[ARENA STAGE] Washington, DC

JONI ANDERSON
Construction Management
AE Senior Thesis Presentation : Spring 2009
The Pennsylvania State University

[PRESENTATION OUTLINE]

- Project Overview
- Introduction to Analyses
- Analysis I: Redesign of the Curtain Wall System
- Analysis III: Redesign of the Fichandler Stage Air Distribution System
- Conclusions
- Question & Answer

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[PROJECT OVERVIEW]

- Owner:
  Washington Drama Society (Arena Stage)
- Occupancy Type:
  Performing Arts Center
- Size:
  200,000 SF
- Cost:
  $125 million
- Construction Dates:
  January 2008 – June 2010

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[PROJECT LOCATION]

The Washington
National Mall

Arena Stage
1101 6th Street SW
Washington, DC 20024

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[ARENA STAGE & THE AWI]

Arena Stage

- Not-for-profit
- Largest producing theater in North America (American plays)
- First regional theater to:
  - Transfer production to Broadway
  - Receive Tony Award
- District of Columbia Inventory of Historic Sites

Anacostia Waterfront Initiative (AWI)

- Make Southwest DC a more alluring section of the city and join the ranks as a leading attraction
- City's #1 economic priority
- Hope to have a contagious effect on other markets

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Restore • Connect • Play • Celebrate • Live

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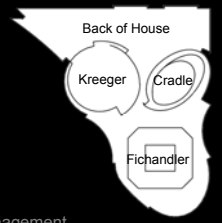
[PROJECT SCOPE]

Renovation
- Fichandler Theater (c. 1960)
- Kreeger Theater (c. 1971)

Expansion
- Cradle Theatre
- Back of House
- Parking Garage
  (1 story below grade)
- Lobby space



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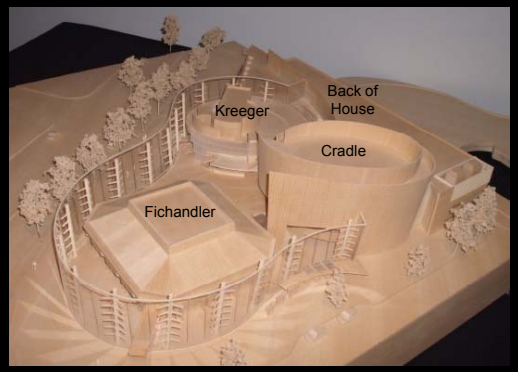

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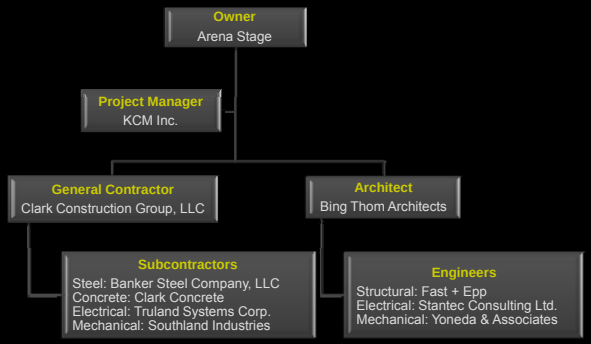
[PROJECT TEAM]



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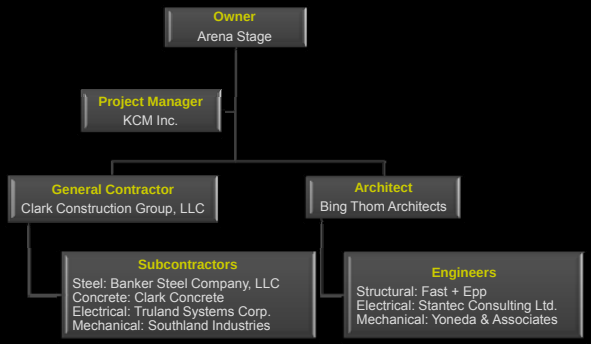

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[PROJECT PRIORITIES]

"The Next Stage Campaign"

*Cost
- •Funded by Donations

*Schedule
- •Grand Opening : 2010-2011 season

*Quality
- •High-end, sophisticated new building

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[ANALYSES INTRODUCTION]

