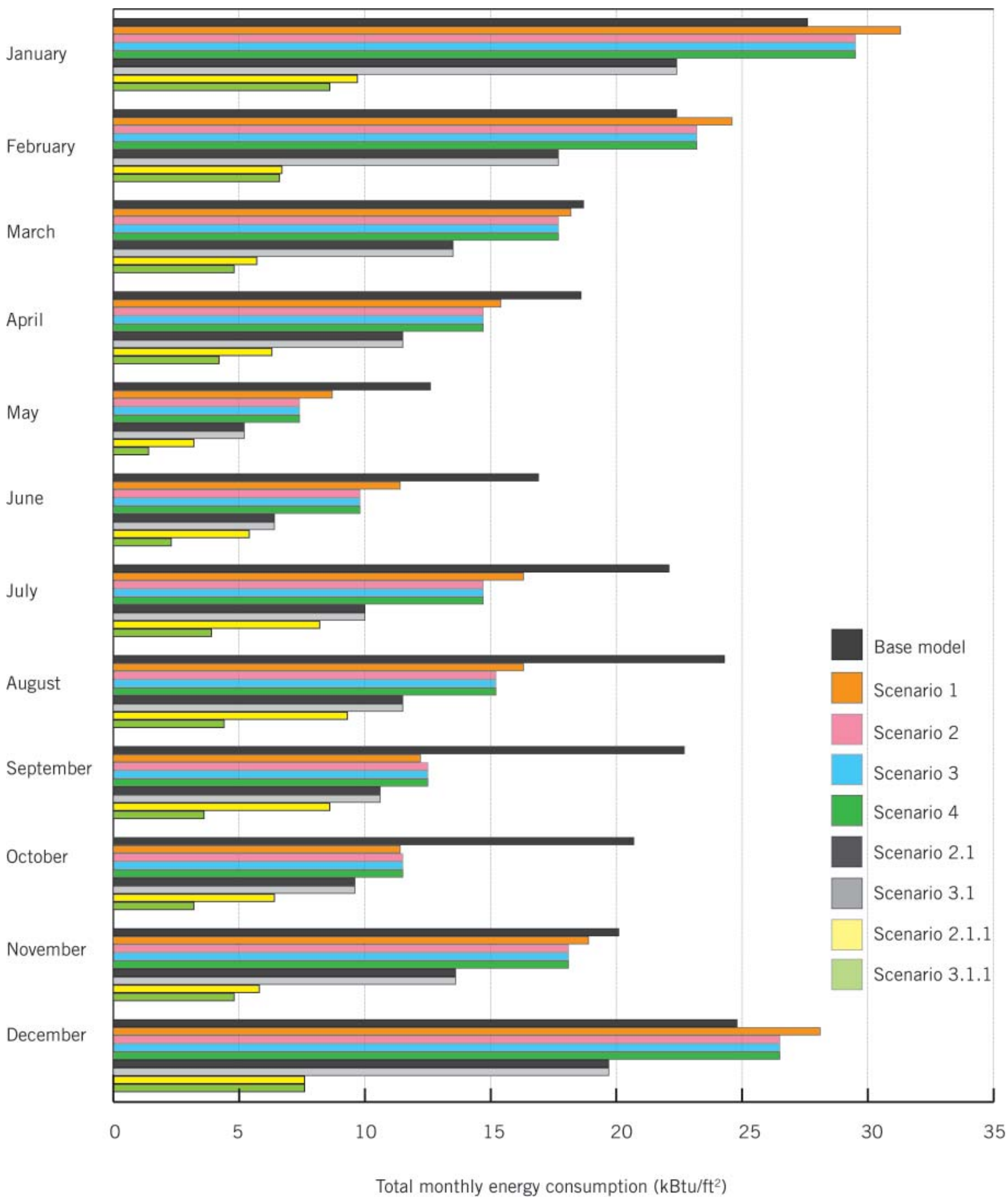



Figure 17: Annual energy demand for single skin and double skin facades.

