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The following Architectural Engineering Senior Thesis analyzes the Elliott School of International Affairs construction project at the George Washington University, Washington, DC. The performed investigations focus on value engineering, constructability, schedule reduction, research of developing methods, and engineering systems integration.

The first investigation examines the site planning considerations of locating onsite construction offices. Moving the construction management offices from their existing location, on the first level of the Elliott School’s underground parking garage, to within a ground level loading dock provides benefits in terms of project efficiency, safety, impact on construction, and cost.

The second investigation analyzes the construction considerations necessary for application of a unitized, dual-layered glass façade. The delivery approach, cost, schedule impact, and construction methodology required for utilization of the proposed system are investigated. Alterations to the project delivery schedule would be required; however the modifications would act to increase the integration and coordination of the project’s design and construction entities. The value added to the project—in terms of improved occupant comfort and energy efficiency—offset the proposed system’s initial cost premium, and will ultimately lead to cost savings. The proposed unitized system also takes full advantage of factory fabrication, decreasing the construction schedule by over four weeks compared to the existing stick system.

The third investigation evaluates an effort to improve building occupant comfort through the utilization of the proposed curtain wall. The performance properties of Permasteelisa Cladding Technologies’ Active Wall™ system were analyzed for application on the Elliott School project. Without sacrificing any of the original architectural design intent, the proposed curtain wall system creates an improved environment—both thermally and acoustically—within the perimeter academic offices of the southern façade of the Elliott School.

The final investigation delves into the research of the construction project considerations associated with buildings incorporating dual-layered glass facades. The research presented includes case studies of representative projects in conjunction with analyses of delivery methods and associated relationships, construction activities, post-construction maintenance, and representative cost and schedule considerations.
ACKNOWLEDGEMENTS
I would like to thank the following for all the help they provided me as I worked to complete this thesis...

- The Architectural Engineering Department faculty, especially Jonathan Dougherty, Dr. Michael Horman, Moses Ling, Dr. John Messner, and Dr. David Riley
- The Gilbane Building Company project staff—Ben Alexander, Larry Hardesty, and Corey Sarver
- Dave Wellman of the George Washington University
- Dave Allerdings of Ridgeview Glass Co.
- Frank Menendez of SmithGroup
- Permasteelisa Cladding Technologies, Ltd.
- My friends and family
- Special thanks to all other members of the 2003 AE Senior Thesis class
PROPOSAL LETTER
Dear Mr. Art Bean,

At your request, I have conducted a detailed investigation of the Elliott School of International Affairs construction project and have enclosed a summary of my analyses for your convenience. Per your request, the performed investigations focused primarily on value engineering, constructability, and schedule reduction.

The first investigation examines the site planning considerations associated with locating onsite construction offices. Moving the construction management offices from their existing location, on the first level of the Elliott School’s underground parking garage, to within a ground level loading dock provides benefits in terms of project efficiency, safety, impact on construction, and cost.

The second investigation analyzes the construction implications of a unitized, dual-layered glass façade. The delivery approach, cost, schedule impact, and construction methodology required for utilization of the proposed system are investigated. Alterations to the project delivery schedule would be required; however, the modifications would act to increase the integration and coordination of the project’s design and construction entities. The value added to the project—in terms of improved occupant comfort and energy efficiency—offset the proposed system’s initial cost premium, and will ultimately lead to cost savings. The proposed unitized system also takes full advantage of factory fabrication, decreasing the construction schedule by over four weeks compared to the existing stick system.

The third investigation evaluates an effort to improve building occupant comfort through the utilization of the proposed curtain wall. The performance properties of Permasteelisa Cladding Technologies’ Active Wall™ system were analyzed for
application on the Elliott School project. Without sacrificing any of the original architectural design intent, the proposed curtain wall system creates an improved environment—both thermally and acoustically—within the perimeter academic offices of the southern façade of the Elliott School.

The final investigation delves into the research of the construction considerations associated with buildings incorporating dual-layered glass facades. The research presented includes case studies of representative projects in conjunction with analyses of delivery methods and associated relationships, construction activities, post-construction maintenance, and representative cost and schedule considerations.

I greatly appreciate your willingness to review my detailed investigation of the Elliott School of International Affairs construction project and trust that they will satisfy your expectations of value engineering, constructability, and schedule reduction.

Thank you for your time.

Respectfully,

Keith J. Mondock
PROJECT OVERVIEW
PROJECT INTRODUCTION

The Elliott School of International Affairs was constructed on the George Washington University campus in downtown Washington, DC. The $73 million, 331,243 GSF building consists of eight levels of academic facilities for the Elliott School and Executive Education programs, ten levels of residential housing for graduate students, one level of retail spaces, and three levels of parking for approximately 200 vehicles.

The academic facilities will consist of theatre/auditorium spaces, seminar rooms, classrooms, and offices. The residential portion of the building will consist of one, two, and three bedroom suites, common areas, and recreation rooms.

Occupying the entire 1900 block of E Street in Northwest DC, the Elliott School sits adjacent to the US State Department and the American Red Cross Headquarters Building and less than a mile from the White House. Construction on the Elliott School and Red Cross Headquarters occurred concurrently.

Construction began in October of 2000 with the academic and residential components being phased for separate completion dates. The residential tower was turned over to the University in August of 2002, while the Academic portion was completed in April of 2003.

Constructed of reinforced and post-tensioned cast-in-place concrete, the exterior of the Elliott School of International Affairs features both granite stonework and a metal-and-glass curtain wall system.
PRIMARY PROJECT TEAM

**Project Owner**
The George Washington University  
2025 F Street, NW  
Washington, DC 20052  
Dave Wellman, Project Manager

**At-Risk Construction Manager**
The Gilbane Building Company  
7901 Sandy Spring Road  
Laurel, Maryland 20707  
Wayne Bishop, Project Manager

**Architect/HVAC Engineer**
SmithGroup  
1825 Eye Street, NW  
Washington, DC 20006  
Frank Menendez, Project Manager

**Structural Engineer**
Smislova, Kehnemui & Associates, P.A.  
1709 N Street, NW  
Washington, DC 20036  
Kamil Akcali, Project Manager

**Civil Engineer**
The Wiles Mensch Corporation  
11860 Sunrise Valley Drive, Suite 200  
Reston, Virginia 20191  
Joe Mensch, Project Manager

**Acoustical Consultant**
Shen, Milsom, & Wilke, Incorporated  
3300 North Fairfax Drive, Suite 302  
Arlington, Virginia 22201  
Richard Derbyshire, Director
PROJECT DELIVERY SYSTEM

Owner
The George Washington University

Fixed Fee
Architect/HVAC Engineers
Smith Group

Owner
The George Washington University

CMP Contract
At-Risk Construction Manager
Gilbane

Structural Engineer
SK&A

Concrete Contractor
Miller & Long

Civil Engineer
Wiles Mensch Corp.

Mechanical/Plumbing Contractor
John J. Kirlin

Acoustical Consultant
Shen Milsom & Wilke, Inc.

Drywall and Partitions GC
C.J. Oakley Co., Inc.

Finish Contractor
Homewood GC

Electrical Contractor
Cranston

Legend
Contractual Agreement
Line of Communication – No Contractual Agreement
PROJECT DESCRIPTION

Construction Milestone Schedule
- Construction Mobilization: October 24, 2000
- Excavation Complete: May 11, 2001
- Structure Begun: May 14, 2001
- Building Enclosed: December 3, 2001
- Residential Component Completion: August 15, 2002
- Academic Component Scheduled Completion: November 15, 2002
- Academic Component Actual Completion: April 15, 2003

Cost Information
- Total Guaranteed Maximum Project Cost: $53,984,092
- Total Project Cost to Date, Following Contract Changes: Approximately $57 million
- CM Contingency (3%): $1,466,875
- CM Fee: $1,300,000

Building Function and Primary Uses
The George Washington University’s Elliott School of International Affairs features both eight academic and eleven residential levels sitting atop three levels of underground parking.

The eleven residential levels contain one, two, and three bedroom dormitory suites— a total of 193 beds— common areas, and recreation rooms.

The Elliott School of International Affairs and Executive Education programs are housed in the eight levels of the academic component. The academic component is composed of theatre/auditorium spaces, seminar rooms, classrooms, and offices. The six auditorium classrooms utilize tiered seating to provide enhanced views during lectures and presentations.

Below the academic and residential components lie three levels of underground parking, providing spaces for approximately 200 vehicles. The parking garage is to be used only by faculty and staff, with its entrance ramp controlled by electronic gate.
Location and Site

Occupying the entire 1900 block of E Street in Northwest Washington, DC, the Elliott School of International Affairs sits adjacent to the United States State Department and the American Red Cross Headquarters Building, near the on/off ramp of the busy E Street Expressway.

The 30,159 square foot lot previously contained an existing structure and parking lot, both of which were demolished prior to construction.

Construction of the Elliott School occurred concurrently with that for the American Red Cross Building.