Analysis I: Redesign of the Curtain Wall System
- Detailed design
- High cost
- Grueling coordination

Analysis II: Application of Photovoltaic Panels
- Critical Industry Issue
- Improve life-cycle cost
- Renewable energy

Analysis III: Redesign of the Fichandler Stage Air Distribution System
- Limited space
- Excess sheet metal duct
- High-throw air delivery

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[ANALYSIS I]

Redesign of the Curtain Wall System:

Elimination of the 4 Degree Slope

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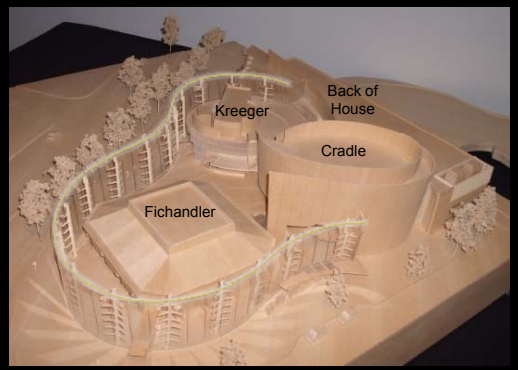

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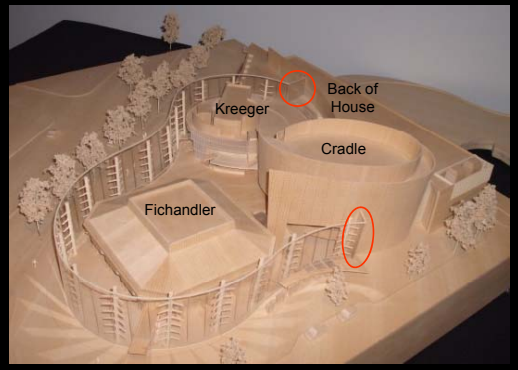
[ANALYSIS I: Curtain Wall]

- Architectural and structural component
- Encloses the lobby
- Terminal Points:
  - Cradle Theater
  - Kreeger café
- 45'-tall
- Serpentine path
  - Multiple radii
- 4 degree inclined slope



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[ANALYSIS I: Discussion]

Problem

The 4 degree slope of the curtain wall causes the glazing units to increase in size as the slope progresses, producing a combination of rectangular and trapezoidal pieces. The size and shape of the glazing units are extremely inconsistent, making the system very expensive and difficult to coordinate.

Objective

Slightly adjust the architecture of the curtain wall by eliminating the 4 degree slope. The façade will then be vertically plumb along the serpentine path, and more uniform glazing unit sizes can be used along each face.

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[ANALYSIS I: Support]

Support

- (18) Parallel strand lumber columns
  - 30” diameter
  - 36’ o.c.
- Cast ductile-iron bases
  - Exaggerated pin
- Wood support arms
- Wood muntins
- Aluminum plates
- Stainless steel cables
  - Support dead load of glass

StructureCraft

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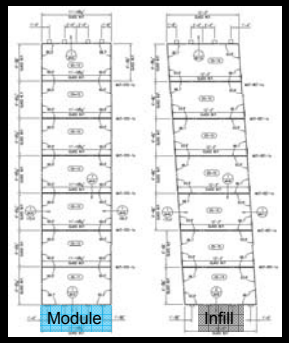
[ANALYSIS I: Glazing]

Glazing

- 1 1/8"-thick insulated vision glass
- 55 faces
  - 36 modules
    - Rectangular
  - 19 infills
    - Trapezoidal
- Typically 7 units high
- 365 units
- 850 lbs per unit



[ANALYSIS I: Glazing Take-Off Summary]

59.5% repeating unit sizes	40.5% exclusively sized units
365 total glazing units	
65.5% rectangular units	34.5% trapezoidal units

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[ANALYSIS I: Take-Off]

Elevation Matrix

- Excel
- Dimensioned all 365 Units
  - Heights (Left & Right)
  - Widths (Top & Bottom)
- Each column supports 4 faces
  - (2) module faces
  - (2) infill faces
- Portals = entryways into the building

