

The Performing Arts Center

&

3D Printing in Commercial Construction

Eric Luttmann



The Performing Arts Center

3D Printing Architecture to Scale

Building Purpose

University

CIP Wall Schedule Acceleration

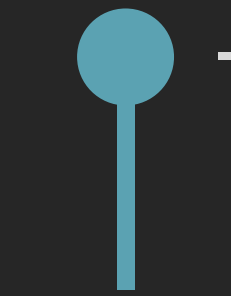
Alternative Façade Schedule Acceleration

FPIU Mechanical System Evaluation

Why

Current Tech

Future



Purpose Design



Goals
Problems
Solutions



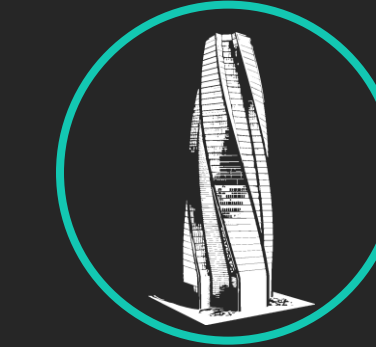
Peri Maximo Form Solution



Semi-Automated Mason



Mechanical Breadth:
FPIU vs. VAV
Acoustics Breadth:
Silencer Design above
Instrument Rehearsal Room



To exceed the status quo for a performance and education space in the arts and music



Music



Theater



Dance



Creative Writing

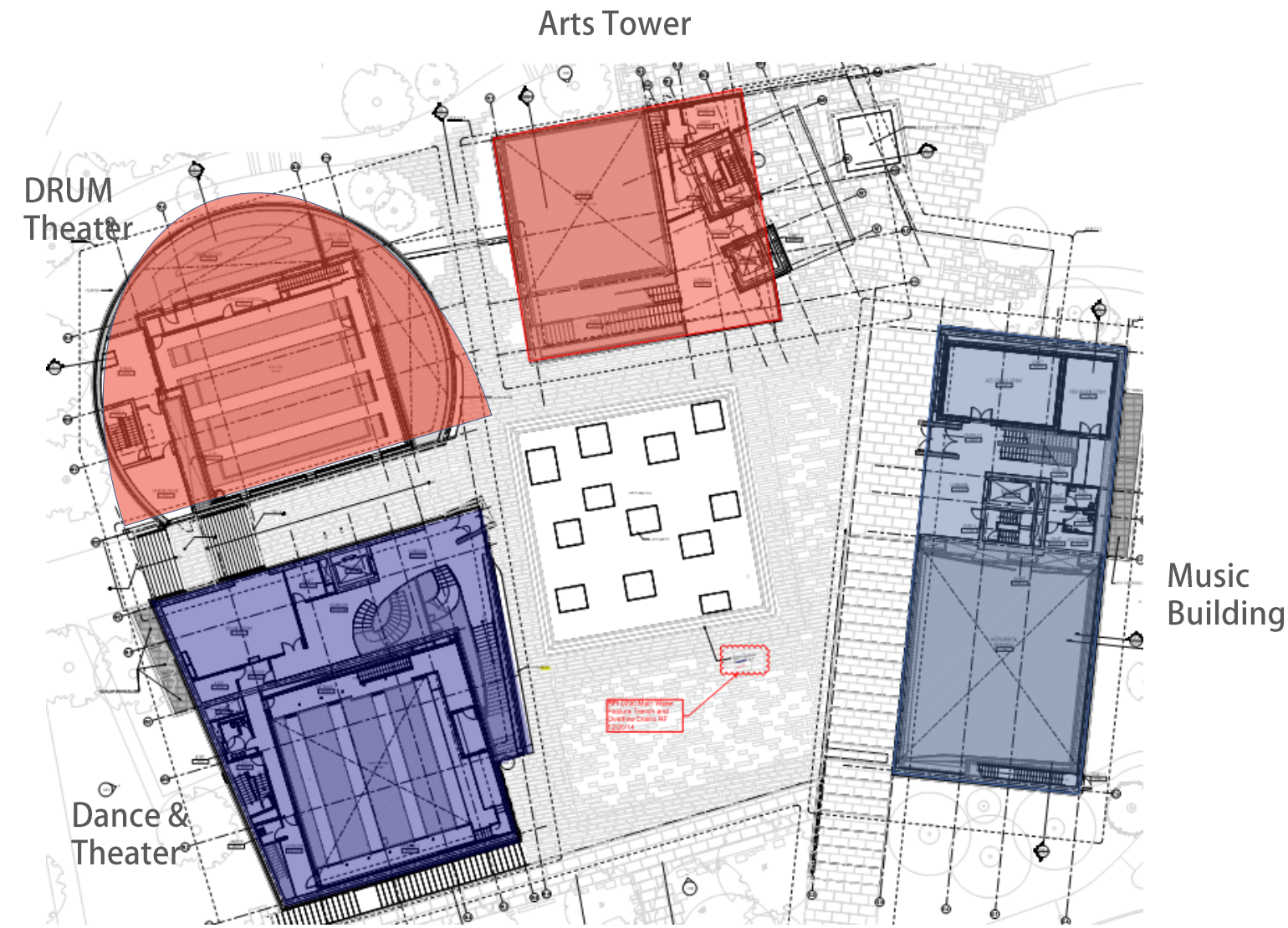


Visual Arts



Offices





Music



Theater



Dance



Creative Writing



Visual Arts



Offices





Schedule



Quality



Challenge status quo

The Un



d LEED

Opportunities

Cast-in-Place Concrete Wall Construction Delayed Interior Fit Out by 30 days



Schedule

Lecce Limestone Facade Installation Delayed Until Summer 2017



Schedule

Project only receives Silver level of LEED certification when the goal is to use 50% less energy than current standards



Quality



Challenge status quo

Cast-in-Place Concrete Wall Construction Delayed Interior Fit Out by 30 days



Wooden Board Forms in Steel Form

Maximo Formwork leveraged over Trio Formwork due to 16% efficiency increase

- One man setup → 50% setup time
- No spacer tubers
 - No cones



Maximo presents 11% cost savings over Trio Formwork

	TRIO	MAXIMO
List price of equipment (\$/sq ft):	80 \$/sq ft	100 \$/sq ft
Rental rate	3.00%	3.00%
Practical Productivity	15.00 sq ft/mh	17.40 sq ft/mh
*** Practical Productivity=estimated productivity/2 ***		
% Increase in productivity		16 %
Cost		
Material cost per square foot (per rental period)	2.40 \$/sq ft/rental period	3.00 \$/sq ft/rental period
Labor cost per square foot(per rental period)	40.00 \$/sq ft/rental period	34.48 \$/sq ft/rental period
	42.40 \$/sq ft/rental period	37.48 \$/sq ft/rental period
total rental expenses	38,400 \$	48,000 \$
Total labor cost	640,000 \$	551,724 \$
Total cost for material and labor	678,400 \$	599,724 \$
Savings using Maximo system	88,276 \$	
Extra rental cost for Maximo System	-9,600 \$	
Benefit of using Maximo system	78,676 \$	