Applicable Codes/District of Columbia Construction Requirements

- 1996 BOCA National Building Code
- 1992 District of Columbia Construction Code
- First Source Hiring Agreement requirement
- MBE/WBE Program participation requirement

Zoning/Historical Considerations

The project meets applicable requirements of the District of Columbia Zoning Commission Order No. 746, Case No. 93-5 F/91-18 P. The site zoning classification is C-3-C.

Building Architecture

A pair of granite towers flanks a metal-and-glass curtain wall system on the upper levels of the buildings south elevation. The academic component’s main entrance features four massive torch fixtures located two stories above the ground. The upper floors provide uninterrupted views of the Washington, Lincoln, and Jefferson Monuments. The seventh floor seminar room, to be available for public and governmental use, features Level 4 millwork.

Building Envelope

Support for the exterior wall system is provided by the building’s cast-in-place concrete structure and reinforcing steel. The exterior wall finish varies

Figure 4 Site Location (MapQuest).
depending on elevation—brick, precast concrete panels, limestone, granite, metal panels, and a metal-and-glass curtain wall system are all utilized.

Granite, limestone, and metal-and-glass storefronts are featured on the ground level of the east, west, and south facades, while precast concrete panels and a metal-and-glass curtain wall system make up the upper floors. The north façade is primarily composed of precast concrete panels and brickwork. The roof system is constructed of hot fluid applied roofing membrane, rigid insulation, filter fabric, and ballast.

**Structural System**

A combination of concrete caissons, column footings, foundation footings, and mat footings, and strap beams form the support structure for the Elliott School of International Affairs. Diverse subsurface conditions throughout Northwest Washington, DC, and specifically the site, led to the necessity of such a varied foundation system.

The superstructure consists of reinforced and post-tensioned concrete girders, concrete columns, and reinforced and post-tensioned concrete floor slabs. A number of the floor slabs in the academic component include drop panels over designated columns providing additional shear support.

**Electrical System**

The Elliott School is fed with 3Ø, 240/480V power provided by the Potomac Electric Power Company (PEPCO). Power is distributed throughout the building through a series of switchboards, electrical panels, transformers, and bus ducts. A 400kw, 240/480V, 3Ø diesel fuel generator provides emergency power.

The Fire Alarm system consists of an addressable, multiplexed, electrically supervised, zoned system.

**Lighting System**

The lighting for the academic and residential structure consists of a combination of fluorescent and incandescent fixtures including strip lighting, down lights, wall washers, flood lights, HID's, track lighting, and fiber optic lighting. The fluorescent lighting is powered by 277 volts of distribution voltage.
Mechanical System

The mechanical system of the Elliott School of International Affairs consists of a forced air VAV system incorporating hot water boilers, perimeter radiation, chillers, cooling towers, and supply and return fans. Pneumatics run throughout the building from a central air compressor controlling VAV boxes from individual thermostats.

A Building Management System allows the University’s Facilities Management Department to monitor the performance of the mechanical system from an off-site location.

A diesel fuel line extends from the Basement level to the Penthouse level to support the Emergency Generator.

Fire Protection

The exterior load-bearing walls, fire walls, enclosures of exits, shafts and elevator hoist-ways, interior load-bearing walls, and floor construction of the Elliott School were constructed to provide a two-hour fire rating. A one-and-a-half hour rating is provided by the structural members supporting the curtain wall system.

The building is serviced by a combination of wet and dry sprinkler systems constructed through a design-build arrangement.

Transportation

The Elliott School is serviced by a total of six elevators—two servicing the residential component and four servicing the academic component.

Steel monumental stairs connect the basement, ground, and second floors of the academic component, while concrete monumental stairs bridge the second-third floors and the sixth-seventh floors.

Telecommunications

Telecommunications conduit and pull strings were installed allowing for the installation of the cable and other devices by contractors independent of Gilbane’s construction management services.
EXISTING PROJECT CONDITIONS
## ESTIMATE SUMMARY

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<tr>
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- Actual Construction Costs provided by the Gilbane Building Company.
A complete summary schedule for the Elliott School of International Affairs project is included in Appendix A, on Page 55.
The Elliott School of International Affairs project cash flow curve was generated using the original construction cost estimate and project schedule developed by the Gilbane Building Company. Schedule activities were separated by CSI division, to which the applicable costs were assigned—a complete Microsoft Excel spreadsheet detailing the cost loading is included in Appendix A, on Page 56.

The developed cash flow curve does not completely adhere to the standard “S” distribution due to the phasing of the project—the residential component was scheduled for completion five months ahead of the academic component.
INVESTIGATION I: SITE PLANNING ANALYSIS
CONSTRUCTION MANAGEMENT DEPTH STUDY
PURPOSE OF INVESTIGATION

The site planning strategy for the Elliott School of International Affairs construction project was examined and analyzed in an effort to increase the efficiency, convenience, and safety of the construction process.

EXISTING SITE LAYOUT PLAN

Description

During excavation and the erection of the cast-in-place concrete structural system of the Elliott School of International Affairs construction, construction management and contractor office and storage trailers were located along the southern fence line of the construction site. During these initial phases of the project, the relatively small construction management staff worked out of a single 8'x28' two-office construction trailer.

Following topping out of the structure, temporary offices were constructed within the building—on the first level of underground parking (a detailed site plan showing the existing site layout can be found in Appendix B, on Page 58). As the project grew in complexity, so did the construction management staff. During peak construction, the construction management team included a project manager, three project engineers, four superintendents, an administrative assistant, and a summer intern. To house the relatively large staff, the temporary offices constructed included three office rooms, a conference room, a plan room, storage spaces, a bathroom, and a coffee/break area.

At no point during the construction process was the structure’s parking garage used for vehicle parking, instead contractors built various temporary offices and storage enclosures throughout the Elliott School’s three levels of underground parking. Areas of the parking garage that were not taken up by temporary enclosures were used for material and equipment storage.

The varying components of the Elliott School building—academic, residential, and parking garage—and the requirements of the University led to a phased schedule, with varying completion dates, for the project. The residential component and parking garage were turned over to the University in time for the Fall 2002 academic semester, while work on the academic component continued through the spring of 2003, ultimately wrapping up in mid-April. To allow for the parking garage to open, a portion of the construction management offices were demolished to allow for vehicle passage. Contractors were also required to demolish their offices and temporary storage enclosures, as well as remove all material and equipment from the parking levels. Offices and storage areas were relocated throughout the upper levels of the academic component, with the majority of contractors running work out of centrally located groups of gang boxes.
Efficiency and Convenience

With the offices located below ground level, construction personnel and site visitors were required to navigate their way two stories down one of the building's stairways or elevators to reach the construction management offices.

Although numerous signs were installed to direct visitors from site entrances to the construction management offices, they were often removed or obstructed by construction activities. As a result of the inconvenience of entering an ever-changing construction site, couriers, FedEx, and the US Mail refused to enter the building, and instead telephoned the CM office so that a member of the staff could exchange deliveries at a gate along the construction fence.

In an effort to promote onsite coordination, contracts between the construction manager and subcontractors included a requirement that at least one field foreman from each contractor was to have a Nextel phone with two-way radio capability. However, the Nextel requirement only led to frustration and confusion, since locating the construction management offices two floors below grade severely disrupted cell phone and two-way radio reception. Within the construction management offices, cell phone and two-way radio calls could not be made nor received.

Safety Considerations

Locating their offices underground restricted the site monitoring capabilities of the construction management site staff. Site entrances, as well as the building entrance itself, were difficult to control. Visitors—often without hard hats or safety glasses—were required to make their way through the site to reach the construction management offices or conference room.

Cost Analysis

The total cost to construct the temporary construction management offices and conference facilities built on the first parking level of the Elliott School of International Affairs was estimated to be $61,407.99. The cost was generated through a detailed estimate performed using RS Means Building Construction Cost Data for the year 2000, and adjusting the cost from the national average to account for the construction occurring in Washington, DC. A complete summary estimate can be found on Page 60, in Appendix B.

PROPOSED SITE LAYOUT CHANGES

Description

Several alternatives were investigated for the relocation of construction management offices. Locating the office in an adjacent, university-owned parking garage was considered, however, the inconvenience of being removed from the site, as well as limited site monitoring capabilities were too detrimental. Two locations within loading docks on the ground floor of the structure were next investigated. The location in the loading dock within the Elliott School's
residential component was eliminated from consideration due to the phasing of the construction project. With the residential component having an earlier completion date, the loading dock would ultimately need to be utilized for operation of the residential building, while construction continued on the academic component.

![Figure 8: Existing and Proposed Construction Management Office Locations](image)

Moving the temporary construction management offices from the first level of parking to the ground level would provide many benefits to the construction and coordination processes of the Elliott School of International Affairs. As illustrated in Figure 8, above, ample space is provided for the location of two mobile construction office trailers in the academic loading dock located along the building’s east façade—a detailed site plan showing the proposed site layout can be found in Appendix B, on Page 59.