Example

- Infill 6, Module 3, and Infill 5

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[ANALYSIS I: Matrix Example]

Infill 6	Module 3	Module 3	Infill 5
12'-5 3/32"	11'-0"	11'-0"	12'-4 27/32"
6'-4 1/4" 6'-4 1/4"	6'-4 1/4" 6'-5"	6'-5" 6'-4 1/4"	6'-4 1/4" 6'-4 1/4"
12'-2 7/16"	11'-0"	11'-0"	12'-2 27/32"
12'-2 7/16"	11'-0"	11'-0"	12'-2 27/32"
6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"
11'-11 13/16"	11'-0"	11'-0"	12'-0 13/16"
11'-11 13/16"	11'-0"	11'-0"	12'-0 13/16"
6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"
11'-9 3/16"	11'-0"	11'-0"	11'-10 13/16"
11'-9 3/16"	11'-0"	11'-0"	11'-10 13/16"
6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"
11'-6 9/16"	11'-0"	11'-0"	11'-8 13/16"
11'-6 9/16"	11'-0"	11'-0"	11'-8 13/16"
6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"
11'-3 29/32"	11'-0"	11'-0"	11'-6 25/32"
11'-3 29/32"	11'-0"	11'-0"	11'-6 25/32"
4'-5 1/16" 4'-5 1/16"	6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"	6'-4 3/8" 6'-4 3/8"
11'-2 3/32"	11'-0"	11'-0"	11'-4 25/32"
Portal	11'-0"	11'-0"	11'-4 25/32"
	6'-5 1/8" 6'-4 3/8"	6'-4 3/8" 6'-5 1/8"	6'-5 1/8" 6'-5 1/8"
	11'-0"	11'-0"	11'-2 3/4"

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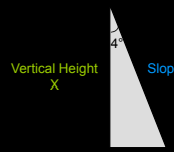
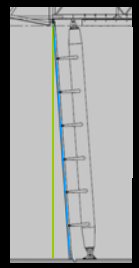
[ANALYSIS I: Redesign]

Vertical Face Heights

- By eliminating the 4 degree slope, the glass faces become too high from floor to ceiling
- Adjusted all faces for their vertically plumb height





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[ANALYSIS I: Redesign]

Adjustment of Unit Heights

- Found most reoccurring height value : 6'-4 3/8"
- Applied it to as many units as possible
- Last unit became custom sized to fit the layout

Adjustment of Unit Widths

- Standard size of modules maintained
- Infills had most inconsistent width dimensions
- Base dimensions added together and averaged
  - Between faces obstructed by portals
  - Created repeating unit sizes
- This method prevented having to redesign the portals

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[ANALYSIS I: New Matrix Example]

Infill 6	Module 3	Module 3	Infill 5
11'-2 3/32" 6'-4 3/8" 6'-4 3/8" 11'-2 3/32"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-9 3/8" 6'-4 3/8" 6'-4 3/8" 11'-9 3/8"
11'-2 3/32" 6'-4 3/8" 6'-4 3/8" 11'-2 3/32"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-9 3/8" 6'-4 3/8" 6'-4 3/8" 11'-9 3/8"
11'-2 3/32" 6'-4 3/8" 6'-4 3/8" 11'-2 3/32"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-9 3/8" 6'-4 3/8" 6'-4 3/8" 11'-9 3/8"
11'-2 3/32" 6'-4 3/8" 6'-4 3/8" 11'-2 3/32"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-9 3/8" 6'-4 3/8" 6'-4 3/8" 11'-9 3/8"
11'-2 3/32" 6'-4 3/8" 6'-4 3/8" 11'-2 3/32"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-9 3/8" 6'-4 3/8" 6'-4 3/8" 11'-9 3/8"
11'-2 3/32" 4'-3 7/8" 4'-3 7/8" 11'-2 3/32"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-0" 6'-4 3/8" 6'-4 3/8" 11'-0"	11'-9 3/8" 6'-4 3/8" 6'-4 3/8" 11'-9 3/8"
Portal	11'-0" 6'-3 3/4" 6'-3 3/4" 11'-0"	11'-0" 6'-3 3/4" 6'-3 3/4" 11'-0"	11'-9 3/8" 6'-3 3/4" 6'-3 3/4" 11'-9 3/8"

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[ANALYSIS I: Results]

Analyzed support and glazing separately.