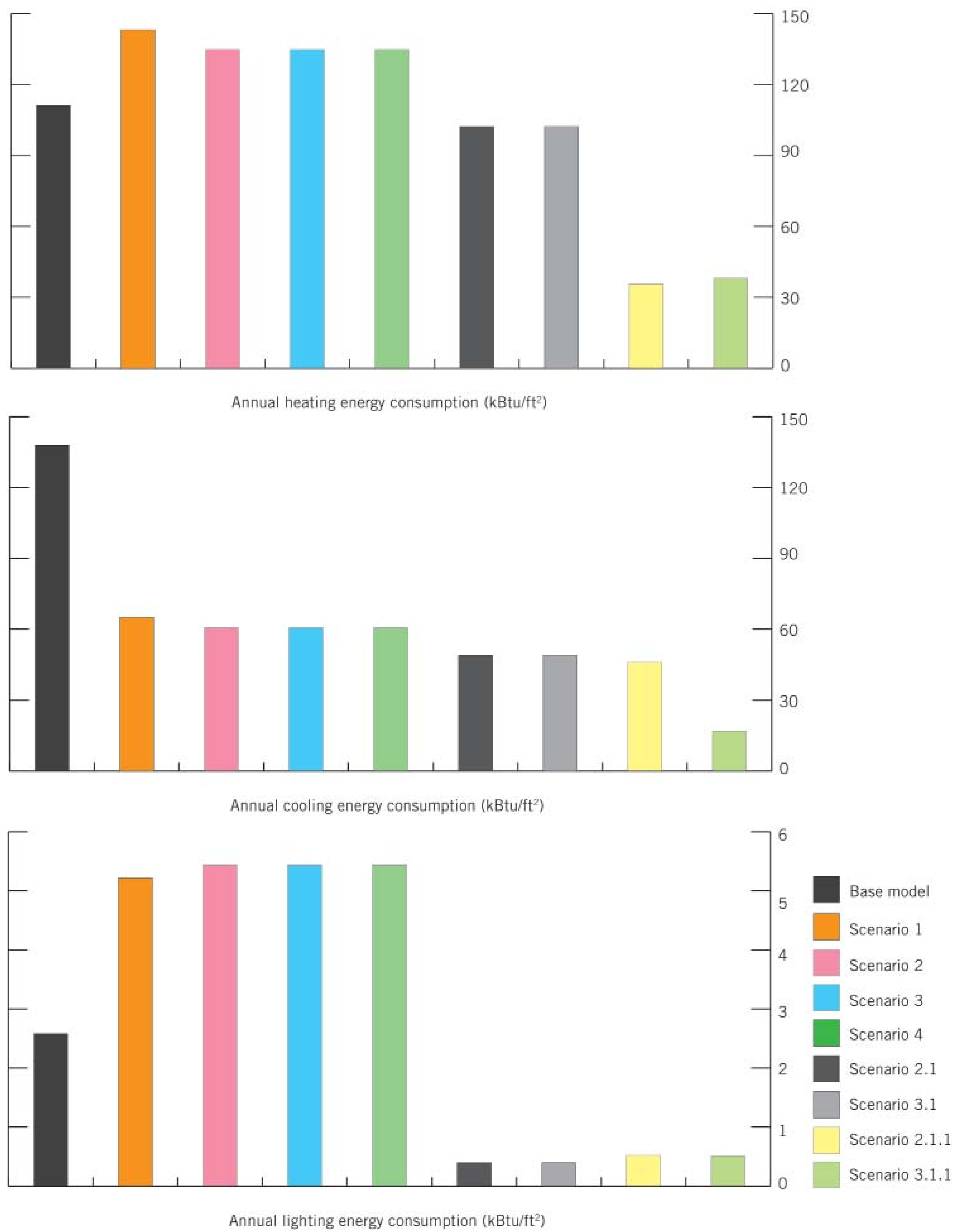



Figure 18: Results for heating, cooling and lighting energy use.

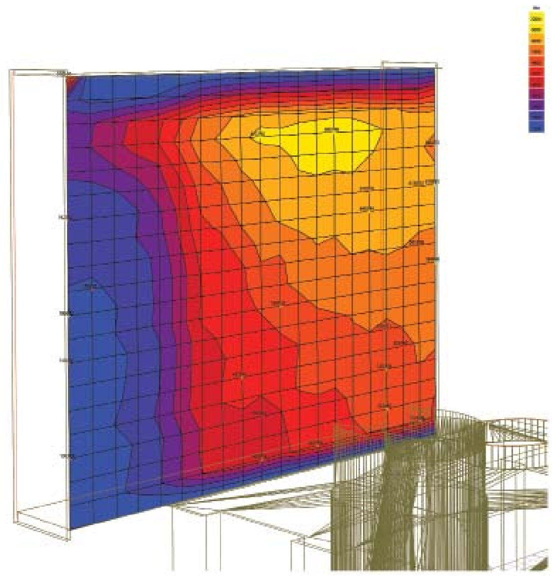
Results are shown in Figure 17. Base model (double glazed single skin facade) has highest overall energy demand. However, looking at the annual energy demand reveals that some cases of double skin wall have higher heating loads during the winter months (Figure 18). In particular, air flow type has a major effect since exhaust air type increases heating demand. Results indicate that trapping air within the air cavity during winter months insulates the double wall, thus significantly lowering the heating loads.

Air cavity size has an effect on energy consumption. However, results indicated that the location of the double glazing is more important and has a greater effect on energy consumption. Results show that exterior placement of double glazing would significantly reduce energy consumption compared to placement on the interior side. Size of air cavity also has an effect, where cavity with a small opening can negatively influence natural buoyancy and stack effect. Also, air cavities that are too large increase the cost. Results showed that the design scenario that performs well for all seasons has air cavity size of 3 feet.

Based on the performed energy analysis for several possible design scenarios, it was concluded that the best possible candidate would contain double glazing on the exterior and single glazing on the interior side, with an air cavity of 3 feet, and hybrid airflow mode (exhausted air during summer months assisted with mechanical fans and air curtain during winter months to decrease heating loads). However, the double skin wall was eliminated in the design development stage due to the high initial costs. The final design incorporated a curtain wall facade with fritted glass to limit the solar heat gain and reduce cooling demand.

## 2.4 Solar Access Analysis

Solar access analysis was performed for several parts of the Entry Pavilion including the south facade of the north bridge as well as the south facade of the entry vestibule. Figure 19 shows average incident solar radiation for the south facade of the north bridge. It ranges from 1,400 to 6,800 BTU and it is highest in the afternoon hours, especially during the winter months. Table 4 shows comparison between available solar radiation on the site and incident solar radiation for this facade. It is evident that this facade spends most of the time in shade.



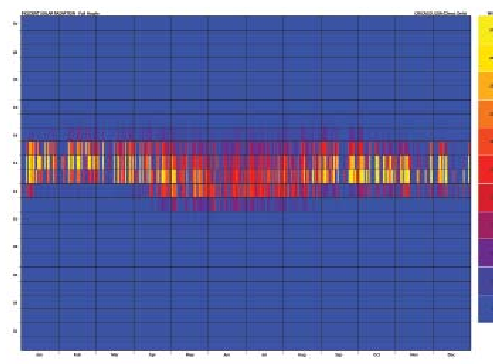


Figure 19: Solar radiation on the south facing facade of the north bridge.

Table 4: Comparison of available and incident solar radiation for the south facade of the north bridge.

| Month | Available solar radiation (Btu/ft$^2$) | Average shade | Incident solar radiation (Btu/ft$^2$) |
|---|---|---|---|
| Jan | 22,045 | 81% | 4,173 |
| Feb | 24,526 | 84% | 3,648 |
| Mar | 29,137 | 83% | 3,458 |
| Apr | 37,267 | 79% | 4,237 |
| May | 51,043 | 75% | 4,930 |
| Jun | 48,763 | 76% | 3,593 |
| Jul | 52,775 | 76% | 4,571 |
| Aug | 40,975 | 77% | 4,157 |
| Sep | 36,775 | 82% | 4,225 |
| Oct | 31,658 | 82% | 4,513 |
| Nov | 19,110 | 80% | 3,372 |
| Dec | 14,378 | 78% | 2,639 |
| **Total** | **408,452** | | **47,516** |

Solar radiation analysis for the south facade of the Entry Pavilion considered three different surfaces, as seen in Figure 20. The first surface receives most of the solar radiation during winter months and incident solar radiation is high during the enitre day due to direct south orientation. The second surface is shaded by the cantilevered part of the facade and has very low incident solar radiation during the summer months. The third surface is shaded during the entire year and has very low incident solar radiation. Table 5 compares average monthly available solar radiation and the incident solar radiation for these three facade surfaces as well as the percentage of time that they spend in shade.