The two proposed trailers are a 10’x44’-three-office and a 10’x32’-two-office available from GE Capital Modular of Baltimore, Maryland. Each trailer comes equipped with baseboard heating, wall-unit air conditioning, half-baths, fluorescent lighting, ample outlets and phone jacks, plan racks, and file cabinets. Together the two trailers provide the office space required of the CM staff, as well as areas for safety training and coordination meetings.

**Efficiency and Convenience**

The proposed academic loading dock location is directly adjacent to the main access gate in the construction site fence, allowing visitors to easily find the offices. By locating the trailers near the site access, package delivery and mail services could easily locate the construction management offices.

Also, construction personnel are provided with direct access from the exterior of site, as well as substantially easier access from within the structure, as the proposed trailer location is within close proximity to a staircase, elevator, and the parking garage ramp.

Locating the CM offices on the ground level would also allow for greater utilization of the Nextel services required of each contractor. Although, contractors and construction management staff would still be unable to use the
cell phones and two-way radios when multiple levels below ground, the technology would be available while in the office—where the majority of the construction management staff’s time was spent.

Placing the construction management staff amongst a greater amount of construction activities would also encourage increased interaction in the process; from simple observation of activities from within the trailers to the promoting of site walks—a relatively seldom done activity because of the inconvenience of the garage level location.

**Safety Considerations**

The safety of the site would be increased by placing the office trailers within close proximity of the main point of site access. The CM staff would be able to monitor and limit the site access of visitors and delivery carriers. Visitors would be less likely to wander the site inappropriately dressed, disrupting construction activities and putting themselves in danger.

The proposed location of the office trailers is also directly adjacent to the material lift servicing the academic component of the Elliott School. Construction management personnel would have the ability to ensure appropriate and safe use of the material lift.

**Cost Analysis**

The proposed office trailers are available for rent on a monthly basis from GE Capital Modular Space of Baltimore, Maryland. 10’x32’ trailer rents for $417.50 per month and would be on site for nine months, while the 10’x44’ trailer, onsite for seventeen and a half months, rents for $437.50 per month. The rental cost of the trailers also includes delivery, blocking and leveling, tie down, dismantling, and return delivery—a summary estimate is included on Page 60, in Appendix B. The total rental cost for the proposed office trailer rental is $17,398.75.

**SITE LAYOUT COMPARISON**

**Efficiency and Convenience**

Locating the construction management offices at ground level would greatly increase the efficiency and convenience of the construction project. The proposed location would provide for greater coordination via Nextel cell phone and two-way radio as required by contract. Also, visitors and delivery services would be able to more easily locate the construction management offices.

**Safety Considerations**

The ability of the construction management field staff to directly monitor site safety would be improved with the proposed ground level office location. The proposed location provides greater proximity to the main site access gate, as well as the material lift.
Impact on Construction Activities

By removing the construction management offices from the first parking level of the structure, additional area for material and equipment storage is created. During the actual construction process, a dumpster was placed in the academic loading dock, with the remaining area being utilized for temporary material storage. The dumpster would be relocated to the exterior of the structure, near the material lift, while the material storage area eliminated would be replaced by that freed on the first parking level. A set of stairs and ramp would be constructed to provide loading of the relocated dumpster in the same manner as if it was located at the loading dock.

Also, working from trailers located in the loading dock would avoid the demolition and hassle of reconfiguration required of opening the parking garage while the temporary offices were maintained as in the existing layout.

Cost Analysis

Comparisons of the cost of the locations was made on the basis of construction cost of the existing system and rental, delivery, and setup costs for the proposed system, and are summarized in the table and figure below. The proposed office trailers cost an estimated $44,000 less than the temporary offices actually constructed within the buildings parking structure. However, it is understood that RS Means—the source of the cost data for the existing temporary office facilities—provides costs that tend to be inflated. Therefore, although the proposed construction management office location is considered more cost efficient, the difference is probably not so dramatic.

<table>
<thead>
<tr>
<th>CONSTRUCTION OFFICE</th>
<th>COST</th>
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<td>Existing Layout - Parking Level</td>
<td>$61,407.99</td>
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<tr>
<td>Proposed Layout - Ground Level</td>
<td>$17,398.75</td>
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<tr>
<td>Difference</td>
<td>$44,009.24</td>
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</table>

![Figure 9](image_url)
CONCLUSIONS

The proposed office location and configuration is more efficient, safer, has minimal impact on construction, and costs far less when compared to the existing temporary office layout.

Increased coordination and convenience is provided to the construction project through the proposed layout. Site coordination via Nextel two-way radio, as required by contract, but severely limited by the existing office location, can be fully realized with the proposed location. By moving the offices to the ground level, the construction management staff is positioned amongst a greater number of construction activities, promoting increased interaction with the construction process.

The overall safety of the project is also increased, since the construction management offices are to be located adjacent to the main site entrance—for both vehicles and pedestrians. With the proposed location, the construction management staff is located in a far better position to monitor and restrict access to the project site.

The proposed trailer layout has little effect on the daily construction activities of the project. Placing the office trailers in the loading dock requires moving a dumpster to the exterior of the site, however it also frees up additional storage space on the first parking level. The loading dock location avoids the hassle of the partial demo required to open the parking garage in conjunction with the residential component, while maintaining the construction office.

The proposed trailer layout also provides the project with cost savings. Compared to the existing temporary construction management offices, the proposed layout would provide savings to the project’s general conditions costs, increasing the profit realized by the construction manager.
INVESTIGATION II: CURTAIN WALL REDESIGN
CONSTRUCTION MANAGEMENT DEPTH STUDY
PURPOSE OF INVESTIGATION

The curtain wall system of the Elliott School of International Affairs was investigated in an effort to reduce the project schedule. Several unitized curtain wall systems were examined for schedule considerations—from standard systems manufactured by the same company as the existing system to the complex double-skin facades prevalent throughout Europe. Due to interest in emerging building technology, as well as sustainable construction, a dual-layered glass façade was proposed and analyzed as an alternative to the existing double glazed unit wall (DGU).

This investigation examines the construction aspects of the proposed dual-layer glass façade redesign. Considerations of the project delivery method, system cost, project schedule, and the construction methodology applicable to Permasteelisa Cladding Technologies’ unitized double-skin Active Wall™ system and the Elliott School of International Affairs construction project are analyzed.

PROJECT DELIVERY METHOD

With the extreme rarity of double-skin facades in the United States, Permasteelisa is the only manufacturer with a presence in the American construction market to produce a tested and readily available unitized double-skin system. Two methods exist in order to identify the Active Wall™ technology for application on a project—performance or proprietary specification—with the design-bid-build featuring at-risk construction management arrangement of the Elliott School project.

Research into existing structures utilizing Permasteelisa’s Active Wall™ system has identified the two available system identification methods. For Manulife Financial’s US Operations Headquarters in Boston, the project architect, Skidmore, Owings & Merrill, LLP, outlined stringent performance specifications which ultimately led to the involvement of Permasteelisa as the façade engineer and system manufacturer. For the University of Pennsylvania’s Levine Hall School of Engineering and Applied Sciences Building, Permasteelisa’s Active Wall™ technology was identified directly by the architect KieranTimberlake Associates, LLP through proprietary specification.

KieranTimberlake rationalized their identification of Permasteelisa through proprietary specification as the only means of guaranteeing application of the tested and applied standard—Active Wall™—system and avoiding the use of another manufacturer’s ‘built-up’ system.

For the Elliott School project, Active Wall™ system delivery is proposed to be identified through performance specification. Detailed energy performance criteria outlining system requirements would work to ensure that the Active Wall™ unitized system be utilized.

Performance specification identifies Permasteelisa’s dual-layered glass façade system; however additional project delivery considerations must also be made.
Due to the complexity of the curtain wall system, as well as its integration into a building's architectural, mechanical, electrical, and structural systems, project's utilizing a dual-layered glass façade require a team effort between the architect, design engineers, and construction contractors. Complete involvement allows for the maximization of the integrated performance benefits of the system.

To allow for complete participation and systems integration for the Elliott School project, it is proposed that changes be made to the timing of the involvement of not only the façade engineer and supplier, but also the construction manager.

To facilitate the integration of the complex façade into the building system as a whole, involvement and participation of the construction manager earlier than as in the existing project, and prior to the bringing on of Permasteelisa would be required. In order to incorporate the proposed dual-layered glass façade it is proposed that the Gilbane Building Company’s involvement in the project would have had to occurred in February of 2000, six months earlier than the CM’s actual August 15, 2000 contract award date, as can be seen through a comparison of Figures 10 and 11. Permasteelisa would have been brought onto the project a month later, in March 2000, through contract with the construction manager, allowing both the construction manager and façade engineer/supplier to be involved in the latter stages of the schematic design process.