Baseline TRIO Schedule: March 17th, 2015 — December 11th, 2015

MAXIMO Schedule: March 17th, 2015 — December 1st, 2015

Arts Tower

DRUM Theater

Music Building

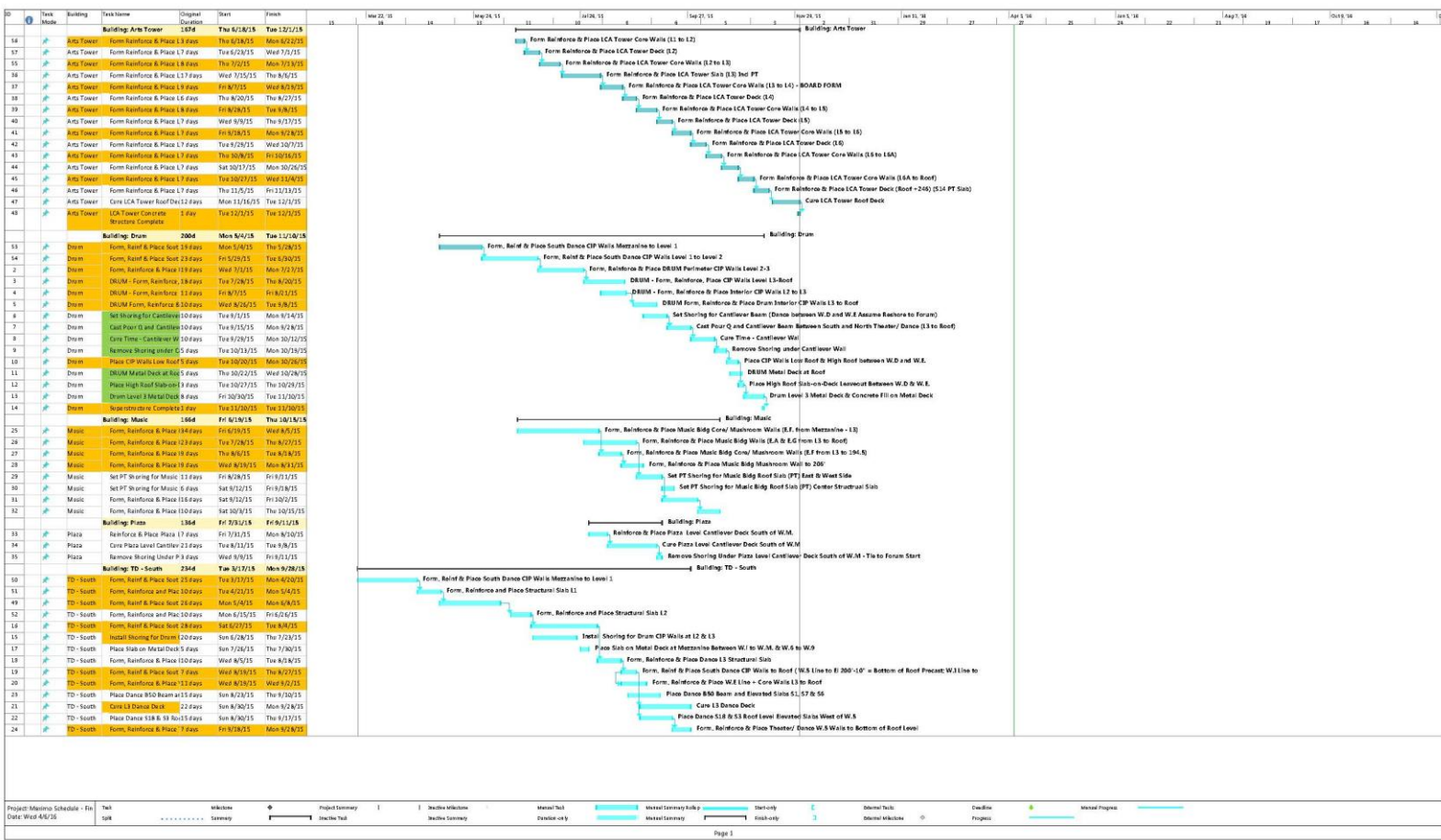
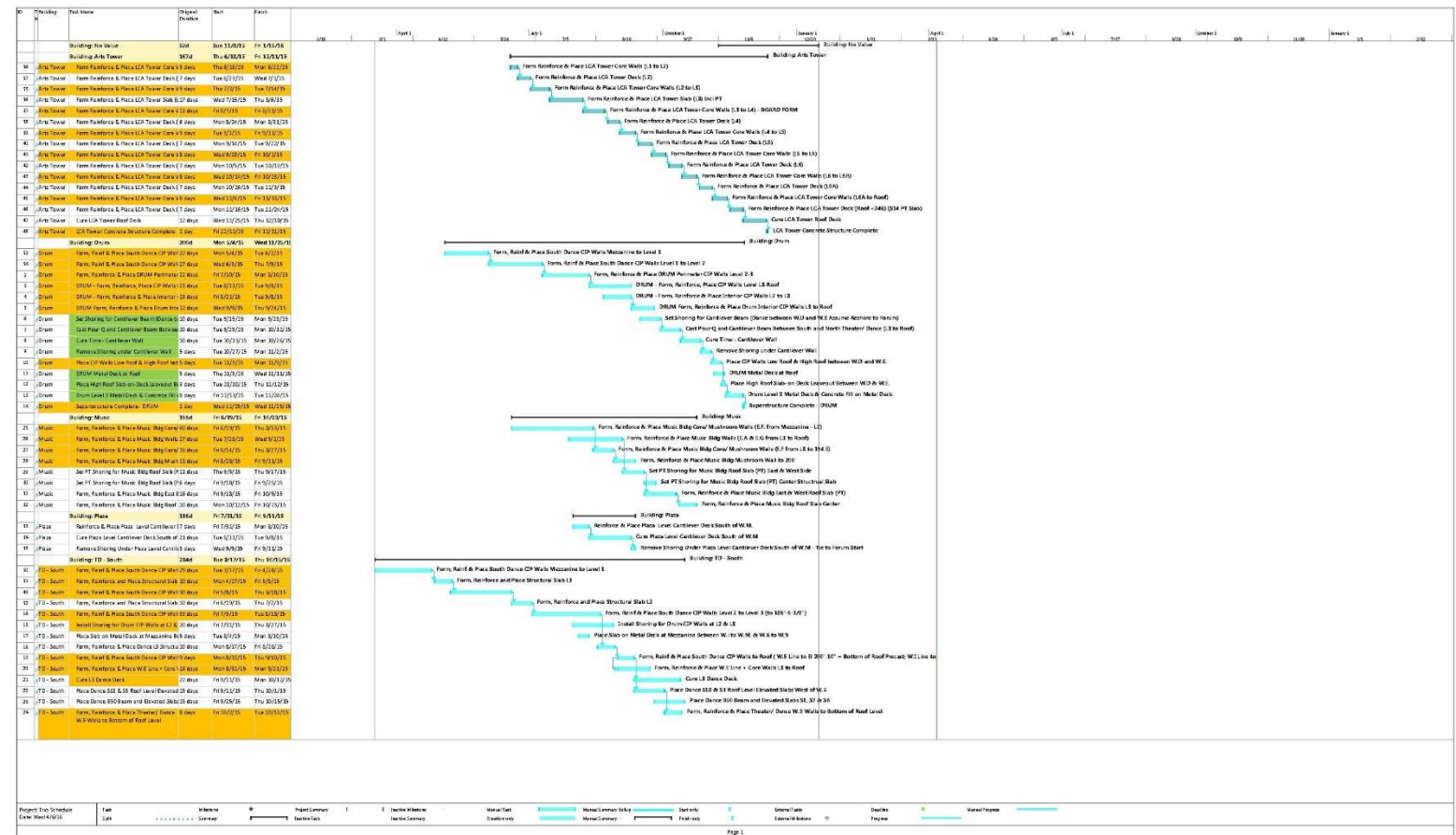
Dance & Theater