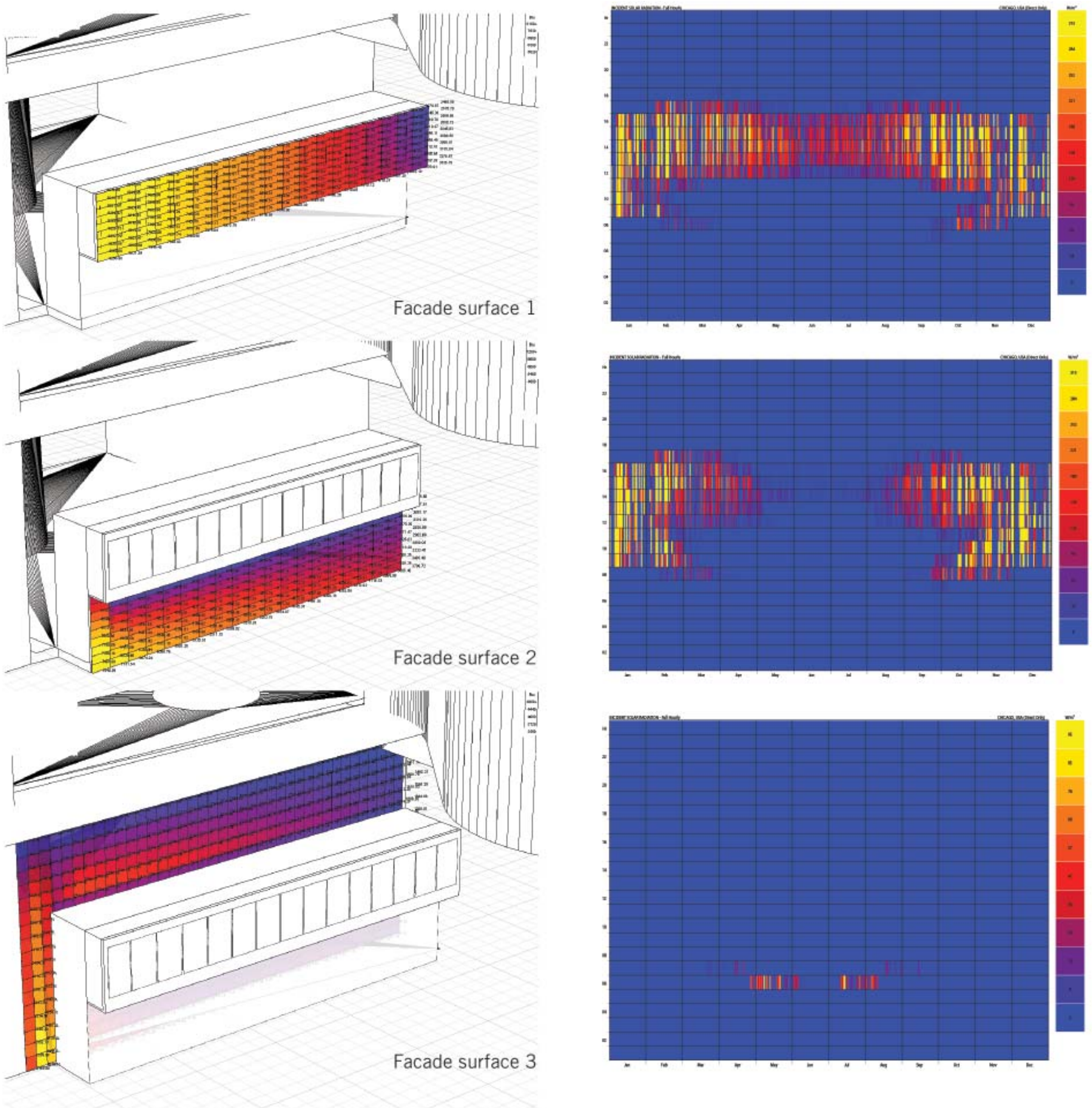



Figure 20: Solar radiation at the south facade.

Table 5: Comparison of available and incident solar radiation for the south facade of entry pavilion.

| Month | Available solar radiation (Btu/ft²) | Facade surface 1 | | Facade surface 2 | | Facade surface 3 | |
|---|---|---|---|---|---|---|---|
| | | Average shade | Incident (Btu/ft²) | Average shade | Incident (Btu/ft²) | Average shade | Incident (Btu/ft²) |
| Jan | 22,045 | 34% | 11,187 | 11% | 15,627 | 100% | 0 |
| Feb | 24,526 | 42% | 8,827 | 34% | 9,335 | 100% | 0 |
| Mar | 29,13 | 51% | 6,787 | 65% | 4,234 | 98% | 13 |
| Apr | 37,267 | 61% | 5,557 | 87% | 2,254 | 97% | 66 |
| May | 51,043 | 65% | 4,808 | 97% | 679 | 97% | 238 |
| Jun | 48,763 | 76% | 3,035 | 97% | 208 | 100% | 44 |
| Jul | 52,775 | 70% | 3,970 | 98% | 310 | 97% | 162 |
| Aug | 40,975 | 63% | 4,841 | 92% | 1,411 | 97% | 127 |
| Sep | 36,775 | 53% | 6,937 | 70% | 4,167 | 100% | 5 |
| Oct | 31,658 | 45% | 9,477 | 43% | 8,722 | 100% | 0 |
| Nov | 19,110 | 36% | 8,343 | 14% | 11,576 | 100% | 0 |
| Dec | 14,378 | 24% | 8,094 | 11% | 11,444 | 100% | 0 |
| **Total** | **408,452** | | **81,863** | | **69,965** | | **655** |

Photovoltiac system was also considered during the design process and an analysis was performed to understand solar access for the roof area of the atrium building[8]. Two different photovoltaic arrays were studied, one being placed on the roof top of the atrium building (covering 2238 SF and with a 35 kW rating) and the second on the roof of the tower (covering 9,873 square feet and with a 143 kW rating). The results showed that the surrounding buildings would not overshadow PV array on the atrium building, however, the payback time for both PV arrays was found to be too high to justify investements into this renewable energy source.

## 2.5 Daylight Analysis

Daylight analysis was performed for two areas of the entry pavilion. The first study analyzed available daylight levels in the terrarium, as seen in Figure 21. Results of the daylight analysis indicated that natural lighting levels in the terrarium would be approximately 120 foot candles (fc) for the horizontal plane (ground level). Analysis of the vertical distribution indicated that the terrarium would receive between 110 and 330 fc of natural light. The middle section receives between 120 and 150 fc. Therefore, the results of the analysis indicated that sufficient lighting levels would be present for the plants and landscaping in the terrarium. The results also indicated that areas of the entry pavilion directly below the skylights would have high daylight levels, therefore, subsequent analysis focused on two design options for distributing daylight evenly in the interior space.