**FIGURE 10** Original Project Schedule Illustrating CM and Contractor Involvement

**FIGURE 11** Proposed Project Schedule Illustrating CM and Contractor Involvement
It is also proposed that the earlier inclusion of Gilbane, not affect the contract value between Gilbane and the George Washington University, since in the additional early months of contract involvement, Gilbane would work on a limited basis in an extension of their value engineering services—primarily integrating the design and construction phases of the building process and specifically the proposed curtain wall system.

During the design phase of the project, Permasteelisa would work primarily in conjunction with SmithGroup, the project’s architect and HVAC engineer. The façade engineer/supplier would produce shop drawings and system submittals specific to the Elliott School in conjunction with the performance requirements of the building and its systems.

Considerations should also be made to extending the adjustment and warranty period provided by Permasteelisa and the project’s HVAC contractor, John J. Kirlin. In order to maximize the performance of the curtain wall system and its energy savings impact on the Elliott School’s mechanical system adjustment and monitoring of the system should be extended beyond commissioning and the standard one-year warranty period.

**SYSTEM COST**

Due to the addition of the second layer of glass, the proposed Active Wall system has an increased initial cost compared to the existing double-glazed (DGU) curtain wall. However, this initial premium is reduced when the changes to the mechanical system and associated cost savings are included—as examined in the subsequent section of this thesis.

The existing DGU wall has a cost of $105/SF, totaling $995,400 for the project’s 9,480 square feet of curtain wall area. The proposed dual-layered glass façade has a cost of $145/SF, totaling $1,374,600. However, adding the perimeter mechanical system costs required of the existing system, $95,836, makes the total cost of the existing curtain wall system $1,091,236. Summarized in the table below and illustrated in Figure 12 on the next page, the proposed system would add an additional $283,364 to the project budget over the existing system and its perimeter heating requirements. However, the value of the proposed system extends well beyond its initial cost of the dual-layered façade.

**Table 3** Curtain Wall System Initial Cost

<table>
<thead>
<tr>
<th>CURTAIN WALL SYSTEM</th>
<th>INITIAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed Dual-Layered Wall</td>
<td>$1,374,600</td>
</tr>
<tr>
<td>Existing DGU Wall &amp; Fin Tube Radiation</td>
<td>$1,091,236</td>
</tr>
<tr>
<td>Difference</td>
<td>$283,364</td>
</tr>
</tbody>
</table>
By eliminating mechanical system components and reducing the size of others, through improving the thermal environment of the office spaces—again, as detailed in the next section of this thesis—the proposed system decreases the energy consumption and requirements of the Elliott School of International Affairs.

Little post-construction data is available to demonstrate how well double-skin facades work in conserving energy and related costs in their application to projects in the United States. In the February 2003 ENR article, Glass Facades Go Beyond Skin Deep, Roberto Biachiarelli, executive vice president of Permasteelisa Cladding Technologies is quoted as stating “The (Active Wall™) system has a medium- to long-term payback.” Although not enticing to developers or speculative builders, the extended payback period does work for owner’s who occupy buildings for many years—such as the George Washington University.

**PROJECT SCHEDULE**

The proposed dual-layered glass façade requires increased design and fabrication time compared to the existing DGU wall, however installation time is decreased due to the system’s unitized mode of assembly. The proposed system relies on increased factory fabrication; decreasing the number of system components, therefore also reducing the number of associated onsite installation activities and the overall construction schedule.

The proposed system reduces the installation of the proposed segments of the building’s curtain wall by 4 weeks compared to the original schedule, as can be seen in a comparison of Figures 13 and 14 on the next page, and 16 weeks compared to actual duration of installation. Delays to the construction schedule were created from the relatively slow final design and fabrication of the buildings.
curtain wall, storefront, and window systems, which resulted in components of the stick-system not being on site in time for scheduled installation. These were unforeseen delays that came about following the construction planning and scheduling process, and therefore are not valid for schedule reduction considerations.

CONSTRUCTION METHODOLOGY

The largest unit of the proposed dual-layered curtain wall system measures 11'-6" x 3'-8" x 1'-6" allowing for shipment via standard tractor-trailer. Once delivered to site, the units are removed from the delivery trucks with a forklift and relocated for installation or to areas of storage around the site.

Anchors are attached to the structural system of the Elliott School, to which the curtain wall and masonry panels are attached. The anchors are attached onsite, rather than during fabrication, to account for variance between design and actual construction.

Installation of the units requires a truck-mounted crane in order to lift the units into place as they are attached to the structural system from within the structure. The capacity and reach of crane onsite for installation of the existing DGU sufficiently fulfills the requirements for installation of the proposed system, since it also was used to place comparatively far heavier air handling units atop the Elliott School's roof.

The proposed installation process involves constructing the vertical segment of dual-layered curtain wall for the Elliott School's residential component separately from the vertical segments of the academic component, as shown in the installation schedule on the next page. This is done to provide for the separate construction schedules of the Elliott School’s residential and academic components. The single segment of curtain wall for the residential component would be constructed floor-by-floor, from the second floor up.

For the eight segments of the academic component, installation would progress in a shingle fashion, working across each floor and then up the
structure— as depicted in the figure below. Following the anchoring of each segment to the building structure, the joints in the system are sealed for air and water infiltration. At this point the other trades can begin their work associated with the curtain wall; the gap between the system and the structure is fireproofed, ductwork is installed to connect the system to the return air plenum, and electrical power is distributed to the mechanical blinds and fans.

CONCLUSIONS

The construction considerations required of a dual-layered Active Wall™ increase project integration and building value, while decreasing the project schedule.

The project delivery requirements for incorporation of the proposed curtain wall system provide for increased coordination between the architecture, engineering, and construction facets of the project. By increasing the amount of project involvement of both the construction manager and façade engineer/supplier, a means of resolving design and implementation challenges is facilitated. The full potential of the design-build delivery method is not realized; however involvement and coordination via at-risk construction management is maximized.
Although there is an increased premium associated with utilizing the proposed curtain wall, the additional cost will be recouped and cost savings will ultimately be realized through the associated energy efficiency. The premium of $283,364 of the proposed system would increase the initial project budget of $48,895,837 by just 0.58 percent. The value of the proposed system—in terms of occupant comfort and energy system savings—far outweighs the additional initial cost.

The unitized Active Wall™ system allows for efficient installation through factory fabrication. The unitized system decreases the installation of the curtain wall by nearly a month compared to the original stick DGU curtain wall. Decreasing the time required for curtain installation allows for subsequent construction activities to occur at an earlier date, reducing the overall project schedule.
INVESTIGATION III: CURTAIN WALL REDESIGN
MECHANICAL AND ACOUSTICS BREADTH STUDIES
PURPOSE OF INVESTIGATION

Originally investigated in an effort to minimize the delays to the construction schedule, the curtain wall system of the Elliott School of International Affairs was also analyzed to increase occupant comfort by utilizing the emerging technology of a dual-layered glass façade. The intent of the proposed curtain wall system redesign was to improve the environment within the academic office spaces located along the building’s south façade and produce a more energy efficient structure, without sacrificing any of the original design intent.

EXISTING STICK CURTAIN WALL SYSTEM

The metal-and-glass curtain wall constructed as an element of the Elliott School of International Affairs complex building envelope consisted of double glazed standard and spandrel glass panels contained within aluminum framing components. As illustrated above, the curtain wall covers an area of nearly 9,500 square feet of the building’s south façade, with the remainder being comprised of a combination of granite panels, precast concrete panels, metal-and-glass storefronts, and standard double glazed windows.

The curtain wall system’s design utilized standard components developed and manufactured by Vistawall, an industry leader in the design and manufacturing of engineered wall systems.

The drawing on the following page illustrates how a precast panel wall system and the metal-and-glass curtain wall comprise the perimeter walls for the office spaces along the Elliott School’s southern elevation. The curtain wall spans from floor-to-ceiling within the office spaces, with upper and lower spandrel glass panels and a clear glass center panel. Fin tube radiation was installed within the framing components of the curtain wall system to prevent convection heat loss through the building envelope.
PROPOSED DUAL-LAYERED GLASS FAÇADE

Investigation of alternative curtain wall systems, specifically unitized systems, progressed from standard unitized systems similar to the installed stick-system and also manufactured by Vistawall, to the developing technology of double-skin glass curtain walls. Due to interest in the emerging technology as well as sustainable design and construction, a dual-layered glass façade was proposed and analyzed as an alternative to the existing metal-and-glass system.

The dual-layered glass façade is a European architectural phenomenon driven by the desire for an all-glass building façade without sacrificing indoor air quality while addressing the growing concern of energy conservation. Prevalent throughout Europe and Asia, dual layered glass facades are gaining popularity in the United States with the emergence of environmentally conscious design and construction—specifically that endorsed by the LEED (Leadership in Energy and Environmental Design) Green Building Rating System.