Arts Tower

DRUM Theater

Music Building

Dance & Theater



Building	Face	SF of Formwork	Trio Rate (sq ft / mh)	Maximo rate (sq ft/mh)	Trio		Maximo		Total days by building	Accelerated Rate	Total Maximo Time (MH)	Maximo in Days	Total days by building	
					Total Trio Time (MH)	Trio in days	Total Maximo Time (MH)	Maximo in Days						
Arts	North Tower Wall	3153	15.00	17.40	210	26	181	23	56	0.862068966	202	25	48	
	South Tower Wall	3516	15.00	17.40	234	29	181	25						
Dance / Theatre	South Wall	3546	15.00	17.40	236	30	204	25	121	0.862068966	135	17	105	
	East Wall	2352	15.00	17.40	157	20	135	17						
DRUM	West Wall	5073	15.00	17.40	338	42	292	36	53	0.862068966	223	28	46	
	North Wall	3590	15.00	17.40	239	30	206	26						
Music Building	South Wall	3877	15.00	17.40	258	32	145	18	117	0.862068966	464	58	101	
	North Wall	2522	15.00	17.40	168	21	145	18						
DRUM	East Wall	8069	15.00	17.40	538	67	341	43	49	0.862068966	341	43		
	West Wall	5939	15.00	17.40	396	49	341	43						
Totals				Total	2776	347	2393	299						
Total savings											47.86			

Time saved in schedule	10 days	5%
Total cost savings	78,676	11%



Limestone cladding installation delayed until May 2017 impacting project completion



Limestone Paneling covering 40% facade

Alternative Façade Construction built with Semi-Automated Mason to finish by January 2017



Alaskan White Velour Brick Facade



Semi-Automated Mason

SAM increases productivity 3-5 times using a crew of 1 mason and 1 laborer to lay **280 bricks/hour**

Delayed Lecce Schedule vs. Alternative SAM Installed Façade:

- 1) Assuming construction begins same day after 314 day procurement
- 2) Assuming procurement takes 90 days for brick façade components

Delayed Lecce Limestone Schedule: October 1st, 2015 — August 10th, 2017

SAM Alternative Façade Installation (90-day procurement) October 1st, 2015— October 19th, 2016

Alternative Façade System with SAM installation recommended from schedule & cost standpoint

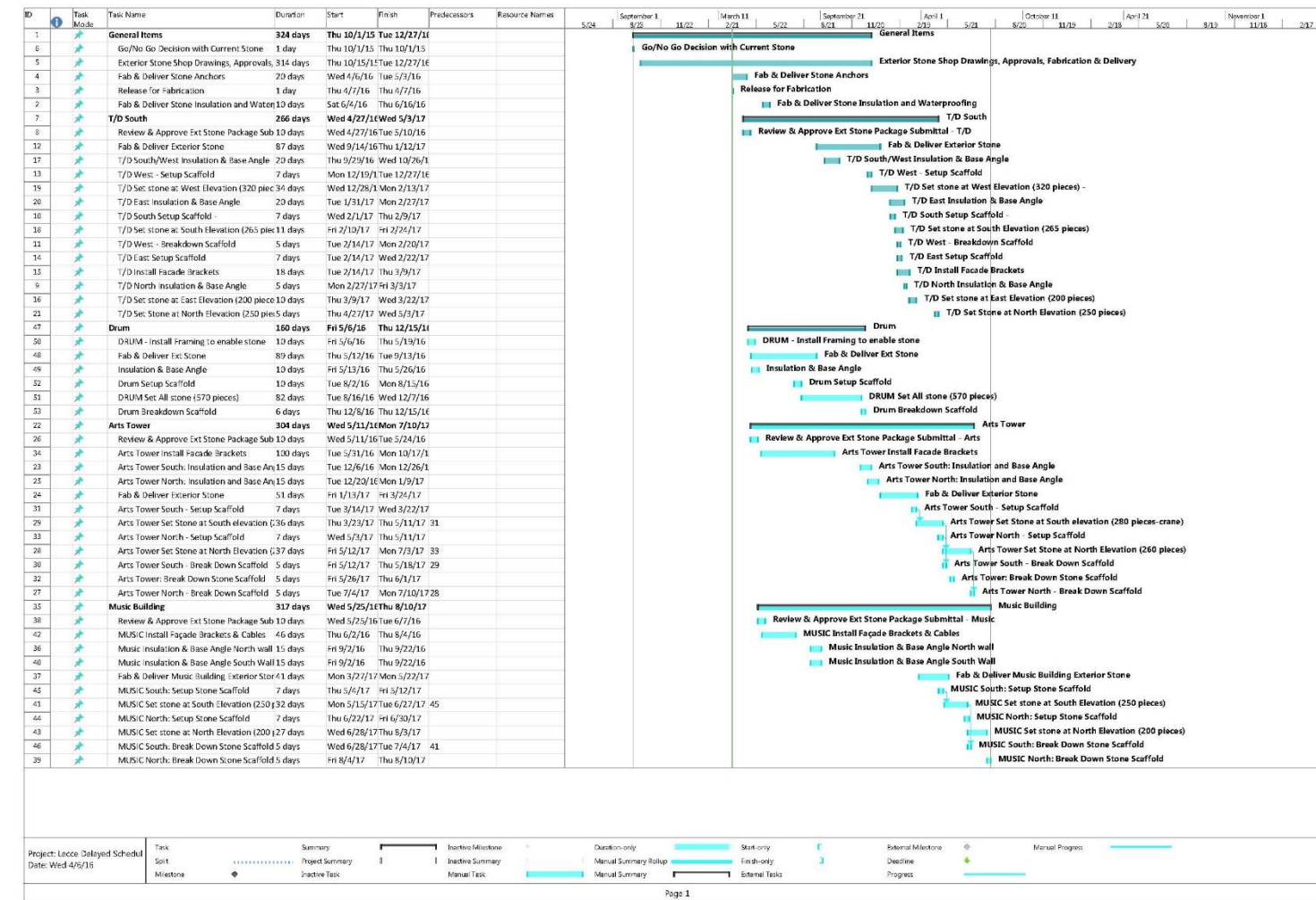
- Actual façade construction time reduced 48% using SAM
- SAM = 45% labor cost savings

