B. Kerem Demirci
Construction Option

The Apartment Building

East Coast, USA

The Pennsylvania State University
Advisor: Dr. Messner

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The Apartment Building

PROJECT STATISTICS

Location: East Coast, USA
Building Type: Apartment Building
Number of Units: 165
Project Size: 150,000 SF
Number of Stories: 10 above + 2 below
Contract Amount: $29,949,641
Contract Type: Negotiated GMP
Construction Dates: 2.11.13 - 2.19.15
Owner: BMPI, LLC
GC: John Moriarty and Associates
Architect: Rust Orling Architecture

Site photo of SE elevation during construction

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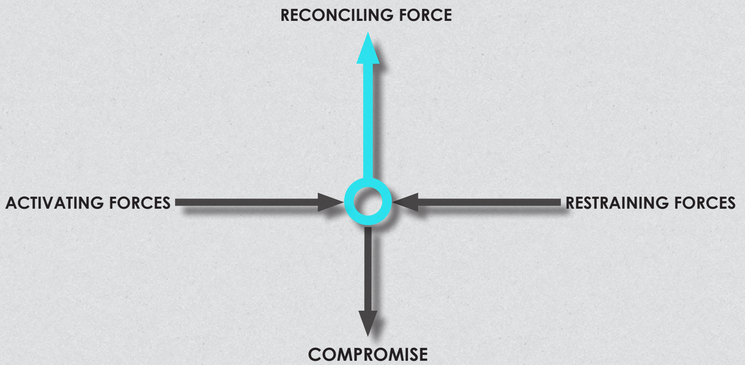
LAW OF THREE FRAMEWORK



Rendering of South elevation

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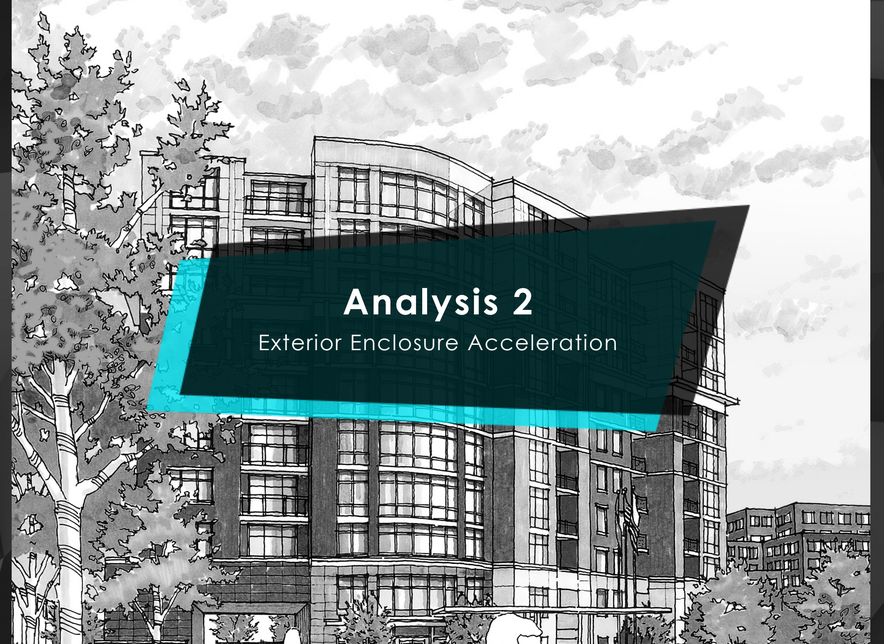
ANALYSIS OVERVIEW

ANALYSIS 1
Effect of Eco Certifications on Marketability → **Critical Industry Research**

ANALYSIS 2
Exterior Enclosure Acceleration → **Breadth 1**: Thermal and Hygrothermal Analysis of PBVSS System

ANALYSIS 3
SIPS for Interior Fit-out → **Breadth 2:** Structural Analysis of PBVSS System

ANALYSIS 4
Tools to Support SIPS Implementation



Analysis 2

Exterior Enclosure Acceleration

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PROBLEM IDENTIFICATION

RECONCILING FORCE
Prefabrication of masonry

ACTIVATING FORCES
- Timely turnover of floors
- High quality construction
- Maintain budget