Double-skin curtain walls vary greatly in their application, size, and mechanical operation. In a typical double-skin curtain wall, an air cavity—measuring a few inches to multiple feet—is created by adding an additional layer of toughened glass behind the standard double glazed glass unit. A sun shade device, typically louvered blinds, is placed within the air cavity to control sunlight as well as heat gain. Various means of ventilating the air cavity exist, with the proposed system being mechanically ventilated. Lower pressure within the cavity draws in a portion of the room’s return air, where it is warmed by the solar radiation absorbed by the sun shades. The air is then drawn out of the cavity mechanically and returned to the building’s HVAC system. In months requiring heating, solar energy can be recovered from the system by utilizing heat exchangers.
The proposed system, illustrated below, is based upon the ‘standard’ double-skin curtain wall manufactured by Permasteelisa Cladding Technologies, Ltd. and utilized on the Levine Hall School of Engineering and Applied Sciences at the University of Pennsylvania. Permasteelisa’s tested and applied Active Wall™ system is readily available from the Italian manufacturer’s American headquarters—based in Connecticut. The relatively standardized system is designed and manufactured to meet a project’s specific architectural and mechanical requirements, and is fabricated and installed as a unitized curtain wall system.

![Proposed Curtain Wall System](image)

**FIGURE 19 Proposed Curtain Wall System**

**PERFORMANCE OF PROPOSED DUAL LAYERED GLASS FAÇADE**

**Architectural**

The aesthetic intent of the original architectural design of the Elliott School is maintained in the proposed dual-layered curtain wall. Permasteelisa manufacturer’s the proposed Active Wall™ system in conjunction with the requirements—both mechanically and architecturally—of each specific project. The relative size of the rails and mullions of the existing stick-system can be applied to an Active Wall™ system, creating a mechanically superior curtain wall which maintains the original aesthetic design.

Within the interior spaces of the structure, the redesign of the curtain wall also has a minimal impact on the original design. Because the air cavity and second layer of glass required of the dual-layered façade is added within the extent of the existing system’s framing components, the intended individual space and total building square footages were maintained.

**Mechanical**

The proposed unitized curtain wall works in conjunction with the Elliott School’s mechanical system, helping to maintain occupant comfort by using the cavity between the inner and outer glazing as a plenum through which return room
air is circulated—as illustrated below. The cavity also houses mechanical blinds. In periods with solar radiation, energy is absorbed by the blinds and removed via the ventilated air.

During periods requiring a heating load, the solar energy absorbed by the blinds and removed via ventilated air can be recovered by means of heat exchangers. However, the proposed redesign does not include the addition of heat exchangers to the Elliott School’s mechanical system for heat recovery, but instead focuses on the thermal insulating properties of the Active Wall™.

**Figure 20** Permasteelisa’s Active Wall™ System and Components (Permasteelisa Cladding Technologies, Ltd.)

Improved occupant comfort—especially at locations near the exterior wall—results from the proposed dual-layered glass façade. Manufacturer supplied thermal transmittance values of the proposed curtain wall systems show that the U-value of the exterior wall is 0.100 BTU/Hr°F, while the existing curtain wall system has a U-value of 0.625 BTU/Hr°F. Due to the increased insulating properties of the proposed system, as well as the return air circulating through wall cavity, the temperature of inner glass surface of the system is maintained within two degrees of the temperature of the room air.

The fin tube radiators installed in conjunction with the existing system work to wash the interior surface of the windows with heated air in an effort to raise the temperature of the inner surface to that of the room air. The proposed system dramatically reduces the Elliott School’s envelope load from 2968 BTU/Hr to 543 BTU/Hr—as illustrated in Appendix D, on Page 64—maintaining air and surface temperatures at the perimeter consistent with the remainder of the space, allowing for the fin tube heating units positioned along each segment of the existing curtain wall to be removed.

Eliminating the nearly one hundred fin tube radiators, also allows for the reduction in the size of the Elliott School’s gas fired boiler. The 2000 MBH
boiler can be reduced to a 1200 MBH boiler, as illustrated by the calculations in Appendix D, on Page 65.

The removal of the fin tube radiators and reduction of the gas fired boiler creates a more efficient mechanical system for the Elliott School of International Affairs. By reducing the heating requirements of the system, energy is conserved and the associated supply and operating costs are reduced.

Acoustical
The southern façade of the Elliott School of International Affairs sits along the traffic congested four outbound lanes of E Street in the heart of Northwest Washington, DC near the entrance ramp of the E Street Expressway. The E Street Expressway feeds the Woodrow Wilson Bridge and the George Washington parkway, acting as a major means of exiting the District of Columbia.

The proposed dual-layered glass façade improves upon the sound insulating properties of the existing double glazed system. Data obtained from Permasteelisa indicates an STC Rating of 40 for the proposed Active Wall™ system, while the STC Rating of the existing curtain wall measures 32. The STC, Sound Transmission Class, Rating of a construction assembly is a single number, calculated by fitting a standard contour to transmission loss data, rating the effectiveness to retard the transmission of airborne sound. A higher STC Rating corresponds to greater sound insulation.

An STC Rating of 40 is considered very high, especially for a complete curtain wall assembly. While glass alone in a standard size might provide an STC Rating of 40, when combined with framing components, its insulating effectiveness typically decreases substantially.

Although the proposed system contains a substantial air cavity, the problems of flanking—lateral sound transmission—are avoided, since the curtain wall components of each office space are horizontally and vertically independent from the others. This horizontal and vertical separation also works to avoid fire and smoke transmission between interior spaces.

Lighting
The amount of window area remains relatively unchanged from the original architectural design; therefore the levels of natural light intended for interior spaces are maintained.

The existing system utilizes motorized shades mounted in a cavity in a bulkhead constructed along the exterior walls. The shade system is replaced by the mechanically controlled louvered blinds. The blinds are fully adjustable, allowing for full shading or visibility, providing greater and more varied occupant control of the light entering each space. The blinds are unobtrusive to the external appearance of the building and require minimal maintenance.
Structural

The proposed curtain wall system is anchored to the Elliott School's structural system at each cast-in-place floor slab via site attached cleats. The existing edge beams at the structure's southern perimeter support a combination of the existing curtain wall and precast concrete panels. Although not specifically analyzed, it is assumed that the added weight of the proposed system is not significant enough to require structural support beyond that which was constructed.

CONCLUSIONS

Application of the Active Wall™ curtain wall system to the Elliott School of International Affairs construction project creates a greatly improved environment within the academic offices along the building perimeter without sacrificing any of the project's original design intent.

The U-value of the proposed system is nearly one-sixth that of the existing system. This dramatic improvement of the insulating properties of the building envelope allows for the fin tube radiation along the building perimeter to be eliminated. The removal of the fin tube radiation allows the Elliott School's gas fired boiler to be reduced in capacity, increasing the efficiency of the building’s mechanical system and providing energy savings.

The proposed Active Wall™ system also increases the acoustical insulating properties of the building envelope. The proposed Active Wall™ system has an STC Rating measured to be 40, while that of the existing system is measured to be 32. With the academic offices looking out on traffic congested E Street in Northwest DC, improving the sound insulation will minimize the distractions of exterior noise.

<table>
<thead>
<tr>
<th>PERFORMANCE CRITERIA</th>
<th>EXISTING DGU WALL</th>
<th>PROPOSED ACTIVE WALL™</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-Value (BTU/Hr°F²°F)</td>
<td>0.625</td>
<td>0.100</td>
</tr>
<tr>
<td>STC Rating</td>
<td>32</td>
<td>40</td>
</tr>
</tbody>
</table>

Improving the environment within the Elliott School does not come as a result of sacrificing the architect's original design intent for the project. The proposed curtain wall can be fabricated to appear nearly aesthetically identical to the existing DGU wall. The proposed wall is able to be constructed within the extents of the existing curtain wall frame, allowing the building and individual space square footages to be maintained. Also, the proposed curtain wall does not alter the amount of daylight provided to the spaces, but instead allows for greater individual control via mechanically louvered blinds.
ANALYSES & METHODOLOGY

The following research delves into the construction and project delivery considerations associated with buildings incorporating dual-layered glass facades. The research presented includes case studies of representative projects, in conjunction with analyses of the project delivery methods and associated relationships, construction activities, post-construction maintenance, and representative cost and schedule considerations.

The analysis and conclusions were derived from Internet, journal, and periodical research related to the emerging curtain wall technology—a complete list of references is included in Appendix E, on Page 68. The analyses focus on the representative American projects; however information and results were also drawn from numerous applications throughout Europe, Asia, and Australia.

BACKGROUND

The dual-layered glass façade is a European architectural phenomenon driven by the aesthetic desire for an all-glass building façade and the practical desire to have natural ventilation for improved indoor air quality without the acoustic and thermal constraints of single-skin façades (Bazjanac et al, 2002).

Aesthetically, there is little difference between the appearance of a building with a double-skin façade and one with a double glazed unit wall (DGU), the typical metal-and-glass curtain wall application in the United States—especially if each incorporates sun shades or blinds.