Considered Impact on:

- Engineering Design
- Detailing (connections)
- Material
- Shop Fabrication
- Site

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[ANALYSIS I: Results]

Support

Cost

Component	Percentage of Overall Cost	Cost
Engineering Design	10%	$390,000
Detailing	10%	$390,000
Material	30%	$1,170,000
Shop Fabrication	25%	$975,000
Site	25%	$975,000
Total		**$3,900,000**

[ANALYSIS I: Results]

Support

Expected Savings

Component	Percentage of Overall Cost	Expected Decrease	Expected Savings	Adjusted Cost
Engineering Design	10%	5% of 10%	$19,500	$370,500
Detailing	10%	3% of 10%	$11,700	$378,300
Material	30%	2% of 30%	$23,400	$1,146,600
Shop Fabrication	25%	0% of 25%	$0	$975,000
Site	25%	0% of 25%	$0	$975,000
Total			**$54,600**	**$3,845,400**

Only 1.4% of cost.

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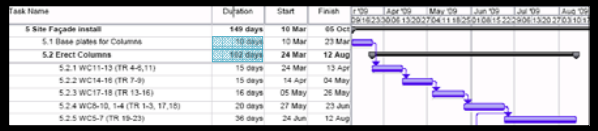
[ANALYSIS I: Results]

Support

Installation



Task Name	Duration	Start	Finish
5 Site Façade install	149 days	10 Mar	05 Oct
5.1 Base plates for Columns	10 days	10 Mar	23 Mar
5.2 Erect Columns	102 days	24 Mar	12 Aug
5.2.1 WC11-13 (TR 4-6,11)	15 days	24 Mar	13 Apr
5.2.2 WC14-16 (TR 7-9)	15 days	14 Apr	04 May
5.2.3 WC17-18 (TR 13-16)	16 days	05 May	26 May
5.2.4 WC6-10, 1-4 (TR 1-3, 17,18)	20 days	27 May	23 Jun
5.2.5 WC5-7 (TR 19-23)	36 days	24 Jun	12 Aug

No change. Will still require 112 days to install.

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[ANALYSIS I: Results]

Glazing

Cost

Component	Percentage of Overall Cost	Cost
Engineering Design	10%	$350,000
Detailing	10%	$350,000
Material	30%	$1,050,000
Shop Fabrication	25%	$875,000
Site	25%	$875,000
Total		**$3,500,000**

[ANALYSIS I: Results]

Glazing

Expected Savings

Component	Percentage of Overall Cost	Expected Decrease	Expected Savings	Adjusted Cost
Engineering Design	10%	45% of 10%	$157,500	$192,500
Detailing	10%	30% of 10%	$105,000	$245,000
Material	30%	10% of 30%	$105,000	$945,000
Shop Fabrication	25%	57% of 25%	$498,750	$376,250
Site	25%	29% of 25%	$253,750	$621,250
Total			**$1,120,000**	**$2,380,000**

32% cost reduction.

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[ANALYSIS I: Results]

Glazing

Installation

- Sequences (19 total)
  - (1) infill and (2) adjacent modules
  - Approximately (21) units each
- 2 main activities
  - Construction of support and framing (3 days each)
    - 57 days total
  - Placement of glazing (4 days each)
    - 76 days total
- Total Schedule: 133 days

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[ANALYSIS I: Results]

Glazing

Installation Comparison

	Original Design	Proposed Design
Framing/Support (1 Sequence)	3 days	1.5 days
Glazing Erection (1 Sequence)	4 days	2 days
Total (19 Sequences)	**133 days**	**66.5 days**

50% reduction in installation time.