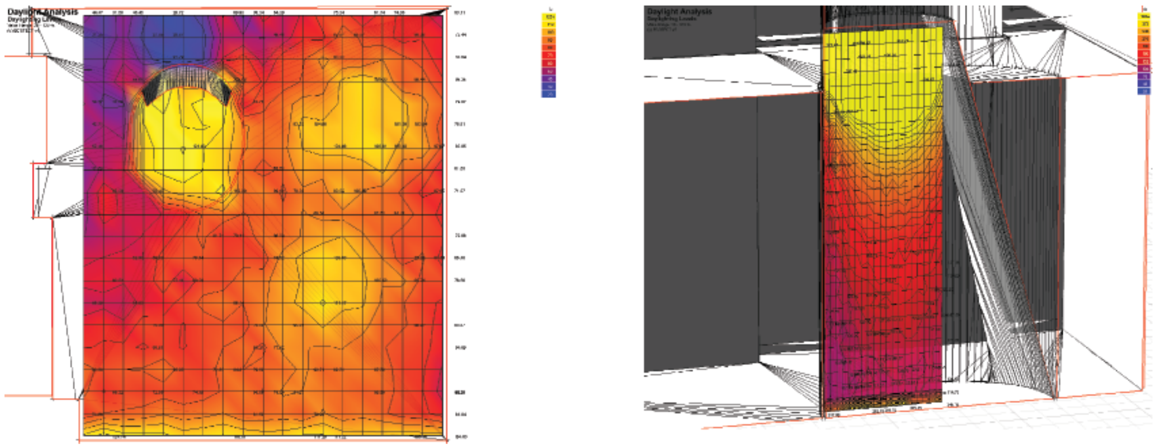


Figure 21: Daylight analysis in the horizontal plane of first floor (left); Daylight analysis along the vertical plane of the terrarium (right).

Results are shown in Figure 22 for two design scenarios. The model on the left side shows daylight levels where ceramic frit is incorporated in both facades (40%). The daylight levels range from 60 to 90 fc. The model on the right side shows daylight levels for a scenario that incorporates ceramic frit coverage in skylight glass as well as building facades. This would reduce daylight levels directly underneath the skylights and would create a more uniform distribution of natural light. The daylight levels would be in the range from 60 to 80 fc.

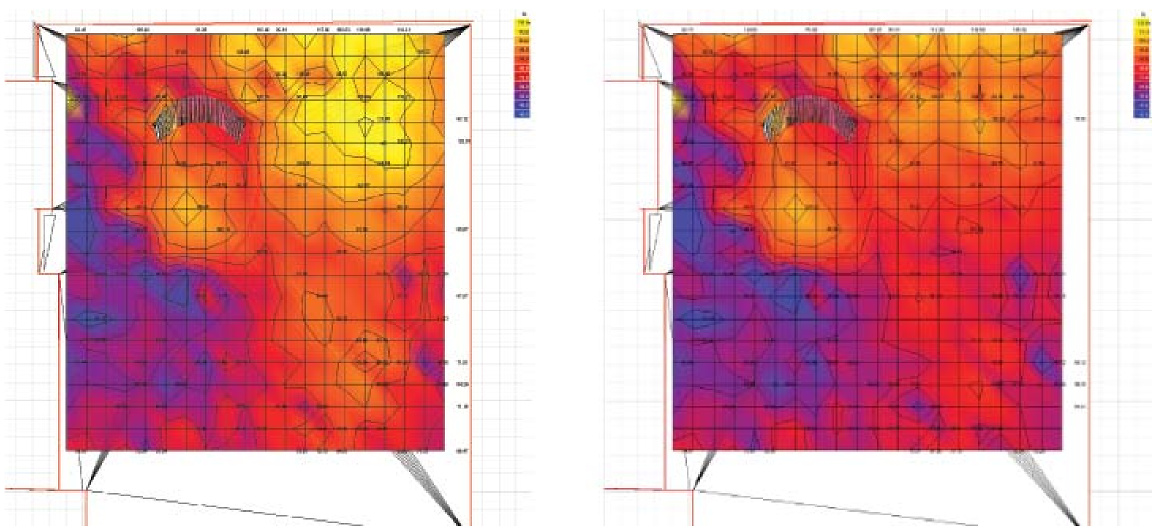


Figure 22: : Daylighting levels - 40% frit coverage for south and north building facades (left); Daylighting levels - 50% frit cover age for skylight and 40% frit coverage for building facades (right).

### 2.6 Living Building Challenge and the Lessons Learned

Although building performance analyses performed during the design process were useful for the assessment of some of the sustainable design strategies and to investigate different design options, the RUMC Entry Pavilion was not able to meet the Living Building Challenge. Primary obstacles that were encountered during the design were:

- Multiple energy-efficiency design strategies were employed to minimize energy consumption. However, it was not possible to design a net-zero energy facility without using renewable energy sources. The initial high costs of renewable energy systems, such as photovoltaics, were prohibitive for including them in the design. Therefore, one of the major requirements of the Living Building Challenge was not met.
- Use of natural ventilation for healthcare facilities (even the lobby areas, such as the Entry Pavilion) is not acceptable for most of North-American hospitals due to infection control strategies. Therefore, inclusion of operable windows, which is one of the requirements of the Living Building Challenge, could not be met.

Still, the employed design strategies resulted in significant energy savings. The modeled Energy Usage Intensity (EUI) for the Entry Pavilion was 62 kBtu/SF compared to the 155 kBtu/SF for a baseline building resulting in 40% energy reduction. Table 6 compares the modeled annual energy consumption for the Entry Pavilion with a baseline building.

Table 6: Modeled annual energy consumption for the Entry Pavilion and a baseline building.

| Building system | Energy consumption (kBtu/yr) | |
|---|---|---|
| | Baseline building | Entry Pavilion |
| Lighting | 310,400 | 201,300 |
| Space heating | 373,200 | 41,800 |
| Space cooling | 147,300 | 77,900 |
| Pumps | 0 | 53,500 |
| Heat rejection | 22,200 | 0 |
| Fans | 386,100 | 53,200 |
| Receptacles | 81,000 | 81,000 |
| Stand-alone base utilities | 39,600 | 36,300 |
| **Total** | **1,359,800** | **545,000** |

## 3.0 TERRARIUM TECHNICAL DESIGN DEVELOPMENT

### 3.1 Terrarium Design Approach and Geometry

Skylights provide natural light for the interior space of the Entry Pavilion and also act as sculptural elements in the roof garden. One of these elements project down to the floor of the Entry Pavilion to introduce an exterior landscaped space without compromising internal contamination issues associated, thus creating a terrarium as one of the feature elements. As per definition, a terrarium is a sealed transparent globe or similar container in which plants are grown. An open-to-above truncated elliptical cone shape, which is an interior courtyard with curtain wall enclosure, greets incoming guests with a grove of trees and a forest floor garden, as seen in Figure 23. The terrarium was introduced as an interesting design feature in the lobby space bringing nature to the interior and breaking down the large volume, as seen in Figure 24.