Dance & Theater

DRUM Theater

Arts Tower

Music Building

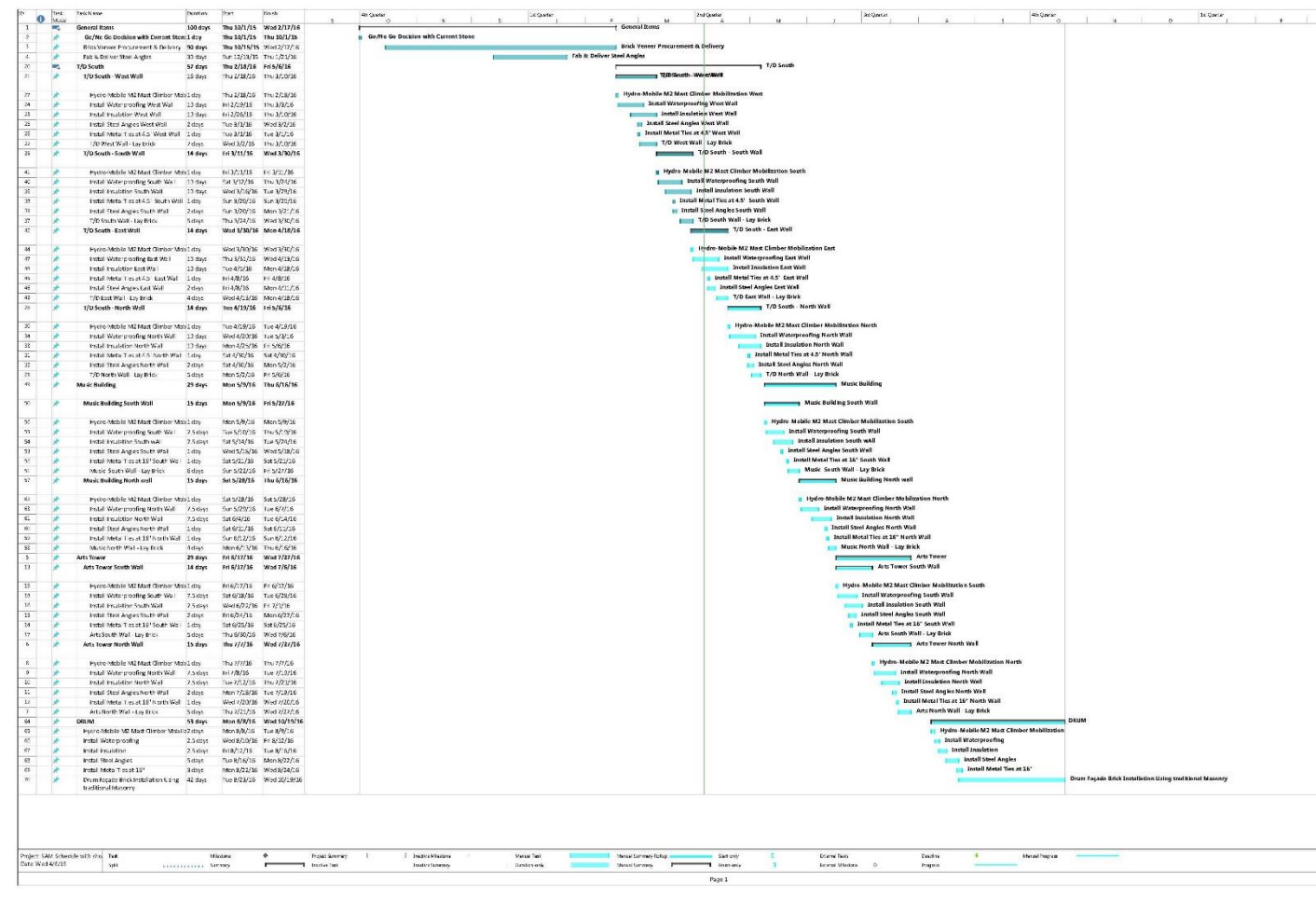


Dance & Theater

Music Building

Arts Tower

DRUM Theater



SAM Brick Veneer vs. Lecce Limestone Façade			
	Start Date	Finish Date	Total Cost
SAM Brick Veneer (90 day procurement)	10/1/2015	10/19/2016	\$ 1,284,389
SAM Brick Veneer (314 day procurement)	10/1/2015	6/1/2017	\$ 1,284,389
Lecce Limestone system	10/1/2015	8/10/2017	\$ 3,001,189



Opportunity 3

System Design & Constructability

Initial Construction Cost

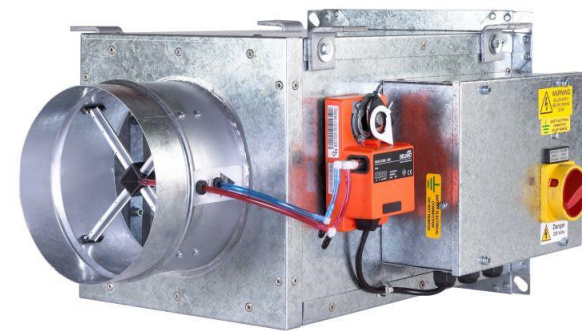
Optimize Energy Performance:

Project only receives Silver LEED certification when the goal is to use 50% less energy than current standards