RESTRAINING FORCES
- 26 day weather delay
- Learning curve for masonry

COMPROMISE
Schedule extension

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Benefits
- Schedule reduction
- Cost reduction
- Improved safety
- Improved quality
- Waste reduction

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COMPROMISE
Schedule extension

METHODOLOGY

Research prefabrication → Review original brick veneer assembly → Propose a prefabricated assembly → Determine transportation constraints → Determine cranage constraints → Sequencing and layout → Schedule impact → Cost impact

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ORIGINAL BRICK VENEER

Facade Material Quantities

Façade Material	Surface Area of Exterior (SF)
ACMU	4,213
Brick	35,322
Metal Cladding	1,733

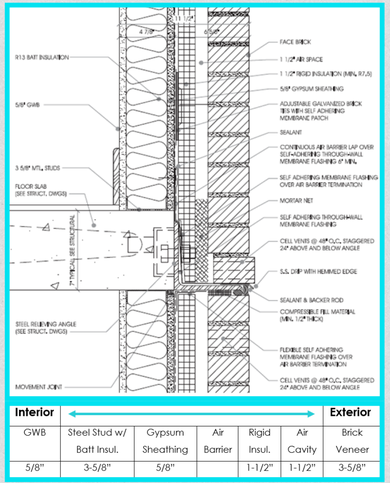
Brick and Mortar Types

BRICK TYPE LEGEND
(ALL BRICKS ARE MODULAR)
BRICK TYPE 1 = RED
BRICK TYPE 2 = BLONDE
BRICK TYPE 3 = BLONDE TEXTURED
BRICK TYPE 4 = RED TEXTURED

MORTAR TYPE LEGEND
MORTAR TYPE 1 = FLAMINGO BRIXMENT C-81
MORTAR TYPE 2 = COLOR TO MATCH ACMU TYPE 6
MORTAR TYPE 3 = COLOR TO MATCH ACMU TYPE 3

NW Elevation

ORIGINAL BRICK VENEER



Interior	←					Exterior
GWB	Steel Stud w/ Batt Insul.	Gypsum Sheathing	Air Barrier	Rigid Insul.	Air Cavity	Brick Veneer
5/8"	3-5/8"	5/8"		1-1/2"	1-1/2"	3-5/8"

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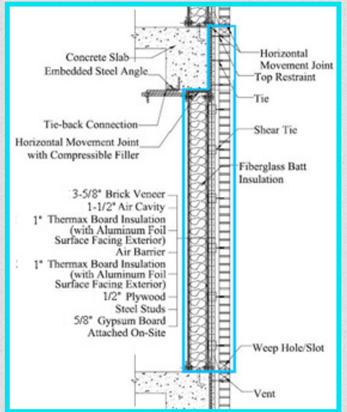
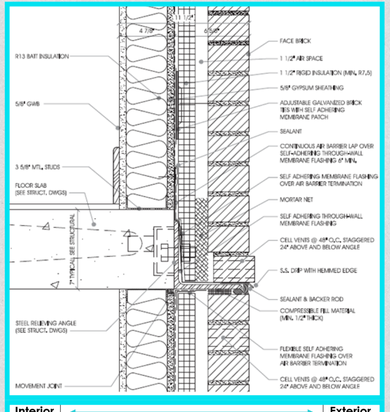
PROPOSED PREFABRICATED SYSTEM



Interior ←							→ Exterior
GWB	Steel Stud w/ Batt Insul.	Plywood Sheathing	Rigid Insul.	Air Barrier	Rigid Insul.	Air Cavity	Brick Veneer
5/8"	3-5/8"	½"	1"		1"	1-1/2"	3-5/8"

ORIGINAL BRICK VENEER



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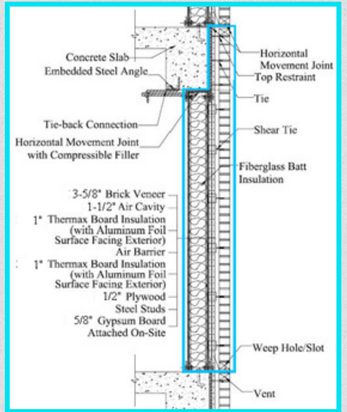

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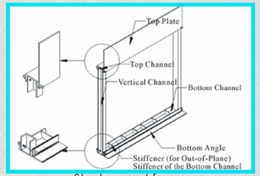
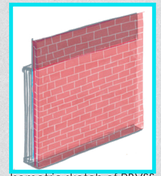


Steel support frame



Isometric sketch of PBVSS

PBVSS construction photos (Liang and Memari 2011)

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TRANSPORTATION AND CRANAGE CONSTRAINTS

Constraints (Department of Transporation)

Max length: 53 ft

Max width: 102in.