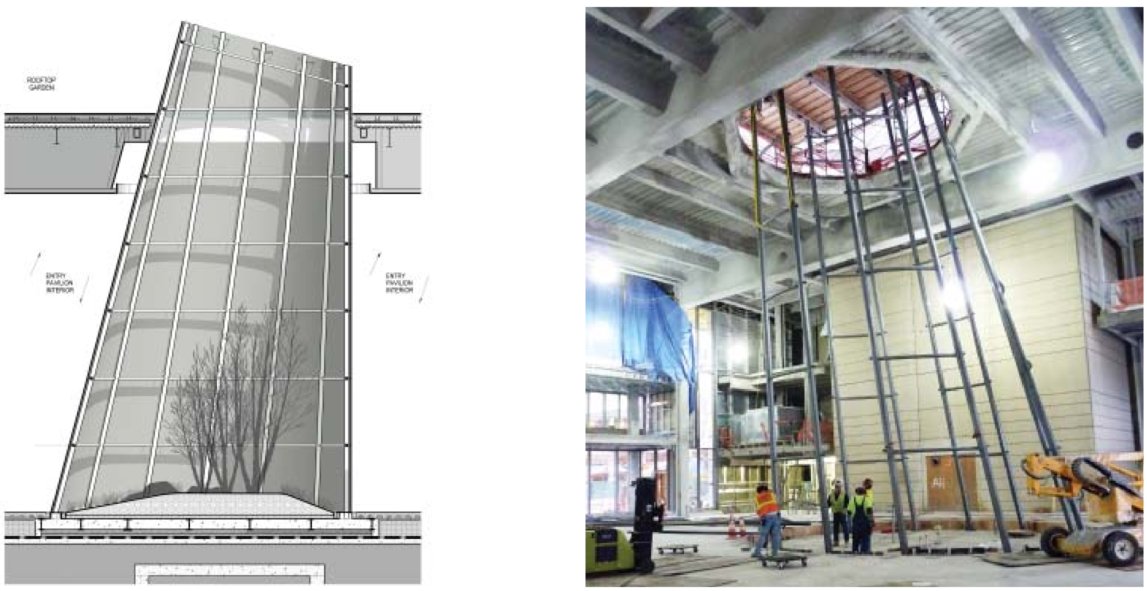


Figure 23: Terrarium cross section (left); Terrarium under construction (right).

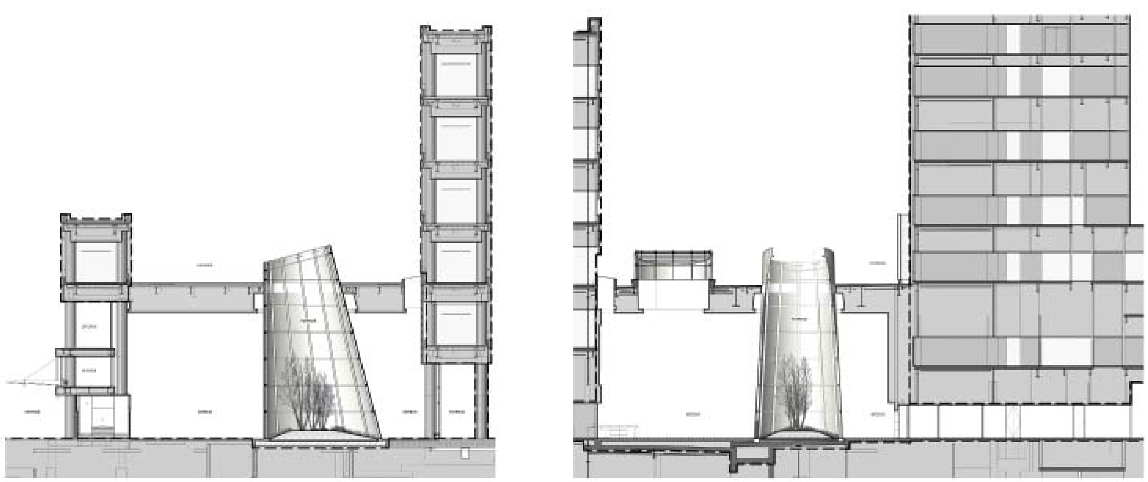


Figure 24: Entry Pavilion north-south cross section (left); Entry Pavilion east-west cross section (right).

Geometrically and three-dimensionally, the terrarium is not a simple shape. In the early design stages, the form was conceived as an ellipse at the base and an angled circle at the top, connected at the quadrant points. The challenge with this concept was that it was very difficult to define the intermediate shapes as they are not ellipses. Therefore, moving from design concept to construction required the adoption of "stacked ellipse" to define the form. The series of plan rings are definable ellipses and transform into a circle at the top ring, which is essentially an ellipse with equal X and Y axes. The enclosure generated from these shapes was projected beyond the roof and then cut in an angle. These two ideas are shown in Figure 25. The ellipses and circle are stacked at one side, while they are offset in the other directions, as seen in Figure 26. When approached through the primary entrance from the south, the vertical edge is perpendicular to the approach direction. Gradually, the form angles on the opposite side. The other two skylights were designed as regular cylinders with an inclination related to the roof plane and then cut off.

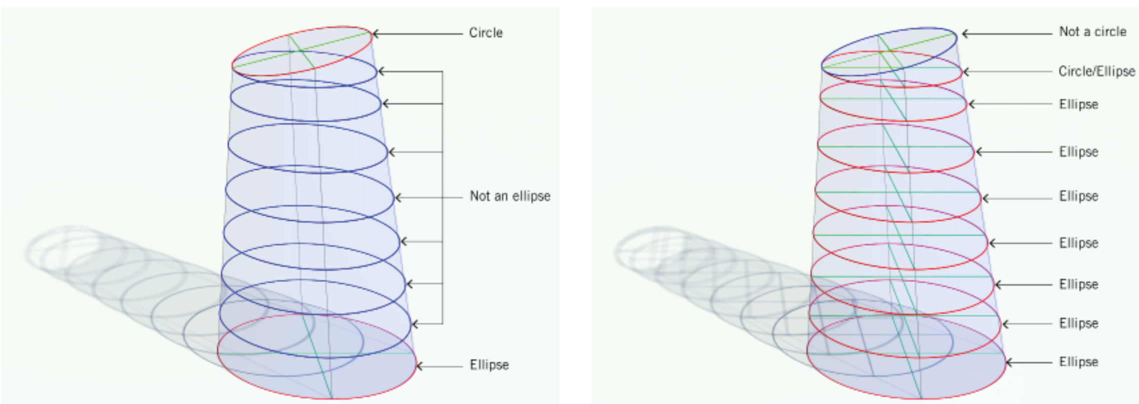



Figure 25: Terrarium geometry schemes - Ellipse and circle (left); Stacked ellipse (right).