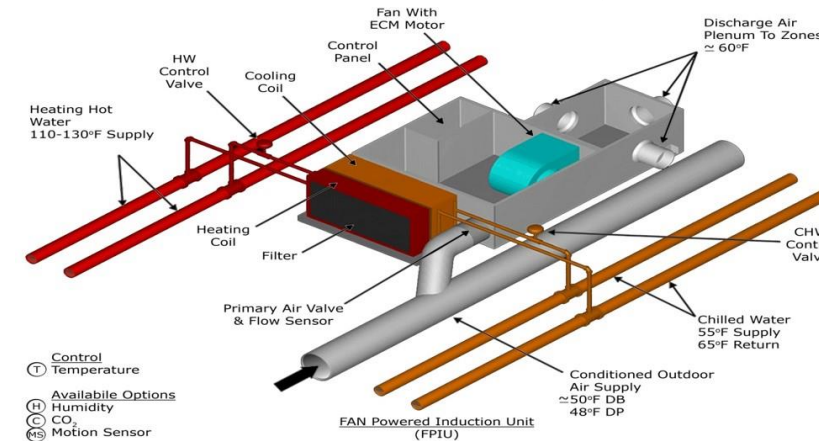
Fan Powered Induction Unit

w/ Dedicated Outdoor Air System

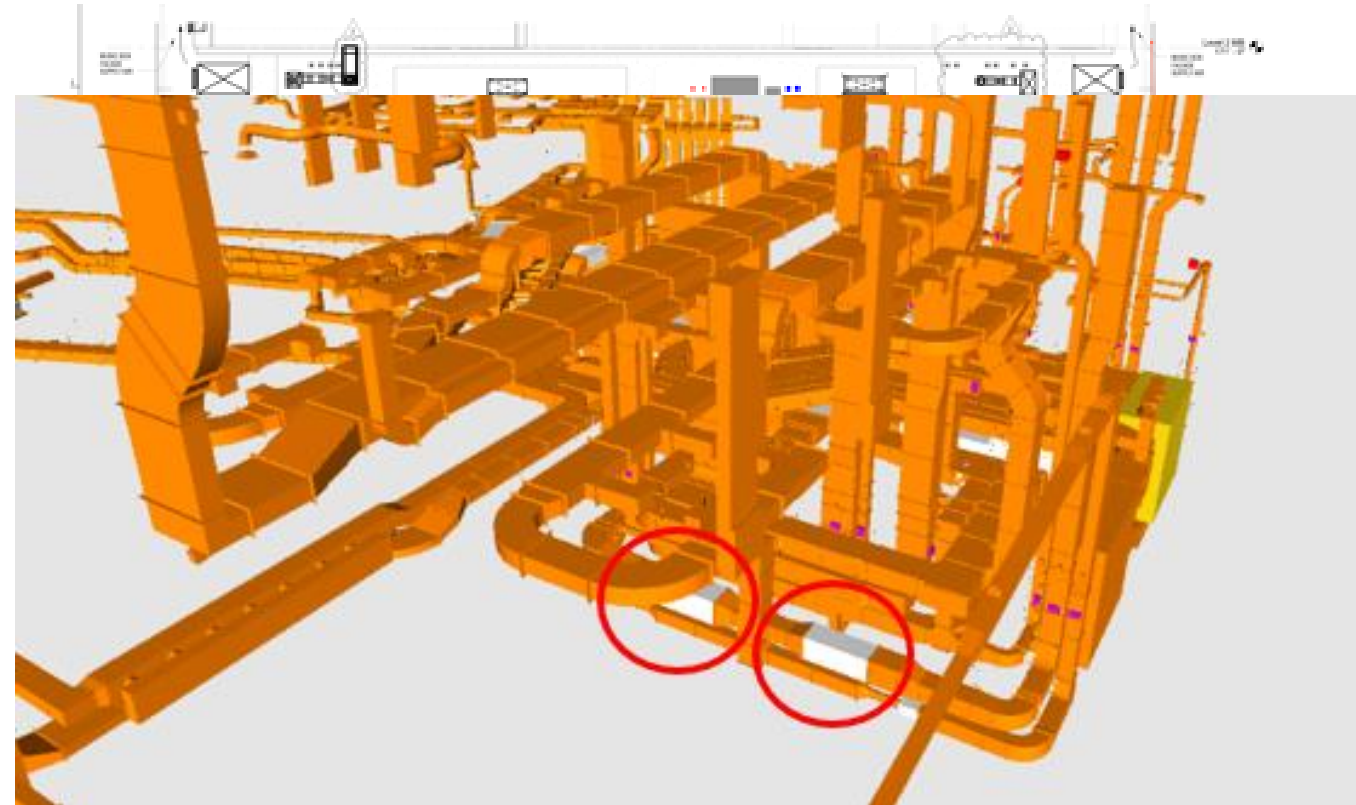
Original VAV System



Krueger KLPS-D Fan Powered Induction Unit w/ Dedicated Outdoor Air System



2 FPIU placed in plenum area above Instrument Rehearsal Room to reduce ductwork



The total cost to build the VAV system is \$117,961 and the total cost to build the FPIU system is \$78,985

Instrument Rehearsal Room Estimate (VAV)							
Item Description	Qty.	Unit	Mat. \$/Unit	Mat. Total	Labor \$/Unit	Labor Total	Grand Total
Sheetmetal	10269.93	lb	\$2.93	\$ 30,090.90	\$0.00	\$0.00	\$ 30,090.90
Sheetmetal Labor	761.77	LF	0	0	\$34.77	\$ 26,486.60	\$26,486.60
Insulation	5922.68	SF	\$0.19	\$ 1,125.31	\$2.10	\$12,437.63	\$13,562.94
Hangers	253.92	EA	\$0.00	\$ -	\$3.26	\$827.79	\$827.79
Linear Diffusers	24	LF	\$92.00	\$ 2,208.00	\$19.10	\$458.40	\$2,666.40
VAV	2	EA	\$840.00	\$ 1,680.00	\$103.00	\$206.00	\$1,886.00
Ebtron Thermal Dispersion Grid	1	EA	\$975.00	\$ 975.00	\$197.00	\$197.00	\$1,172.00
Trane AHU-1	1	EA	\$25,500.00	\$ 25,500.00	\$1,350.00	\$1,350.00	\$26,850.00
Subtotal				\$61,579		\$41,963	\$103,543
Tax (6%)				\$65,274			
Overhead and Profit (10%)				\$6,527		\$4,196	\$0
Grand Total				\$71,801		\$46,160	\$117,961

Instrument Rehearsal Room Estimate (FPIU)							
Item Description	Qty.	Unit	Mat. \$/Unit	Mat. Total	Labor \$/Unit	Labor Total	Grand Total
Sheetmetal	3423.31	lb	\$2.93	\$0.00	\$0.00	\$0.00	\$0.00
Sheetmetal Labor	253.92	LF	0	0	\$34.77	\$ 8,828.87	\$8,828.87
Insulation	1974.23	SF	\$0.19	\$ 375.10	\$2.10	\$4,145.88	\$4,520.98
Hangers	84.64	EA	\$0.00	\$ -	\$3.26	\$275.93	\$275.93
Linear Diffusers	24	LF	\$92.00	\$ 2,208.00	\$19.10	\$458.40	\$2,666.40
Hot & Cold Water Supply Piping (50' Each)	8	EA	\$615.00	\$ 4,920.00	\$33.50	\$268.00	\$5,188.00
FPIU	2	EA	\$4,200.00	\$ 8,400.00	\$150.00	\$300.00	\$8,700.00
DOAS AHU	1	EA	\$35,000.00	\$ 35,000.00	\$1,350.00	\$1,350.00	\$36,350.00
Controller	2	EA	\$1,000.00	\$ 2,000.00	\$50.00	\$100.00	\$2,100.00
Subtotal				\$52,903		\$15,727	\$68,630
Tax (6%)				\$56,077			
Overhead and Profit (10%)				\$5,608		\$1,573	\$0
Grand Total				\$61,685		\$17,300	\$78,985

Energy Model Results

Acoustical Breadth

Trane TRACE 700 Energy Model reveals lack of cost savings & energy optimization for FPIU

To maintain 15 PNC, (4) 5 foot pressure drop duct silencers are recommended in addition to the Existing 4" thick sound-absorbing treatment in ceiling

FPIU + DOAS alternative system is recommended based off discussions with Senior Design Engineer personnel at Southland Industries