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[ANALYSIS I: Constructability]

Constructability Discussion

- Long lead time item
  Damaged units difficult to replace
- Coordination nightmare
  365 units
  No interchangeable locations
- Setting on a 4 degree slope
  Multiple radii

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  Damaged units difficult to replace
- Coordination nightmare
  365 units
  No interchangeable locations
- Setting on a 4 degree slope
  Multiple radii

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[ANALYSIS I: Architecture]

Architectural Discussion

- Prominent feature
- Owner reluctant to change
  Fear it will compromise quality
- Congruence with the Cradle Theater
  4 degree slope

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[ANALYSIS I: Recommendation]

Decision must be made by Arena Stage.

- Change in architectural appearance
- Coordination and installation greatly simplified
- Installation
  Saved 66.5 days (27% of total schedule)
  50% reduction in installation of glazing
- Cost
  $1,174,600 saved (16% of total cost)
  32% reduction in cost of glazing

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[ANALYSIS III]

Redesign of the Fichandler Stage Air Distribution System

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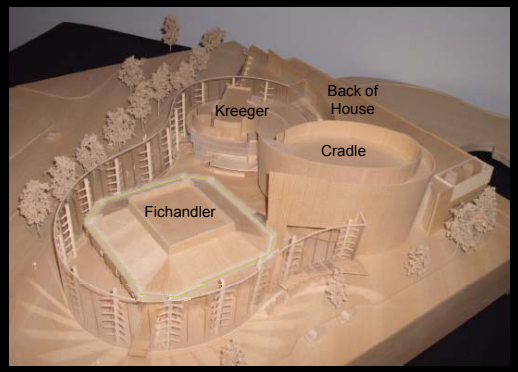

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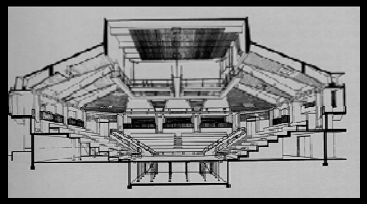
[ANALYSIS III: The Fichandler]

The "Fich"

- Originally built in 1960
- Architect Harry Weese
- Most well known icon of Arena Stage
- Theater-in-the-round (surrounded by audience on all four sides)



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[ANALYSIS III: Current Design]

(1) Air Handling Unit – Supply Air Flow: 10,500 cfm

Sheet Metal Duct – 618 LF
- Ring duct plenum
- (8) Branch ducts above wood ceiling
- (16) Open diffusers with hinged air deflectors

Duct Size	Length (LF)
16x16	55
20x20	140
20x26	75
20x40	245
38x11	55
45° Angles	(16) 3
Total Run of Duct (LF)	**618**

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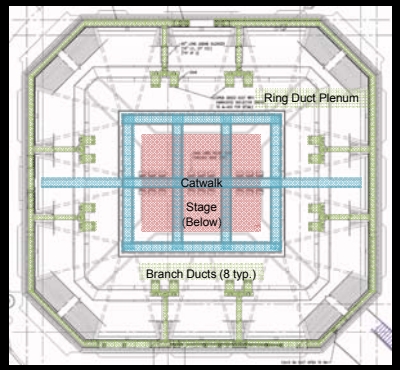

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[ANALYSIS III: Current Design]

Installation

Man Hours	Week(s)	Crew Size (men)
532	3	4

Cost

	Unit	Multiplier	Expanded
Material	$28/LF	618 LF	$17,304
Labor	$57.68/hr (budgeted labor rate)	532 hrs	$30,686
Total Cost (to engineer, furnish, and install)			**$47,990**

[PRESENTATION OUTLINE]

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Joni Anderson

[ANALYSIS III: Discussion]

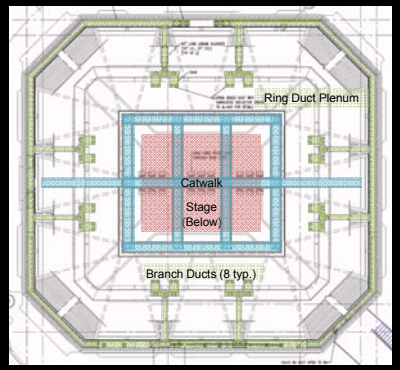
Problem

The ring duct plenum and the branch ducts are difficult to install due to the limited amount of space in the Fichandler. This design also requires a lot of sheet metal, which is expensive and, when supplying air at a high-throw, has the potential to be noisy.