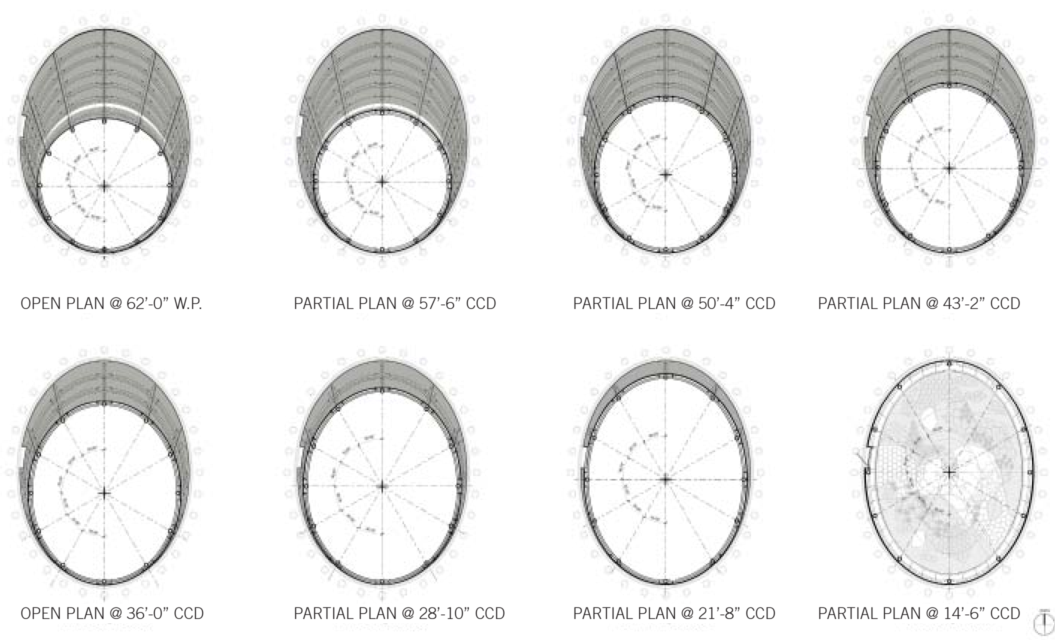



Figure 26: Horizontal terrarium plan along its height.

## 3.2 Technical Challenges

*3.2.1 Inverted Curtain Wall*

The terrarium's curtain wall is inverted compared to a normal curtain wall, as its structure is located at the exterior space rather than interior. Generally, the internal volume of a form is its interior space and outside of the form is the exterior environment. As the terrarium is open at the top, this is actually reversed and the internal volume is now outside. Therefore, the structure of the terrarium curtain wall including the tubes and the fittings are located outside. At the same time, they must resist weather, water, snow and ice. The sealant joint that usually faces outside now faces inside. All these factors were taken into account designing the structure members that are exposed to the outdoor environmental elements.

The components of the curtain wall support system were first pre-assembled off-site similar to ladders shown in Figure 27. Then, these components were erected at the site and the glass elements in-between the ladders were installed and connected.

Figure 27: Structural ladders (left); Assembly of the ladders to create the terrarium form (right).

*3.2.2 Location and Structural Load Transfer*

The terrarium is located on top of the junction of the Atrium Building and the Tower basement. The terrarium is located right at the spot where the two buildings come together. Below the terrarium lies the only usable pathway for service and transportation of materials between the loading dock and the Atrium Building and west side of the campus. There is a 4hr fire-rated vestibule at the basement below the Entry Pavilion that separates the dock from the Atrium Building. This path could not be disrupted, changed or reduced in size and foundations could not be placed in this area.

As the terrarium is large and has significant weight, providing structural support was a major challenge. The existing foundations could not take this additional load since more than half of the Entry Pavilion is situated on top of the existing Atrium Building basement. All these reasons precluded the terrarium to be supported on its columns.

The terrarium was considered to be placed on a platform. The solution was a structural concrete mat slab with micro-pile foundations supporting the terrarium. Structural steel beams running in two directions were embedded in the light-weight concrete. The mat has its own columns near the corners avoiding the logistic circulation path and foundations are drilled through the floor of the basement of the Atrium Building.

*3.2.3 Roof Connection*

The terrarium was totally disengaged from the Entry Pavilion's roof structure, and there is no structural connection between the Entry Pavilion roof and the terrarium. Any kind of structural connection would interrupt the glass layer of terrarium, which would require this area to be sealed for water-tightness.

The terrarium enclosure is made of glass without interruptions as it rises through the roof. Careful attention was given to the roof interface detail in order to maintain