4-pipe induction unit used in Trace 700 as closest model to FPIU

Energy Model Results

	VAV	FPIU
Total Load (kBTU/hr)	405	414
Annual Energy Consumption (MBTU/yr)	457	592
Annual Operating Cost	\$9,107	\$11,228

$$TL = NR - 10\log(A_{rec}/S)$$

NR = noise reduction
 S = surface area
 A_{re} = total room absorption

Acoustical Breadth: IRR Sound Barrier Design							
Octave Band Sound Pressure Level (dB)							
Frequency (Hz)	125	250	500	1000	2000	4000	
NC							
FPIU Noise level	38	47	48	43	38	35	31
Desired IRR Noise level	15	35	28	21	15	10	8
Required NR (dB)	23	12	20	22	23	25	23
Required TL (dB)		9.304871	17.30487	19.30487	20.30487	22.30487	20.30487
PCI Industries 5 ft. Silencer Transmission Loss (dB)		10	25	40	55	55	50

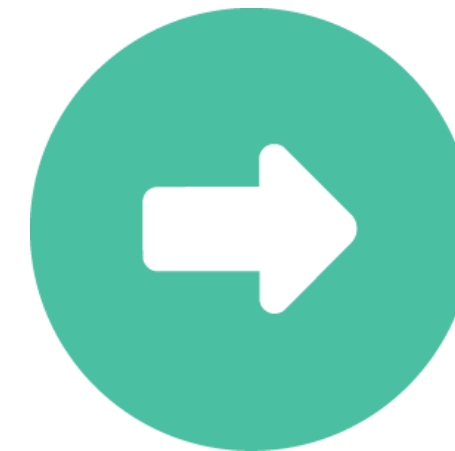
	VAV	FPIU
Construction (Material + Labor) Cost	\$117,961.12	\$ 78,984.80
Long Term Cost (\$/year)	\$9,107	\$11,228.00
Long Term Cost Savings	\$2,121	\$0.00
Yearly Energy Consumption (MBTU) / (year)	457	405