Objective

To redesign the current mechanical system of the Fichandler stage using fabric duct suspended beneath the catwalk. This will provide closer air distribution, ease installation, reduce installation time, and reduce the overall cost of the system.

Construction Management



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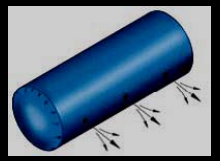
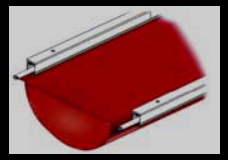
[ANALYSIS III: Redesign]

STEP 1: Series/Shape

- 2 Possible Shapes
  - Cylindrical
    - High open ceilings
    - Few obstructions
  - Surface Mount (D-Shape)
    - Flush mount
    - Ceilings lower than 14 feet





DUCTSOX DESIGN STEPS

STEP 1: Series/Shape
STEP 2: Design Layout
STEP 3: Fabric
STEP 4: Air Dispersion
STEP 5: Suspension

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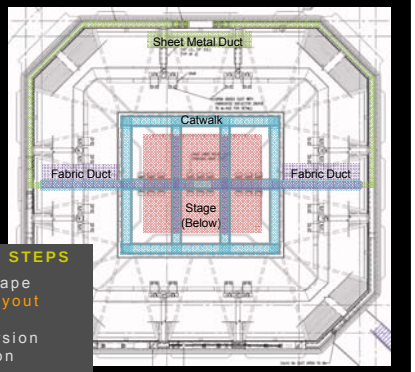
[ANALYSIS III: Redesign]

STEP 2: Design Layout

- Half of ring duct plenum to remain along beam shelf
- Terminate at catwalk bridge
- Size: 20x40
- Each branch: 5,250 cfm

Duct Size	Length (LF)
20x40	170
45° Angles	(4) 3
Rectangular to Round Duct Transition	(2) 2
Total Run of Sheet Metal Duct (LF)	**186**

Construction Management



DUCTSOX DESIGN STEPS

STEP 1: Series/Shape
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Joni Anderson

[ANALYSIS III: Redesign]

STEP 2: Design Layout

- Diameter: 30”
- Low inlet velocity: 1,070 fpm (< 1,200 fpm)

Diameter	Inlet Velocity			
	1,000	1,200	1,400	1,600
8	349	419	489	559
10	545	654	764	873
12	785	942	1,100	1,257
14	1,069	1,283	1,497	1,710
16	1,396	1,676	1,955	2,234
18	1,767	2,121	2,474	2,827
20	2,182	2,618	3,054	3,491
22	2,640	3,168	3,696	4,224
24	3,142	3,770	4,398	5,027
26	3,687	4,424	5,162	5,899
28	4,276	5,131	5,986	6,842
30	4,909	5,890	6,872	7,854
32	5,585	6,702	7,819	8,936
34	6,305	7,566	8,827	10,088
36	7,069	8,482	9,896	11,310

CYLINDRICAL SERIES

Diameter based on airflow and inlet conditions. Lower inlet velocities (1,000-1,200 FPM) reduce stress, noise and yield a better balanced system.

1,600 FPM Maximum: Straight Run
1,400 FPM Maximum: Inlet with Fittings

If the required diameter is too large for the space - consider breaking the system down into multiple runs.

Construction Management

DUCTSOX DESIGN STEPS

STEP 1: Series/Shape
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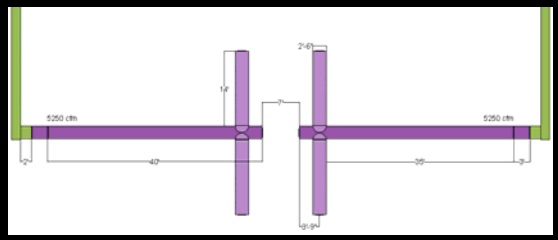
[ANALYSIS III: Redesign]

STEP 2: Design Layout

•Total length of fabric duct: 142’