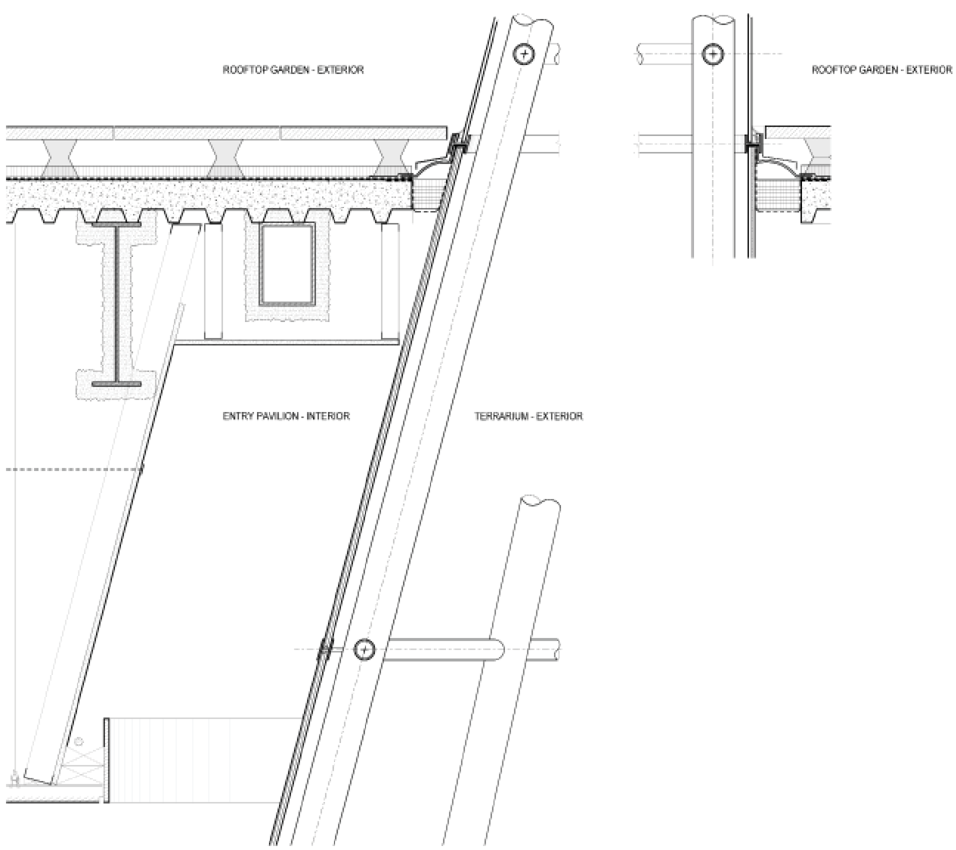



Figure 28: Detail at the roof connection.

the design intent of a pure form punching through the roof deck. One option that was studied was a perimeter skylight, but was rejected because it would create a barrier for occupants on the roof. Also, simulations and modeling preformed during the design indicated that the two large skylights provided sufficient daylight to the interior space, therefore, the additional perimeter skylight would be redundant.

The solution to this issue was introduced, which included a twisting “H” shaped channel at the roof level. It is vertical at one edge of the terrarium, tilted at the opposite end and twisted in between. As the roof of the Entry Pavilion is a sloping deck and meets the irregular geometric shape of the terrarium, the channel has to change profile constantly around the terrarium. A flexible gasket was attached to the channel to cover the gap between Entry Pavilion roof opening and terrarium glass surface and to allow three dimensional movements. The glass of the terrarium surface changes from insulated at the bottom part of the terrarium to laminated above the roof line. This allowed some extra space so that the “H” shaped channel and gasket are not visible at the rooftop.

## 3.3 Materials and Components

### *3.3.1 Glazing Units*

The terrarium glass pieces measure 7’-2” in height and their width varies around six feet. Although the terrarium is symmetrical along its long axis, the opposite corresponding pieces are not the same in terms of dimensions. The terrarium is composed of total 84 unique shapes of glass (42 on each side). Insulated glass panels were used with laminated glass on both sides with air space between. Each glass panel consists of four panes of glass in this order: glass, PVB inner layer, glass, air space, glass, PVB inner layer and glass. This composition increased the thickness of the overall glass panels as well as their weight. The structural load was analyzed to make sure that it will not impart too much additional load to the underlying structure.

### *3.3.2 Patch Fittings*

To show the corner joint, the terrarium glass panels were designed to be attached with small size patch fittings at the both sides of the vertical corner joint. These were later changed to a comparatively bigger size patch fittings at the corners, seen in Figure 29.

Figure 29: Patch fittings at the corner of glass units (left); Terrarium after construction (right). Photo credit Steve Hall © Hedrich Blessing Photographers.

*3.3.3 Terrarium Access Door*

In general, the terrarium has to be sealed, but, there is a need for an access point for maintenance. It was difficult to design a door in a complex geometric shape. The solution was to design a vertical, flat glass door with steel plate jambs at both sides. This would allow access to the terrarium through a weather-tight door, seen in Figure 30.

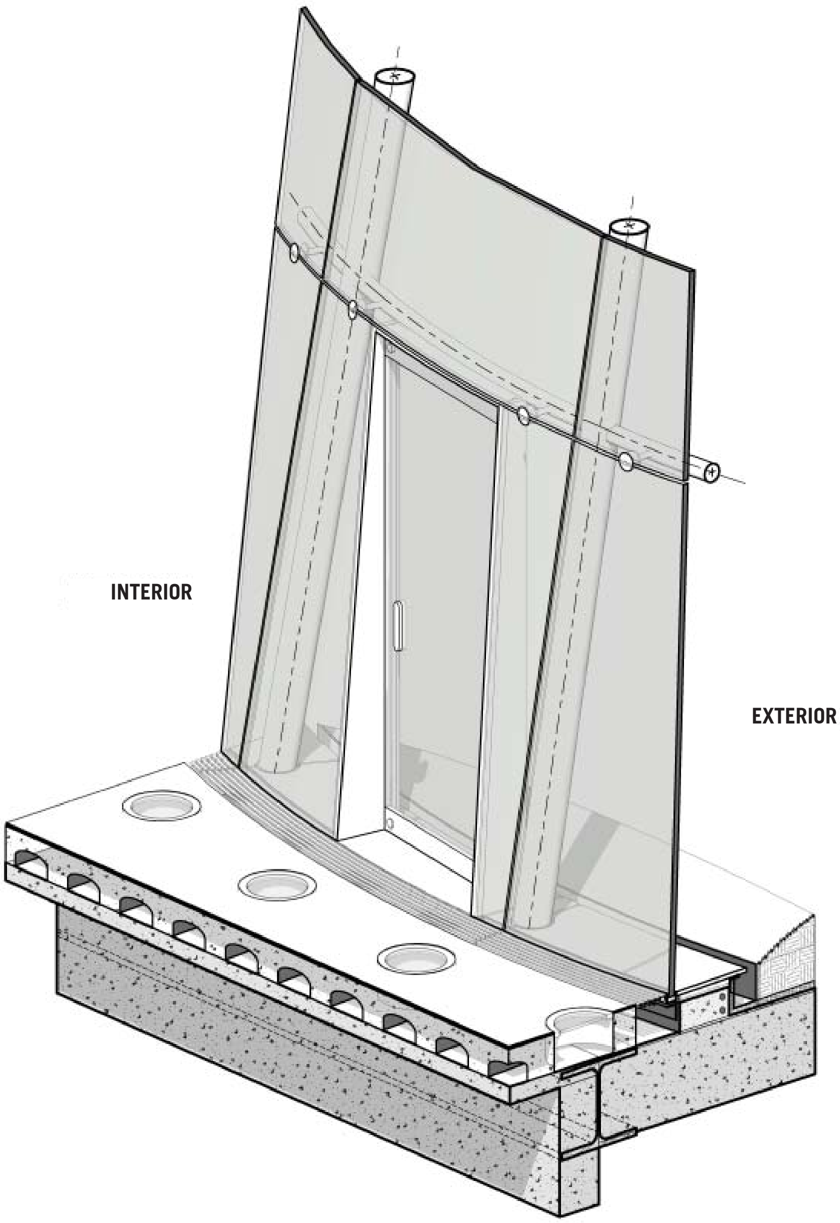



Figure 30: Terrarium access door.