Schedule

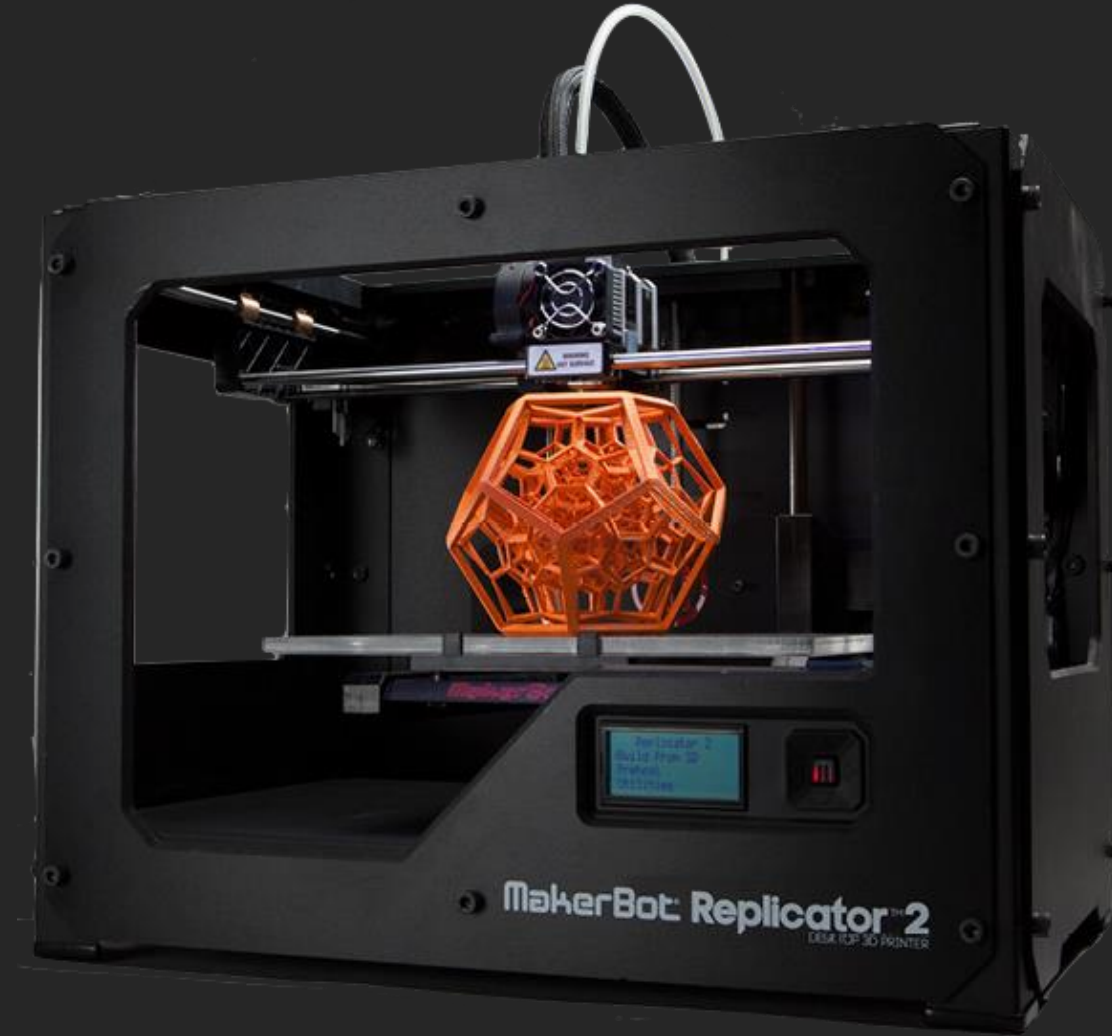


Quality



Challenge status quo

3D Printing Architecture to Scale



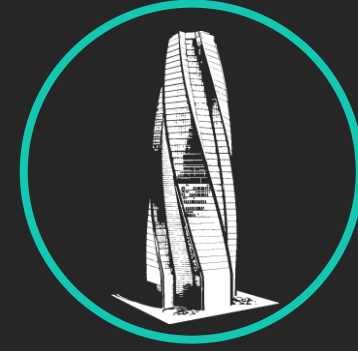
Why



Current Tech



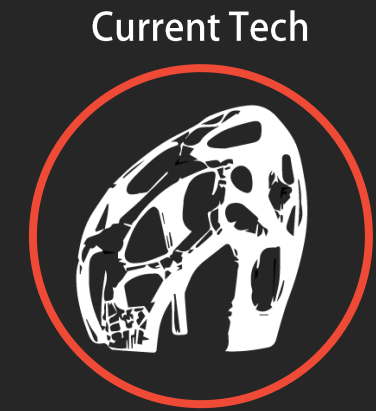
Future



Need for Automated Construction

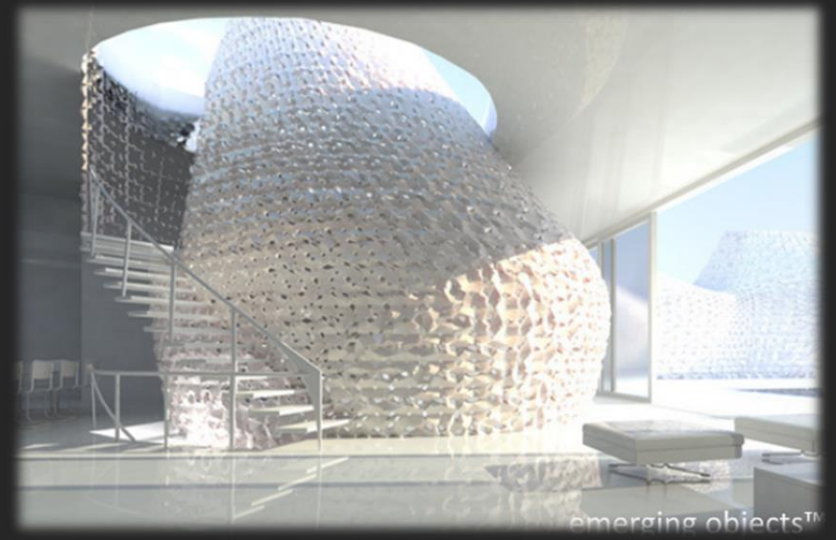
3D Printing Architecture to Scale

Digital Fabrication Opportunity



“Robotic construction methods have the potential to usher in the next era of architectural design”