The U.S. lags Europe—and the rest of the world—in the development of advanced building systems and high-performance facades, due in part to North America’s lower energy costs. Curtain wall technology in the United States "is about 10 to 15 years behind," says Alistair Lazenby, technical director of curtain wall contractor Schmidlin A.G., Aesch, of Switzerland (Gonchar, 2003). The significantly higher energy costs of Europe allow for a faster return on the increased initial investment compared to that available in the United States.

American architects and building owners are beginning to embrace dual-layered curtain wall systems because of increasing energy costs and the emergence of sustainable design and construction—such as that promoted by the United States Green Building Council’s Leadership in Energy and Environmental Design (LEED) Green Building Rating System.

It has been estimated that a third of the world’s energy is consumed by buildings, and with gasoline prices rising and electrical blackouts plaguing California and threatening the rest of the country, conserving energy seems to be more and more of a necessity (Gewertz, 2001).

With a growing record of success, a proliferation of government incentives and grant programs, and honed marketing strategies, sustainable projects are popping up in all shapes, sizes, and building types throughout America. More and more architects, engineers, and contractors are gaining experience in and an
understanding of the field (Post, 2002). Bottom-line conscious developers and investors are being sold on sustainable buildings not through the green principles of sustainability, but through energy conservation and lifecycle savings.

**ANALYSIS**

**Representative Projects**

Dual-layered glass facades are applicable in all types of building projects, from a section of a single exterior wall of a low rise building to all four sides of a high rise structure. By nature, the system is highly customized and engineered, lending itself to various applications.

The following case studies summarize representative recent double-skin curtain wall construction projects in the United States. The varying curtain wall systems, curtain wall system and building sizes, and building uses illustrates the numerous applications of the technology.

- **Manulife Financial US Operations Headquarters**
  
  **Location:** Boston, Massachusetts  
  **Architect:** Skidmore, Owings & Merrill, LLP  
  **Façade Engineer:** Permasteelisa Cladding Technologies, Ltd.  
  **Owner:** Manulife Financial - Real Estate Division  
  **Construction Manager:** Clark/Suffolk (Joint Venture)  
  **System Delivery:** Performance specification, identifying unitized curtain wall system with stringent energy performance criteria  
  **Building Use:** Class A Office Building  
  **Curtain Wall Area:** 222,017 SF  
  **Curtain Wall Description:** Active Wall™; double-skin wall with unitized aluminum and stainless steel components covering fourteen stories; the north and south elevations provide continuous curves, while the east and west elevations run parallel to the property edge

- **Levine Hall School of Engineering and Applied Sciences**
  
  **Location:** Philadelphia, Pennsylvania  
  **Architect:** KieranTimberlake Associates LLP  
  **Façade Engineer:** Permasteelisa Cladding Technologies, Ltd.  
  **Owner:** University of Pennsylvania  
  **Construction Manager:** Keating Building Corp.  
  **System Delivery:** Proprietary specification
Building Use: Academic
Curtain Wall Area: 12,300 SF
Curtain Wall Description: Active Wall™; dual-layered curtain wall system, compromised of transparent and translucent glass, with a blind system between two panels of glass and a mechanically ventilated air space serving as the building’s insulation; covers six stories of the building’s southern façade

- Seattle Justice Center

Location: Seattle, Washington
Architect: Naramore, Bain, Brady and Johanson (NBBJ) Architects
Façade Engineer: NBBJ Architects
Owner: the city of Seattle
Construction Manager: Hoffman Construction Company
Building Use: Courthouse and police headquarters
Curtain Wall Description: buffer façade; double skin glass façade covering nine stories of the building’s west façade which protects the interior from excessive solar heat gains, while providing maximum day-lighting and uninterrupted views of Elliott Bay

Delivery Method
Contractor Involvement
- In the United States, the architect typically involves the façade engineer late in the design process, sometimes in the latter stages of design development, which is much later than projects in both Europe and Austral-Asia. For advanced façade-building systems, a team effort between architect, design engineers, and construction contractors is required to resolve design and implementation challenges. To maximize the integrated performance benefits, it is greatly beneficial for the team of design and construction personnel to work together from the project’s inception (Gonchar, 2003).
- Earlier involvement by more project team members implies a greater cost over time. An effort to minimize design costs often results in a reluctance to involve the façade engineer until late in the design project. This can be offset by appropriately limiting the scope and involvement of the additional
design personnel. The façade performance may initially be designed and
analyzed for preliminary design conditions, rather than for a full-scale
investigation of the building's performance over a typical year. The level of
analysis is dictated by the client's desire and budget, as well as the
complexity of the system and its implications on architectural and structural
design (Bazjanac et al, 2002).

Delivery Methods
- The collaborative model of complete project involvement—from the owner
to the architects and engineers to the construction contractors and
vendors—is in response to the demand for higher value at a time when
there is also a need for higher design aspirations. Design-led integrated
delivery processes, such as the design/build approach, provides high
levels of both value and design expertise.
- Performance and proprietary specifications have been used to identify
established active curtain wall systems for application on design-bid-build
projects. The detailed specifications name the supplier of the system, in
the case of the proprietary specification, or provide detailed and stringent
system performance values, as in the performance specification.

The Future
- To aid the advancement of design documents, many design/build firms are
turning to project web sites and the next generation of computer design
tools. Parametric 3-D models, that contain all of the information on a
building project in a single database, drive the collaborative effort of
design and construction even further.
- Advances in project delivery over the past decade have resulted in an
ability to tighten schedules and control budgets. However, the impact on
design and document quality has not kept pace, but experts are looking
toward the next decade as the era of improved design and document
quality (Bazjanac et al, 2002).

Engineer-Contractor Interaction
Managing Risk
- For successful implementation of design intent, it is critical for the design
team to educate the contractors and specialty subcontractors on the
components and workings of the façade system. Typically on construction
projects, the burden—as well as the risk—of engineering the façade is
placed not on the design team, but on the curtain wall vendor. This is
particularly common on projects with design-build contracts, which carry
contingency costs.

Prequalification
- For application of advanced curtain wall systems, the contractor and
manufacturer must be involved early on in the project. Curtain wall
contractors can be prequalified, allowing involvement of their expertise early on toward designing a least-cost solution that eases construction and utilizes appropriate and readily available components.

Curtain Wall Installation
Specialized Construction

- Installation of the double-skin façade is carried out by a separate, specialized façade contractor, typically a subsidiary of the façade engineer/supplier. Although a dual layered façade is integral to a building's HVAC system, the construction requires tools and methods unfamiliar to HVAC contractors.

A Unitized System

- Typically, the dual-layered glass façade is installed as a unitized curtain wall system, allowing the majority of the fabrication to take place in the controlled conditions of the manufacturer's workshop. The unitized nature of the system helps to offset some of the installation complexities of the associated intricate components and numerous connections and joints.

Curtain Wall Kit

- Constructing the designed dual-layered glass façade system can be simplified as merely putting together a kit of standard parts together in a slightly different way than normal. The actuators, throttling flaps, and power supply at the window wall may be perceived as unique, but such systems are conventionally used with mechanical systems and can be applied with the same labor in façade systems. The installation may require a period of learning; however efficiency will increase as the installers progress through the project (Bazjanac et al, 2002).

- Construction of the double-skin façade system requires a number of different components. For efficient installation, all of the necessary components must be on site and available to the installation contractor. Material lay-down and protection becomes an issue with especially large or complex systems.

Separate Structures

- The greatest problems in erection have arisen from insufficient tolerances in the systems joints. Typically, a cantilevered bracket system ties the façade into the structural system through the welding of steel cleats at intermediate floors. To allow for appropriate variation between the design and actual constructed conditions, the cleat should not be connected to the façade fabrication shop, but welded into place on site.

- On especially large projects, such as high-rise structures, façade contractors suggest strengthening the double-skin facades supporting structure to act as a horizontal support for the scaffolding necessary for installation to ease installation of the curtain wall system and minimize its
impact on other construction activities. On the majority of existing projects, the scaffolding was supported vertically from the inner envelope, meaning that at each floor one outer glass pane had to be mounted at a later time—unnecessarily exposing the inner layer and its components to the elements (Uuttu, 2001).

Weather
- Especially rough weather—such as hard wind, rain, or snow—hinders the mounting of the glass panes required of dual-layered systems. Structural glazing cannot be performed during cold and rain, this is a critical issue, because joints will be left open until weather gets warmer, allowing for the collection of dirt and water unless temporarily covered (Uuttu, 2001).

Post Construction
System Adjustment
- Increased concern of performance issues through commissioning, measurement, and verification has arisen due to the LEED program. It often takes two seasons to completely adjust and commission the curtain wall and mechanical systems properly in order to maximize energy efficiency and the associated cost savings. Full performance is accomplished with follow-up post-occupancy evaluations and adjustments (Bazjanac et al, 2002).