Inlet Duct: (2) 20x40 @ 5250 cfm each	
Rectangular to Round Duct Transition: (2) 2’	
Fabric Duct Dimensions	
Diameter	2’-6” (30”)
Elevation Transition	(2) 3’
Long Run	(2) 40’ (7’ gap between)
Short Run	(4) 14’
Total Length	**142’**

Construction Management



DUCTSOX DESIGN STEPS

STEP 1: Series/Shape
STEP 2: Design Layout
STEP 3: Fabric
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[ANALYSIS III: Redesign]

STEP 3: Fabric

•DuctSox System Recommendation

Application	Fabric Options	Model Options	Suspension and Attachment Options
Auditorium, Sports Arena, Convention Center, Church	Verona	CF	Galvanized Cable and Nylon Snap Clips
	TufTex or DuraTex Sedona-Xm	CF or HT	

CF = comfort-flow
HT = high-throw

Construction Management

•Chose Verona fabric
- •Polyester
- •All-purpose
- •Air-permeable
- •Fire retardant
- •Commercial-quality

Color: Black

DUCTSOX DESIGN STEPS

STEP 1: Series/Shape
STEP 2: Design Layout
STEP 3: Fabric
STEP 4: Air Dispersion
STEP 5: Suspension

Match rigging, catwalk, acoustical reflectors, and lighting fixtures

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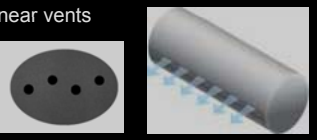
[ANALYSIS III: Redesign]

STEP 4: Air Distribution

- Verona only offers Comfort-Flow
- Air delivered through linear vents

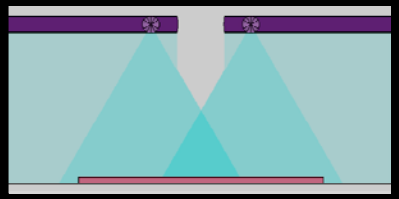
L-VENTS

L-Vents (standard) are developed for a quiet and even more low maintenance vent option. The hole patterns grow larger as vent size increases.



- Vents located at 5&7 o'clock orientations
- Stage dimensions: 35'-6" x 29'-6"

Construction Management



DUCTSOX DESIGN STEPS

STEP 1: Series/Shape
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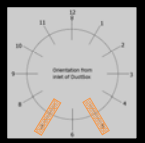

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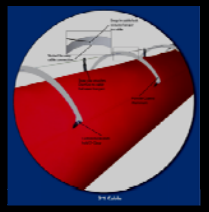
[ANALYSIS III: Redesign]

STEP 5: Suspension

- 3x1 hanger suspension system
  - Best aesthetics
  - Smooth inflation (no "pop")
  - Easy installation



Construction Management

DUCTSOX DESIGN STEPS

STEP 1: Series/Shape
STEP 2: Design Layout
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[ANALYSIS III: Redesign]

Benefits of DuctSox

- Superior air dispersion
- Easy installation
- Balancing
- Lightweight (142 lf = 71 lbs)
- Shipping
- Flexible
- Quiet air delivery
- Air porous fabric
- Hygienic
- Launderable

Construction Management

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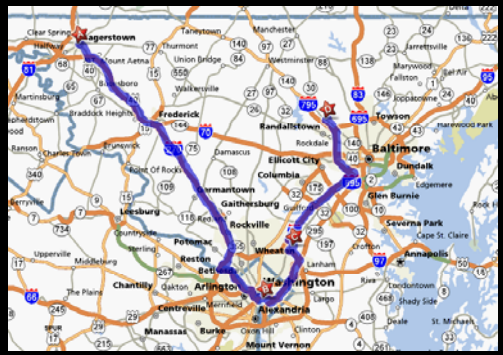
[ANALYSIS III: Companies]

Material Provider / Installer

•3 companies within close proximity to Arena Stage

Label	Company	City	State	Distance from Arena Stage
A	Ward Boland	Hagerstown	MD	74 miles
B	Arena Stage	Washington	DC	–
C	C.G. Wood Company	Beltsville	MD	19 miles
D	Ward Boland	Owings Mills	MD	52 miles

Construction Management



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Joni Anderson

[ANALYSIS III: New Design]