Max height: 13ft 5in

Constraints (Potain)

Max capacity: 20,000 lbs

Critical pick at 196ft: 13,230 lbs

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Constraints (Potain)

Max capacity: 20,000 lbs

Critical pick at 196ft: 13,230 lbs

PANEL SIZING

Weight of PBVSS Panel

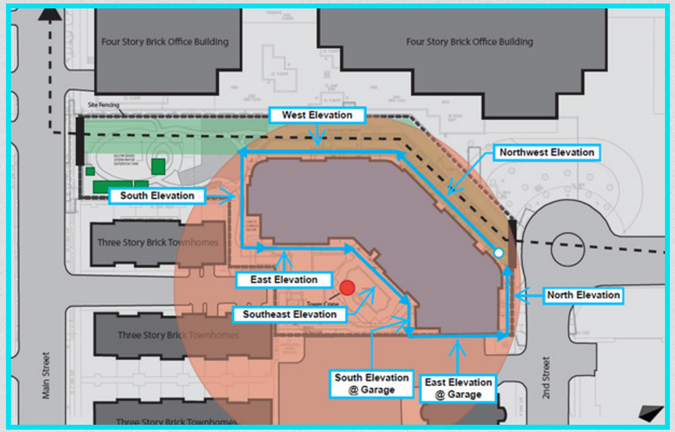
Item		Quantity	Unit	Weight (psf)
Brick Veneer	3-5/8"		SF	39
Rigid Insulation	1"		SF	0.75
Air Barrier			SF	0.7
Rigid Insulation	1"		SF	0.75
Plywood Sheathing	1/2"		SF	1
Batt Insulation	3-5/8"		SF	1.1
GWB	5/8"		SF	2
Steel Studs	12 gauge 3-5/8"		LF	4
Steel Relieving Angle	6x6x3/8		LF	1.5
Stud Shear Connector Ties			ea	1
Embeds with two stud (1/2" dia)	1/2x8x8			1
Steel Frame				2
		Total Weight		**54.8**

Maximum Panel Dimensions and Weight

Max panel height	10 ft.
Max panel length	38 ft.
Max panel weight	20,948 lbs.

The Apartment Building

PANEL SEQUENCING



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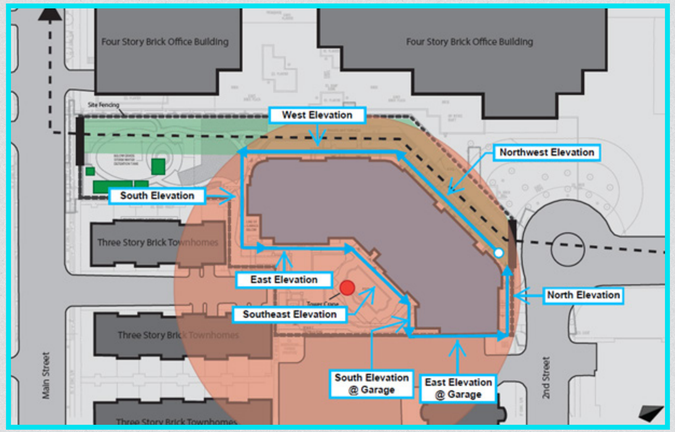


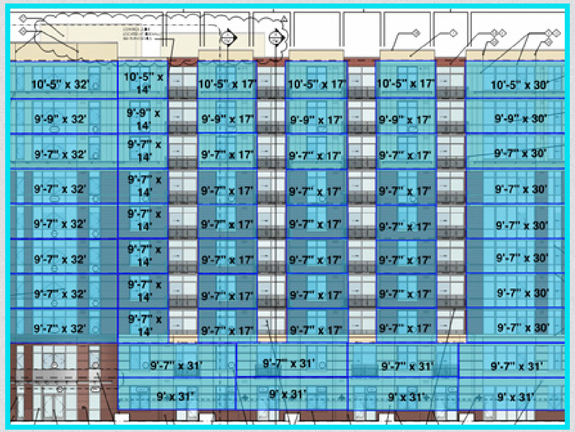
PANEL LOCATIONS

Total Panel Count

Elevation	# of Panels
North Elevation	26
East Elevation	31
East Elevation @ Garage	28
Southeast Elevation	31
South Elevation	17
South Elevation @ Garage	10
West Elevation	35
Northwest Elevation	56
Total	234