Maintenance
- The addition of an air cavity to the standard curtain wall system requires additional maintenance, such as the cleaning of the interior glass surfaces and blinds once a year.
- The exterior glass surface of the dual-layered façade can be cleaned in the manner typical of metal-and-glass curtain walls—from scaffolding supported from the roof of the structure.

Cost and Value
Additional Layer = Additional Cost
- Due to the addition of an added layer of glass compared to a similar DGU curtain wall, dual-layered systems have a higher cost. Estimates for dual layered systems range from an increase of a conservative 25-35% to nearly 400% depending on the complexity and intricacy of compared DGU and dual-layered systems.

Lifecycle Savings
- The initial costs can be recouped through lifecycle savings brought about through the insulating characteristics as well as heat exchange and recovery applications.
- Roberto Biachiarelli, executive vice president of Permasteelisa Cladding Technologies is quoted as stating “The (Active Wall™) system has a
medium- to long-term payback." Although not enticing to developers or speculative builders, the extended payback period does work for owner's who occupy buildings for many years—such as a university of government buildings.

Prefabrication of Components
- Because of the initial costs associated in researching and designing standardized systems, some design teams have been able to apply their efforts to dual-layered façade design and installation consistent with the prefabricated unit prices on a site-specific basis tailored to the architectural aesthetics and maximizing engineering performance.
- European curtain-wall contractors have begun to provide generic solutions to the design challenges in the form of standardized dual-layered façade systems. The preliminary units have a budgeted cost of between $120-$180/SF. A few Canadian manufacturers have picked up on the trend and have begun to advance prefabrication in North America—which has historically been dominated by the American division of Permasteelisa Cladding Technologies, Ltd. of Italy (Bazjanac et al, 2002).

RESEARCH CONCLUSIONS FOR SYSTEM APPLICATION
Applicable Projects
- Due to the extended period over which initial costs are recovered through associated energy savings and productivity due to increased occupant comfort, dual layered glass systems are best applied to buildings that will be utilized by the owner for an extended period of time. Government and university buildings lend themselves to the system since they allow the owner to recoup the additional initial costs of the system through lifecycle savings, while fully utilizing the newly constructed facilities.

Delivery Method
- A dual layered glass façade is an integral component in all aspects of a building project—its construction, its technical equipment, and the overall energy balance—therefore delivery methods that fully integrate the design and construction processes are most effective. The Design/Build approach with early façade contractor involvement best allows for complete project and systems integration.

Engineer-Contractor Interaction
- The Design/Build arrangement allows for complete interaction between applicable engineers and contractors. The design/build method works to promotes integration of architecture, engineering, and construction, maximizing the performance of the building and project as a whole. The
method also transfers burden and risk, through the contingency of the appropriate contract, to the experienced specialty contractor.

Curtain Wall Installation
- Installing the dual-layered facade as a unitized curtain wall system allows the majority of the fabrication to take place in the controlled conditions of the manufacturer’s workshop. The prefabrication of the system also helps to minimize the time required of the construction schedule.

Post-Construction Adjustment
- Contracts for the complex system should extend beyond commissioning and the standard yearlong warranty, in order to provide proper adjustment of the system over the varying heating and cooling conditions.

Maintenance
- The glass surfaces of the interior cavity and blinds must be cleaned at least once each year in order to maintain the desired performance characteristics of the system. The exterior is cleaned in the same manner and frequency as a standard, metal-and-glass curtain wall—typically from scaffolding supported from the building’s roof. Interior cleaning is allowed for by opening the inner layer of the curtain wall with a specialized key.

Cost and Value
- A dual layered glass façade requires additional design and construction costs due to the complexity of the systems and the addition of an additional layer of glass over a standard DGU curtain wall system. With few buildings in the United States utilizing the technology, engineers and contractors lack the familiarity of the systems to produce cost effective applications. The true values of a dual layered glass façade, however, are primarily associated with improved occupant comfort, through increased indoor air quality, day lighting, and acoustical performance. The added initial costs of the systems are eventually recouped through lifecycle energy savings derived from decreased heating and cooling requirements. As North American energy prices increase and industry gains familiarity with the complex system, owners will realize earlier returns on their investment through accelerated lifecycle savings and reduced initial costs.
CONCLUSIONS
This Architectural Engineering Senior Thesis examined the Elliott School of International Affairs construction project with a focus on value engineering, constructability, and schedule reduction. Each of these analysis areas were addressed and satisfied through investigations of the project’s site planning and curtain wall system, as well as a research study of the developing building technology of dual-layered glass facades.

Value engineering was examined in the curtain wall redesign and associated construction management considerations. The proposed dual-layered glass façade increases the overall quality of the building without dramatically adding to the project budget and not sacrificing any of the original design intent. The premium that is added to the project will ultimately be recouped through a long-term payback period created by the energy savings associated with the system.

The site planning investigation is also an effort in value engineering, since it decreases project costs without negatively affecting the project. The proposed site construction office location increases the efficiency and safety of the Elliott School construction process, while reducing the overall construction budget.

Constructability considerations are included in the construction management investigation of the curtain wall system redesign, as well as in the research section. Delivery method, schedule, and installation of the proposed system are all discussed.

The schedule of the Elliott School of International Affairs construction project is reduced through the installation of the proposed unitized curtain wall system. The proposed system emphasizes factory fabrication in an effort to minimize the schedule requirements of installation.

This detailed investigation resulted in cross-disciplinary suggestions for the improvement of the Elliott School of International Affairs construction project, as well as the final product, the building itself.
APPENDIX A: EXISTING PROJECT CONDITIONS

- SUMMARY SCHEDULE
- CASH FLOW CURVE DATA
- Cash Flow Curve Data
APPENDIX B

- EXISTING SITE PLAN
- PROPOSED SITE PLAN
- COST ANALYSES
• EXISTING SITE PLAN
• PROPOSED SITE PLAN
## Cost Analyses

### Table B.1 Temporary Office Estimate

<table>
<thead>
<tr>
<th>ITEM</th>
<th>QTY</th>
<th>UNIT</th>
<th>TOTAL INCL O&amp;P</th>
<th>COST INCL O&amp;P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prehung 3'x7' Exterior Steel Door</td>
<td>3</td>
<td>ea</td>
<td>305.00</td>
<td>915.00</td>
</tr>
<tr>
<td>Prehung Interior Lauan Passage Door</td>
<td>4</td>
<td>ea</td>
<td>161.80</td>
<td>647.20</td>
</tr>
<tr>
<td>Commercial Grade 40 oz Carpet</td>
<td>150</td>
<td>sy</td>
<td>34.50</td>
<td>5175.00</td>
</tr>
<tr>
<td>18 ga x 3-5/8&quot; Metal Studs (16&quot; OC)</td>
<td>2200</td>
<td>lf</td>
<td>15.60</td>
<td>34320.00</td>
</tr>
<tr>
<td>1/2&quot; Thick Drywall (Taped and Finished)</td>
<td>5418</td>
<td>sf</td>
<td>1.06</td>
<td>5743.08</td>
</tr>
<tr>
<td>Packaged AC (12,000 BTU cooling)</td>
<td>3</td>
<td>ea</td>
<td>1250.00</td>
<td>3750.00</td>
</tr>
<tr>
<td>2'x4' Surface Mounted 40W Lighting Fixture</td>
<td>19</td>
<td>ea</td>
<td>174.00</td>
<td>3306.00</td>
</tr>
<tr>
<td>Temporary Circuit Breaker (400 Amp)</td>
<td>1</td>
<td>ea</td>
<td>2325.00</td>
<td>2325.00</td>
</tr>
<tr>
<td>2-Way Wall Switch (Type MC Cable)</td>
<td>8</td>
<td>ea</td>
<td>100.00</td>
<td>800.00</td>
</tr>
<tr>
<td>Duplex Receptacle (Type MC Cable)</td>
<td>29</td>
<td>ea</td>
<td>49.00</td>
<td>1421.00</td>
</tr>
<tr>
<td>Electrical Wiring (MC Cable)</td>
<td>3</td>
<td>clf</td>
<td>216.00</td>
<td>648.00</td>
</tr>
<tr>
<td>Floor Mounted Water Closet</td>
<td>1</td>
<td>ea</td>
<td>276.00</td>
<td>276.00</td>
</tr>
<tr>
<td>Wall Mounted Service Sink</td>
<td>1</td>
<td>ea</td>
<td>670.00</td>
<td>670.00</td>
</tr>
<tr>
<td>Sewage Ejector</td>
<td>1</td>
<td>ea</td>
<td>1325.00</td>
<td>1325.00</td>
</tr>
<tr>
<td>Plumbing Piping &amp; Fittings</td>
<td>150</td>
<td>lf</td>
<td>8.70</td>
<td>1305.00</td>
</tr>
<tr>
<td>PVC Piping &amp; Fittings</td>
<td>75</td>
<td>lf</td>
<td>17.80</td>
<td>1335.00</td>
</tr>
<tr>
<td>Miscellaneous 2&quot;x4&quot; Lumber</td>
<td>0.2</td>
<td>mbf</td>
<td>592.00</td>
<td>118.40</td>
</tr>
<tr>
<td>Miscellaneous Plywood</td>
<td>10</td>
<td>sheet</td>
<td>8.75</td>
<td>87.50</td>
</tr>
<tr>
<td><strong>SUM</strong></td>
<td></td>
<td></td>
<td>64,167.18</td>
<td></td>
</tr>
<tr>
<td><strong>LOCATION FACTOR</strong></td>
<td></td>
<td></td>
<td>0.957</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>$61,407.99</td>
<td></td>
</tr>
</tbody>
</table>