Sheet Metal

Installation

Man Hours	Week(s)	Crew Size (men)
160	1	4

Cost

	Unit	Multiplier	Expanded
Material	$28/LF	186 LF	$5,210
Labor	$57.68/hr (budgeted labor rate)	160 hrs	$9,230
Total Cost (to engineer, furnish, and install)			**$14,440**

Construction Management

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[ANALYSIS III: New Design]

Sheet Metal

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Total Cost (to engineer, furnish, and install)			**$14,440**

Construction Management

[ANALYSIS III: New Design]

Fabric Duct

Installation

Man Hours	Day(s)	Crew Size (men)
12.5	1	2

Cost

	Item		Cost
Material	Duct and Fittings		$6,095
	Knee Braces and Bar Joist Angle Irons		$250
	Freight		$175
	Unit	**Multiplier**	
Labor	$72.50/hr (budgeted labor rate)	12.5 hrs	$907
Total Cost (to engineer, furnish, and install)			**$7,427**

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[ANALYSIS III: New Design]

Combined

Installation

	Man Hours	Week(s)	Crew Size (men)
Sheet Metal	160	1	4
DuctSox	12.5	0.2	2

Cost

	Material	Labor
Sheet Metal	$5,210	$9,230
DuctSox	$6,520	$907
Combined	$11,730	$10,137
Total Cost (to engineer, furnish, and install)		**$21,867**

Construction Management

[ANALYSIS III: Comparison]

Original Sheet Metal Design				New Design with DuctSox			
	Duration		Cost		Duration		Cost
Man Hours	Week(s)	Crew Size (men)	Total	Man Hours	Week(s)	Crew Sizes (men)	Total
532	**3**	**4**	**$47,990**	**172.5**	**1**	**4 2**	**$21,867**

54% cost reduction.

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[ANALYSIS III: Recommendation]

Absolutely! All objectives were fully achieved.

- Closer air distribution
- Easier installation
- Installation
  1 week (67% reduction)
- Cost
  $21,867 (54% savings)

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[CONCLUSIONS]

Analysis I: Redesign of the Curtain Wall System
- •Glazing
  - •Saved $1,120,000 (32%)
  - •Saved 66.5 days (50%)

Analysis II: Application of Photovoltaic Panels
- •6 kW BIPV Array (Parking lighting)
- •Material Cost: $40,409
- •51 year payback period
- •$15,000 rebate incentive (32 year payback)

Analysis III: Redesign of the Fichandler Stage Air Distribution System
- •Saved $26,123 (54%)
- •Saved 10 days (67%)

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[ACKNOWLEDGEMENTS]

Penn State Faculty:
Dr. John Messner
Dr. David Riley
Dr. Chimay Anumba

ISEC Inc:
Michael Vergari
Matthew Moore

Clark Construction Group, LLC:
Anna Samaha
Mary Thomas
Matt Galbraith

Arena Stage:
Angie Moy

Bing Thom Architects:
James Brown
Derek Kaplan
Rosalynn Chung

Southland Industries:
Jessica Baker
Shawn Cingle

StructureCraft Builders Inc:
Brian Woudstra

My Family & Scott

My Penn State AE Friends

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Construction Management

[Questions?]

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[ANALYSIS II: PV Panels]

Information

- Sun path study
- Shadow analysis
- Parking garage lighting load = 6kW
- BIPV – Uni-Solar 144 Watt Solar Laminate Module (PVL-144)
  - Roof: Hot asphalt and TPO sheet membrane
- Inverter – Fronius IG Plus 6.0-1

EDSGN 498A

- Array to Inverter Matching Program
- 5 strings, 9 modules in series
- 45 modules total (23.25 ft^2)
- 93% Inverter max output

[ANALYSIS II: PV Panels]

Cost

- Modules
  - $800 per module (Advanced Green Technologies Rep)
  - $36,000 total
- Inverter
  - $4,409 (Online quote)
- PV Watts
  - Electricity cost = $0.08/kWh (*no inflation)
  - 51 year payback period
- Incentives (DDOE REIP)
  - Eligible for $15,000 rebate
  - 32 year payback period
  - *No tax

*Not taken into consideration