NW Elevation Panel Count

	Panel Height	Panel Length	Quantity
Northwest Elevation	10'-5"	32'	1
		30'	1
		17'	3
		14'	1
	9'-9"	32'	1
		30'	1
		17'	3
		14'	1
	9'-7"	32'	6
		31'	4
		30'	6
		17'	18
		14'	6
	9'	31'	4
		Total	**56**



NW Elevation Panel Breakdown

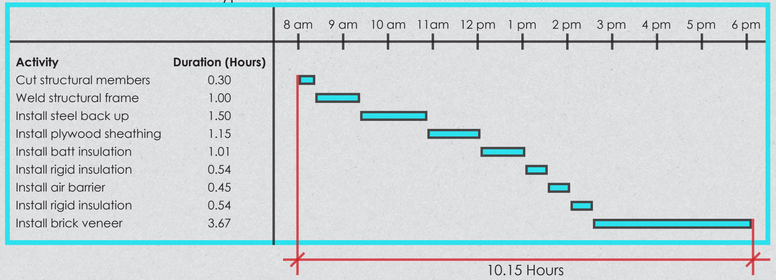
The Apartment Building

SCHEDULE IMPACT

Construction Duration of a Typical PBVSS Panel

	Activity	Quantity	Unit	Total Duration (Hours)
Off Site Work	Cut structural members	4	EA	0.30
	Weld structural frame	24	LF	1.00
	Install Steel Backup	150	LF	1.50
	Install Batt Insul	201	SF	1.15
	Install Plywood Sheathing	201	SF	1.01
	Install Rigid Insul	201	SF	0.54
	Install Air Barrier	201	SF	0.45
	Install Rigid Insul	201	SF	0.54
	Install Brick Veneer	201	SF	3.67
			Off Site Duration for One Panel	10.15

Typical PBVSS Panel Construction Schedule



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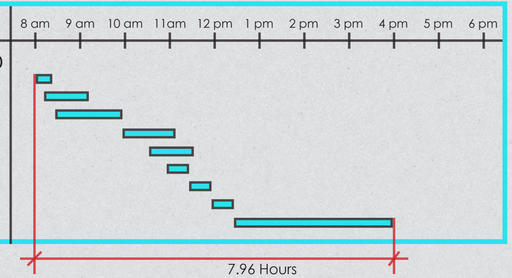
	Install Brick Veneer	201	SF	3.67
	Off Site Duration for One Panel			10.15
	Off Site Duration for One Panel With Sequencing			8

Typical PBVSS Panel Construction Schedule

Activity	Duration (Hours)
Cut structural members	0.30
Weld structural frame	1.00
Install steel back up	1.50
Install plywood sheathing	1.15
Install batt insulation	1.01
Install rigid insulation	0.54
Install air barrier	0.45
Install rigid insulation	0.54
Install brick veneer	3.67



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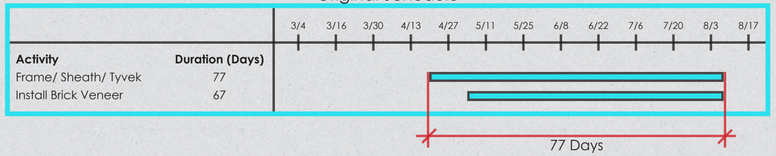
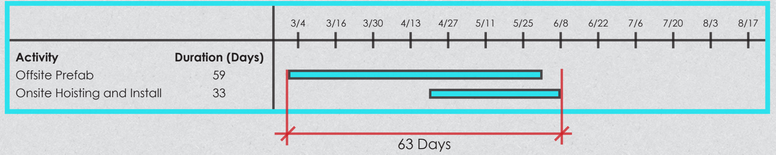
	Off Site Duration for One Panel			10.15
	Off Site Duration for One Panel With Sequencing			8
	Total Off Site Duration for all 234 Panels			**59 days**
On Site Work	Hoisting and Installation	201	SF	1.12
	On Site Duration for One Panel			1.12
	Total On Site Duration for all 234 Panels			**33 days**