## 4.0 CONCLUSION

This article reviewed in detail the design, building performance analyses and solutions to technical challenges that were encountered during the design of the Entry Pavilion. Sustainable design strategies, which were identified as a possible method for meeting the Living Building Challenge, were discussed in detail in the second part of the article. Also, different building performance studies that were performed during the design process were presented. These included solar exposure studies for the roof garden of the Entry Pavilion, double skin facade analysis, investigation of solar access for different facades and daylighting analysis for the terrarium and the interior space of the Entry Pavilion. The last part of the article discussed technical challenges that were encountered during the design of the terrarium due to its complex, unique geometry and location within the Entry Pavilion.

Complex facilities that are being designed and constructed today require integrated design, research, analysis and smart approach for solving technical issues. With environmentally-friendly use of resources and architecture that enhances the experience of those who inhabit and use it every day, the new Rush University Medical Center campus has transformed into an exciting new setting for the delivery of 21st century healthcare. The Entry Pavilion is the front door of this medical campus and was designed to provide an exceptional experience to the patients, visitors and medical staff. The unique design features of the Entry Pavilion, such as the roof garden, terrarium and large open space are meant to provide welcoming, healing environment to the patients and an improved working environment for the medical employees. These design features were intended to improve building performance, but also satisfaction, productivity and performance of building occupants. Further research would be required to analyze actual occupants' satisfaction and performance by administering post-occupancy evaluations.

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## PEER REVIEWERS

JOHANNA BRICKMAN
Oregon Built Environment & Sustainable Technologies Center

PATRICK CAROLL
Perkins+Will

TODD COHEN
MedStar Montgomery Medical Center

WILLIAM CONWAY, FAIA
School of Architecture, College of Design
University of Minnesota

DR. DANIEL FRIEDMAN
College of Built Environments, University of Washington

DR. IVANKA IORDANOVA
Pomerleau

DR. PAVANKUMAR MEADATI
Southern Polytechnic State University

DR. MARDELLE McCUSKEY SHEPLEY
Center for Health Systems & Design
Texas A&M University

DR. THERESE TIERNEY
University of Illinois at Urbana-Champaign

GAIL VITTORI
Center for Maximum Potential Building Systems

## AUTHORS


01.

HELENA O'CONNOR

Helena is a licensed architect in Brazil, where she received a 5-year professional degree in architecture and urban planning from the Federal University of Rio de Janeiro. She is a LEED accredited professional, works in our Perkins+Will Atlanta office and is currently pursuing a Master of Science in Construction Management at Southern Polytechnic State University. Helena has more than nine years of professional experience working with a variety of architectural and urban planning projects in Brazil and the United States.

02. & 05.

AJLA AKSAMIJA

Dr. Aksamija is a building technology researcher and leads Perkins+Will's Tech Lab. Dr. Aksamija has worked on developing building analysis applications, implementation of novel materials in architectural design, development of computational models and has collaborated with researchers from various disciplines including engineering, computer science and material science. She has contributed to several books, has published numerous research articles and has presented at various national and international conferences.

02.

TODD SNAPP

Todd is an associate principal at Perkins+Will with a variety of experience ranging from high-rise residential and corporate office developments to cultural and higher education facilities. His professional design experience with large and complex projects is an asset to our Perkins+Will team. His most recent projects are also his most impressive, Musee de Louvain-la-Neuve in Belgium and the Merchant Square mixed-use development in London, England.

02.

MICHAEL HODGE

Michael is a designer with an interest in computational design. At the time of the collaboration with the University of Cincinnati, he was a designer in our Perkins+Will Atlanta office and a design technology leader.

02.

MING TANG

Ming Tang is an assistant professor at the School of Architecture and Interior Design, University of Cincinnati. His multi-disciplinary research includes parametric architecture and urban design, fabrication, BIM, performance-driven design, computation, virtual reality, GIS, simulation, interactive design and visual effects. His research has been published in various international conferences, journals, books and exhibitions. He is the author of the book, *Urban Paleontology: Evolution of Urban Forms*. He founded his design firm, Tang & Yang Architects, LLC and won numerous international design awards.

03.

JEFF TYNER

Jeff is a principal in our Perkins+Will Atlanta office and is focused on healthcare architecture. He has experience leading many significant projects from their early master planning/programming stages through the project ribbon cutting. His ability to listen and communicate well with the owner and their staff as well as the general contractor, has been honed over his twenty years of professional experience.

03.

SANDY DUNBAR

In her twenty-five year nursing career, Sandy Dunbar has championed medical-surgical nursing in a variety of roles. She has held positions in surgical intensive care, medical-oncology, long term care, in the quality department and in her current role as a Medical-Surgical Performance Improvement Coordinator at Gwinett Medical Center.

03.

BOWMAN DAVIS

Dr. Davis is Professor Emeritus with the Department of Biology and Physics at Kennesaw State University. He has held adjunct research positions at Georgia Institute of Technology with research interests in neurobiology and aging. He presently consults with Perkins+Will on evidence-based design studies in neonatal intensive care, cardiovascular care and postoperative surgical management facilities. Previous publications range from academic textbooks and manuals to journal articles on the biochemistry of aging and neurobiological and behavioral model systems.

## AUTHORS

04. 

KEVIN BACON

Kevin is an urban designer in our Perkins+Will Atlanta office. He is a certified planner who has also worked as an architect and holds master's degrees for both disciplines from the Georgia Institute of Technology. His expertise in multiple disciplines and passion for the urban realm has enabled him to work on a wide variety of projects such as the Atlanta Beltline Corridor design and Subarea Planning, Connect Atlanta Comprehensive Transportation Plan and Innovation Square at the University of Florida.

04. 

DAVID GREEN

David focuses on large-scale urban design and planning projects for Perkins+Will. He has been involved in the execution of hundreds of projects in the past twenty years ranging from the adaptive re-use of multiple historic structures to multi-thousand acre urban design and planning projects. His work and research focuses on issues of development, particularly within an urban framework and the creation of a strategy for sustainable cities that includes aspects of public policy implementation, criteria for implementation of development controls and design guidelines as well as strategic infrastructure implementation.

05. 

ABUL ABDULLAH

Abul is a designer in our Perkins+Will Chicago office with more than eleven years of experience. His expertise is in BIM and parametric modeling with a main emphasis in complex 3D modeling, especially technical modeling to resolve constructability of enclosures and features of complex exterior building envelopes. Beside architectural practice, he also taught in architecture schools at BUET, BRAC University and Ohio State University.

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