- Cost information from the 2000 RS Means Building Construction Cost Data

### Table B.2 Proposed Office Trailer Estimate

<table>
<thead>
<tr>
<th>ITEM</th>
<th>QTY</th>
<th>UNIT</th>
<th>UNIT COST</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>10'x32' Mobile Office Trailer</td>
<td>9</td>
<td>mo</td>
<td>417.50</td>
<td>3757.50</td>
</tr>
<tr>
<td>10'x44' Mobile Office Trailer</td>
<td>17.5</td>
<td>mo</td>
<td>437.50</td>
<td>7656.25</td>
</tr>
<tr>
<td>Site Delivery</td>
<td>2</td>
<td>ea</td>
<td>450.00</td>
<td>900.00</td>
</tr>
<tr>
<td>Block and Level</td>
<td>1</td>
<td>ea</td>
<td>1995.00</td>
<td>1995.00</td>
</tr>
<tr>
<td>Tie Down</td>
<td>12</td>
<td>ea</td>
<td>45.00</td>
<td>540.00</td>
</tr>
<tr>
<td>Return Delivery</td>
<td>2</td>
<td>ea</td>
<td>450.00</td>
<td>900.00</td>
</tr>
<tr>
<td>Dismantling</td>
<td>1</td>
<td>ea</td>
<td>1650.00</td>
<td>1650.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>$17,398.75</strong></td>
<td></td>
</tr>
</tbody>
</table>

- All cost information provided by GE Capital Modular Space--Baltimore, MD
APPENDIX C: CURTAIN WALL REDESIGN - CONSTRUCTION MANAGEMENT DEPTH

• COST ANALYSES
## COST ANALYSES

### Table C.1 Curtain Wall Square Foot Costs

<table>
<thead>
<tr>
<th>CURTAIN WALL SYSTEM</th>
<th>COST ($/SF)</th>
<th>CURTAIN WALL AREA (SF)</th>
<th>TOTAL SYSTEM COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing DGU Wall</td>
<td>$105</td>
<td>9480</td>
<td>$995,400</td>
</tr>
<tr>
<td>Proposed Dual-Layered Glass Façade</td>
<td>$145</td>
<td>9480</td>
<td>$1,374,600</td>
</tr>
</tbody>
</table>

- SF cost for the existing DGU curtain wall provided by Ridgeview Glass Co.
- SF cost for the proposed curtain wall provided by Permasteelisa Cladding Technologies, Ltd.
APPENDIX D: CURTAIN WALL REDESIGN - MECHANICAL BREADTH

- ENVELOPE LOADS
- BOILER REDUCTION
- COST SAVINGS
CURTAIN WALL SYSTEM ENVELOPE LOADS

TABLE D.1  Precast Panel Wall

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>R-VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside Surface</td>
<td>0.69</td>
</tr>
<tr>
<td>0.625&quot; Gypsum Board</td>
<td>0.56</td>
</tr>
<tr>
<td>2.5&quot; Metal Studs</td>
<td>0.91</td>
</tr>
<tr>
<td>2.5&quot; Rigid Insulation</td>
<td>8.01</td>
</tr>
<tr>
<td>0.5&quot; Air Space</td>
<td>0.91</td>
</tr>
<tr>
<td>6&quot; Precast Panel</td>
<td>2.02</td>
</tr>
<tr>
<td>Outside Surface</td>
<td>0.33</td>
</tr>
<tr>
<td>Total</td>
<td>13.43</td>
</tr>
</tbody>
</table>

TABLE D.2  Existing Wall System Envelope Load — Heating

<table>
<thead>
<tr>
<th>EXISTING CURTAIN WALL</th>
<th>U-VALUE</th>
<th>WALL AREA (FT²)</th>
<th>°T</th>
<th>Q (BTU/HR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precast Panel Wall System</td>
<td>0.07</td>
<td>21</td>
<td>55</td>
<td>80.85</td>
</tr>
<tr>
<td>DGU Curtain Wall</td>
<td>0.625</td>
<td>84</td>
<td>55</td>
<td>2887.5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>2968.35</td>
</tr>
</tbody>
</table>

TABLE D.3  Proposed Wall System Envelope Load — Heating

<table>
<thead>
<tr>
<th>PROPOSED CURTAIN WALL</th>
<th>U-VALUE</th>
<th>WALL AREA (FT²)</th>
<th>°T</th>
<th>Q (BTU/HR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precast Panel Wall System</td>
<td>0.07</td>
<td>21</td>
<td>55</td>
<td>80.85</td>
</tr>
<tr>
<td>Dual-Layered Curtain Wall</td>
<td>0.10</td>
<td>84</td>
<td>55</td>
<td>462</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>542.85</td>
</tr>
</tbody>
</table>

- Design temperature and R-value data taken from the 2001 ASHRAE Handbook of Fundamentals, I-P Edition
- Active Wall™ U-Value provided by Permasteelisa Cladding Technologies
- DGU Curtain Wall U-Value provided by Ridgeview Glass
**BOILER REDUCTION CALCULATIONS**

Fin Tube Radiator Specifications
- 2070 BTU/Hr/Ft
- 7.48 GPM
- 3.5’ Length

Gas Fired Boiler Specifications
- 2000 MBH Input
- 86% Combustion Efficiency

\[
2070\ \text{BTU/Hr/Ft} \times 3.5' = 7245\ \text{BTU/Hr} = 7.245\ \text{MBH/Radiator}
\]

\[
7.245\ \text{MBH/Radiator} \times 98\ \text{Radiators} = 724.5\ \text{MBH Reduction}
\]

\[
2000\ \text{MBH} \times 86\% = 1720\ \text{MBH Maximum Output}
\]

\[
1720\ \text{MBH} - 724.5\ \text{MBH} = 995.5\ \text{MBH}
\]

\[
995.5\ \text{MBH} / 86\% = 1157.6\ \text{MBH} \rightarrow 1200\ \text{MBH Boiler}
\]

Associated Cost Savings
- 1999 RS Means Building Construction Cost Data
- 1960 MBH Gas Fired Boiler: $26,700
- 1200 MBH Gas Fired Boiler: $18,100
- Washington, DC City Cost Index (Mechanical): 95.9
- 2000 Historical Cost Index: 119.6
- 1999 Historical Cost Index: 117.6

\[
$26,700 - $18,100 = $8600
\]

\[
$8600 \times .959 \times 119.6/117.6 = $8387.66\ \text{Total Adjusted Savings}
\]
### TABLE D.4 Mechanical System Savings

<table>
<thead>
<tr>
<th>ITEM</th>
<th>QTY</th>
<th>UNIT</th>
<th>TOTAL INCL O &amp; P</th>
<th>COST INCL O &amp; P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fin Tube, 2-3/4&quot; copper tube, 4-1/4&quot; alum. fin</td>
<td>343</td>
<td>lf</td>
<td>82.08</td>
<td>$28,153.44</td>
</tr>
<tr>
<td>Copper Piping, 3/4&quot;</td>
<td>900</td>
<td>lf</td>
<td>7.2</td>
<td>$6,480.00</td>
</tr>
<tr>
<td>Steel Shade Supports</td>
<td>785</td>
<td>lf</td>
<td>42</td>
<td>$32,970.00</td>
</tr>
<tr>
<td>Mechanically Operated Sun Shades</td>
<td>3780</td>
<td>sf</td>
<td>5.25</td>
<td>$19,845.00</td>
</tr>
<tr>
<td>Boiler Reduction</td>
<td></td>
<td>-</td>
<td>-</td>
<td>$8,387.66</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$95,836.10</strong></td>
</tr>
</tbody>
</table>

- Fin tube and copper piping costs were taken from 2000 RS Means Mechanical Cost Data
- Pricing for the steel shades supports provided by the project steel contractor, Baltimore Steel Erectors
- Pricing for the mechanically operated sun shades were provided by the project shade contractor, Sun Coast
- Pricing for the boiler reduction was calculated on the previous page
APPENDIX E: RESEARCH

- RESEARCH REFERENCES
RESEARCH REFERENCES


Nippon Sheet Glass Co. “RWE Tower—a Glass Giant Coming into Existence in the City Center of Essen.” Space Modulator, No. 86. 1999.