Original Schedule



PBVSS Schedule



Brick construction decreased by 14 days (onsite and offsite)

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SCHEDULE IMPACT

Construction Duration of a Typical PBVSS Panel

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	Off Site Duration for One Panel			10.15
	Off Site Duration for One Panel With Sequencing			8
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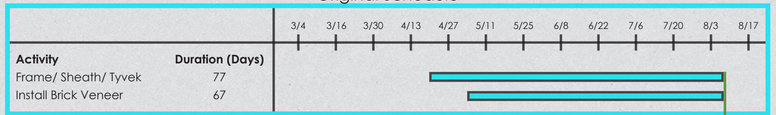

PBVSS Schedule

The Apartment Building

COST IMPACT

Original Brick Veneer Estimate

	Costcode	Item		Quantity	Unit	Unit Material	Unit Labor	Unit Equipment	Extended Total
04 21 13	132020	Brick Veneer	3-5/8"	201	SF	4.04	7.5		$ 2,319.54
07 21 13	102120	Rigid Insulation	1-1/2"	201	SF	0.48	0.49		$ 194.97
07 26 10	100700	Air Barrier		201	SF	0.0292	0.097		$ 25.37
09 29 10	302250	Gypsum Sheathing	5/8"	201	SF	0.47	0.74		$ 243.21
07 21 16	200080	Batt Insulation	3-5/8"	201	SF	0.32	0.27		$ 118.59
09 29 10	302090	GWB	5/8"	201	SF	0.37	0.93		$ 261.30
05 41 13	305140	Steel Studs	18 gauge 3-5/8"	150	LF	9.55	9.45		$ 2,850.00
05 12 23	400476	Steel Relieving Angle	6x6x3/8	20	LF	5.6	21.5	2.53	$ 592.60
04 05 19	161100	Adjustable Galvanized Brick Ties		105	ea	0.405	0.34		$ 78.23
05 12 23	650400	Embeds with two stud (1/2" dia)	1/2x8x8	6	ea	12.6632			$ 75.98
								Subtotal	**$ 6,759.78**
								Location Factor (0.93)	$ (473.18)
								Time Factor (1.04)	$ 270.39
								Tax (6% on Materials)	$ 168.63
								Subtotal	**$ 6,725.62**
								Extrapolated for Entire Brick Veneer	**$ 1,573,795.12**
01 54 26	500710	Swing Stage		6	mo	18000			$ 108,000.00
								Total Cost of Original Brick Veneer	**$ 1,681,795**

PBVSS Estimate

	Costcode	Item		Quantity	Unit	Unit Material	Unit Labor	Unit Equipment	Extended Total
04 21 13	132020	Brick Veneer	3-5/8"	201	SF	4.04	6		$ 2,018.04
07 21 13	102100	Rigid Insulation	1"	201	SF	0.24	0.36		$ 120.60
07 26 10	100700	Air Barrier		201	SF	0.0292	0.0776		$ 21.47
07 21 13	102100	Rigid Insulation	1"	201	SF	0.24	0.36		$ 120.60
07 46 29	101000	Plywood Sheathing	1/2"	201	SF	1.38	0.824		$ 443.00
07 21 16	200080	Batt Insulation	3-5/8"	201	SF	0.32	0.216		$ 107.74
09 29 10	302090	GWB	5/8"	201	SF	0.37	0.744		$ 223.91
05 41 13	308800	Steel Studs	18 gauge 3-5/8"	150	LF	9.55	7.56		$ 2,566.50
05 12 23	400476	Steel Relieving Angle	6x6x3/8	20	LF	5.6	17.2	2.53	$ 506.60
04 05 19	161100	Stud Shear Connector Ties		105	ea	0.405	0.272		$ 71.09
05 12 23	650400	Embeds with two stud (1/2" dia)	1/2x8x8	6	ea	12.6632	0		$ 75.98
05 12 23	400660	Steel frame		61.6	LF	1.39	8.48	1.25	$ 684.99
								Subtotal	**$ 6,960.52**
								Location Factor (0.93)	$ (487.24)
								Time Factor (1.04)	$ 298.60
								Tax (6% on Materials)	$ 184.75
								Subtotal	**$ 6,956.63**
								Total Onsite Construction Cost for all 234 Panels	**$ 1,627,850.31**
03 41 16	500050	Hoisting and Installation		234	ea		194.97	80.4	$ 64,436.58
		Warehouse Lease		3	month	12750			$ 38,250.00
		Transportation		78	trip	200			$ 15,600.00
		Forklift Rental		3	month	1,930			$ 5,790.00
								Total Offsite Construction Cost for all 234 Panels	**$ 124,076.58**
								Total Cost of PBVSS System	**$ 1,751,927**