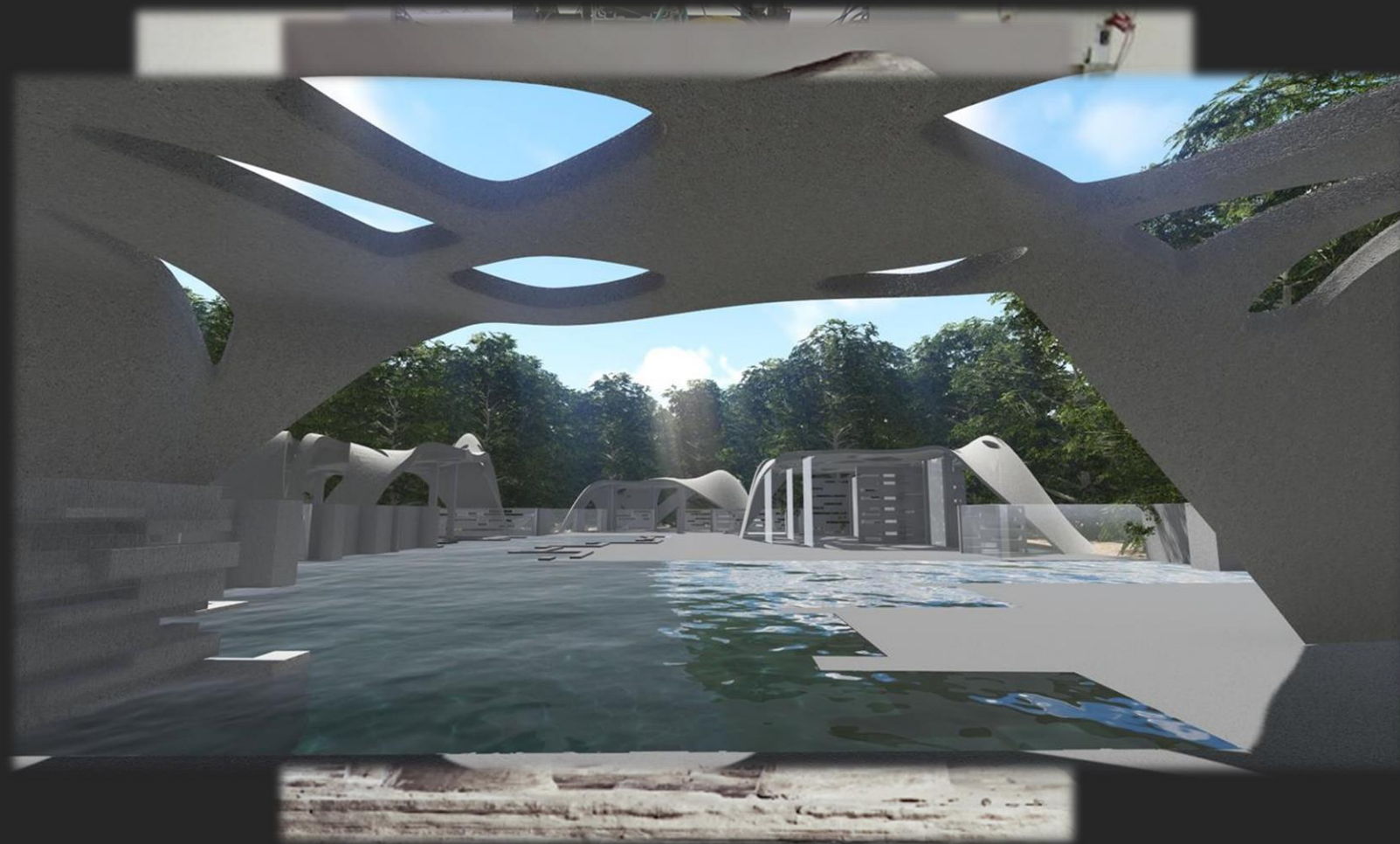
Neri Oxman — MIT Media Lab



emerging objects™

3D Printing Architecture to Scale

Stereolithography



Current Tech



Concrete Nozzle Extrusion

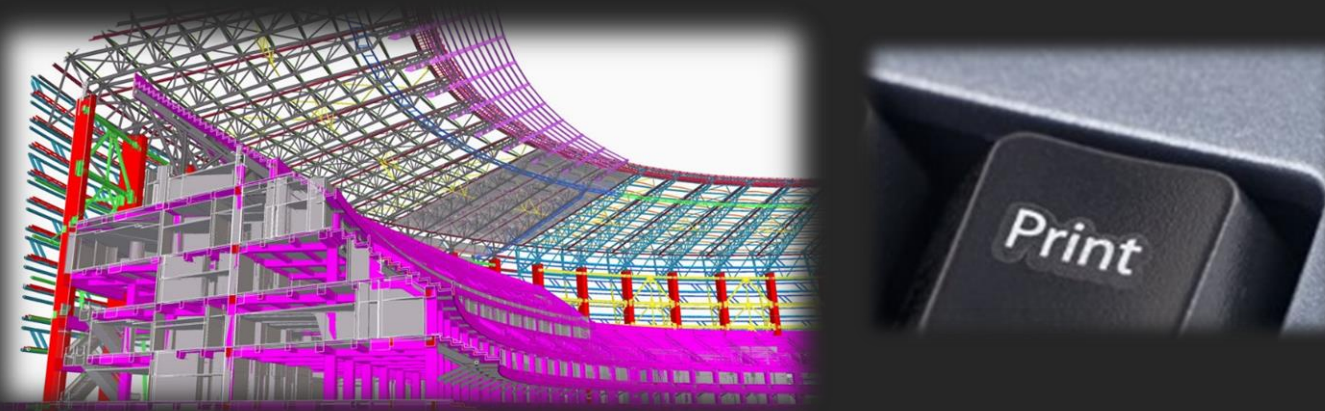


Contour Crafting

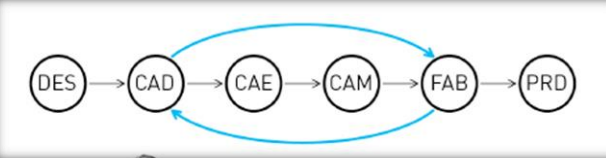


Hotel Suite in Philippines
TotalKustom

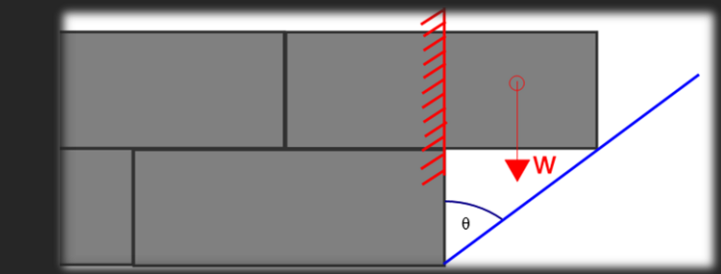
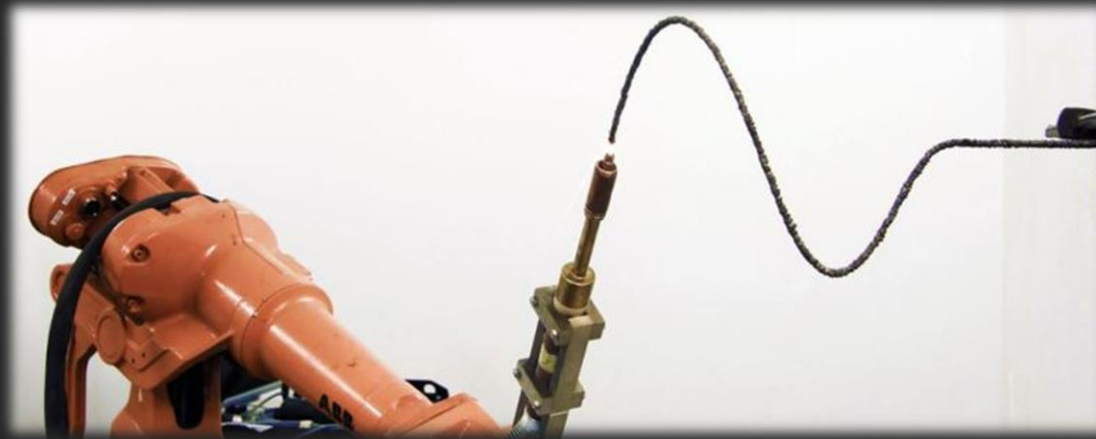
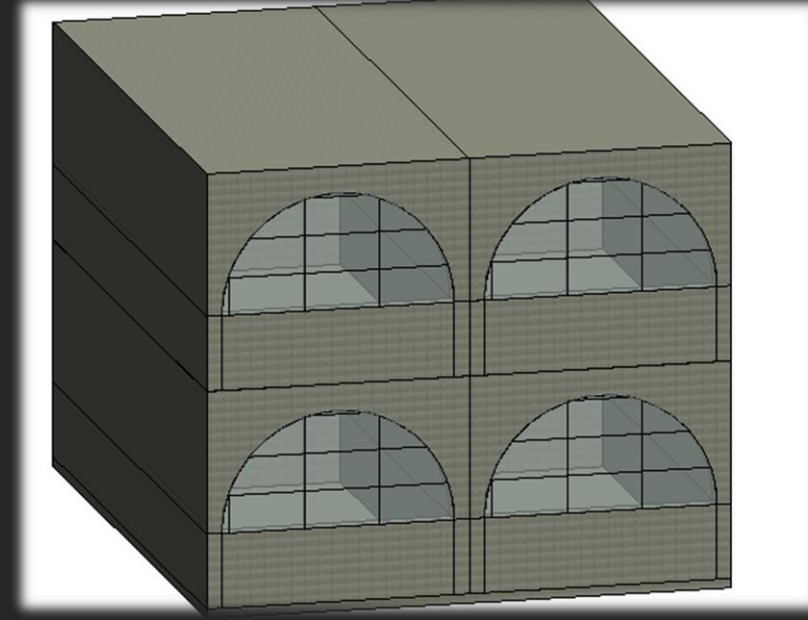
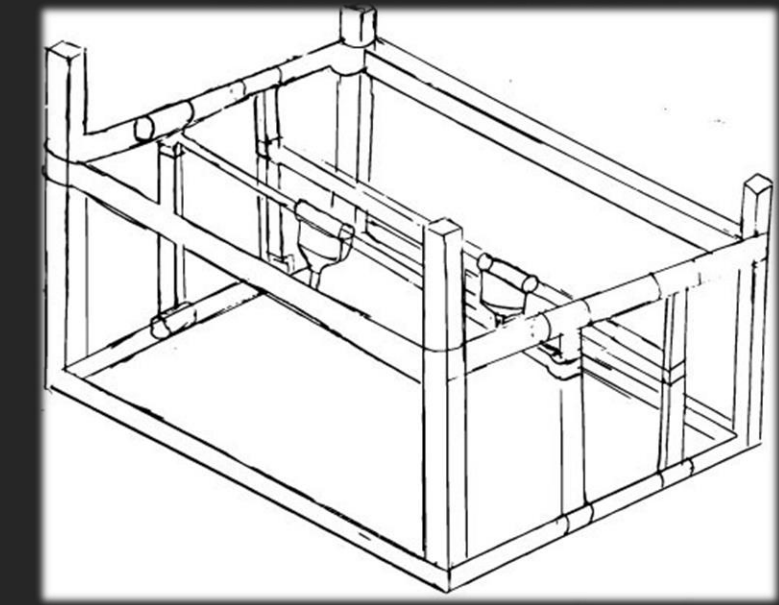
3D Printing Architecture to Scale



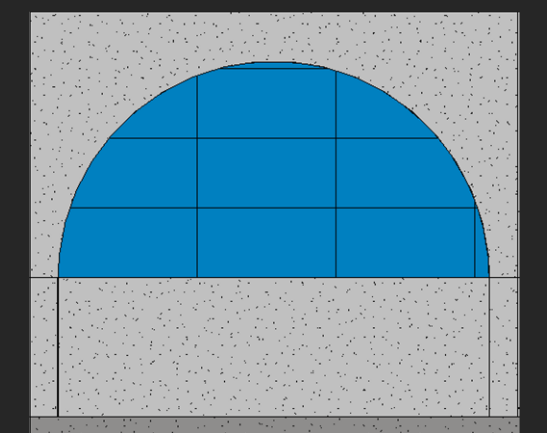
Fabrication Information Modeling (FIM)



Future



$$\rho > .855 * MOR \left(\frac{lb}{in^3} \right)$$



Acknowledgements



Turner Construction Company
Architectural Engineering Department
Dr. Messner
Dr. Rob Leicht & CIC Research Group
Dr. Asadi
Family & Friends