The Apartment Building

COST IMPACT

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05 41 13	305140	Steel Studs							$ 2,850.00
05 12 23	400476	Steel Relieving Angle						2.53	$ 592.60
04 05 19	161100	Adjustable Shear Connector Ties							$ 78.23
05 12 23	650400	Embeds with two stud (1/2" dia)							$ 75.98
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Cost difference: + $70,132

PBVSS Estimate

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		Transportation		78	trip	200			$ 15,600.00
		Forklift Rental		3	month	1,930			$ 5,790.00
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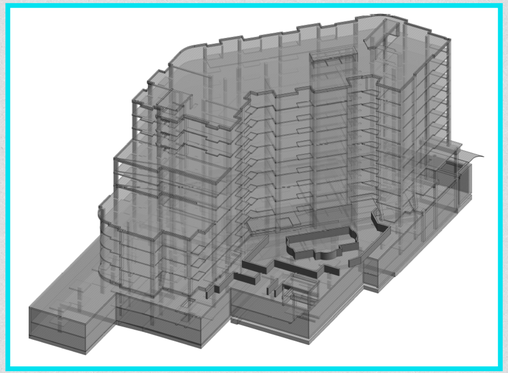
Construction Option

The Apartment Building

BREADTH 2: STRUCTURAL ANALYSIS OF PBVSS



3D rendering of structure

Ensure the existing post-tensioned structure can support the additional weight from the PBVSS system

B. Kerem Demirci

Construction Option

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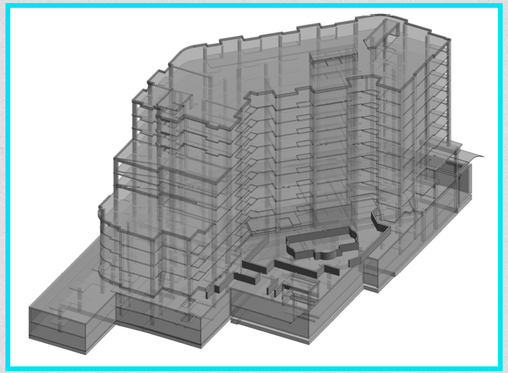
BREADTH 2: STRUCTURAL ANALYSIS OF PBVSS



3D rendering of structure

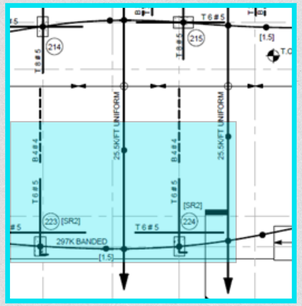
Ensure the existing post-tensioned structure can support the additional weight from the PBVSS system

METHODOLOGY

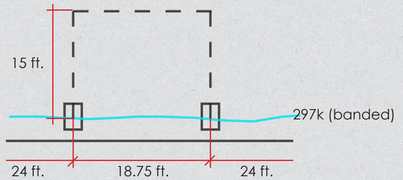
Moment Coefficient Approximation → Allowable Stress Analysis → If structure does not support, then redesign

The Apartment Building

MOMENT COEFFICIENT APPROXIMATION



4th Floor Slab Edge



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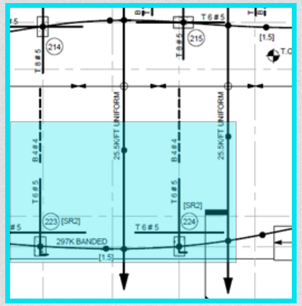
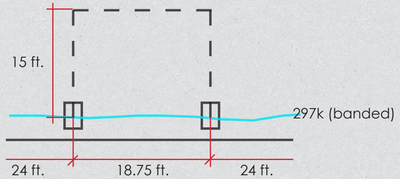
Construction Option

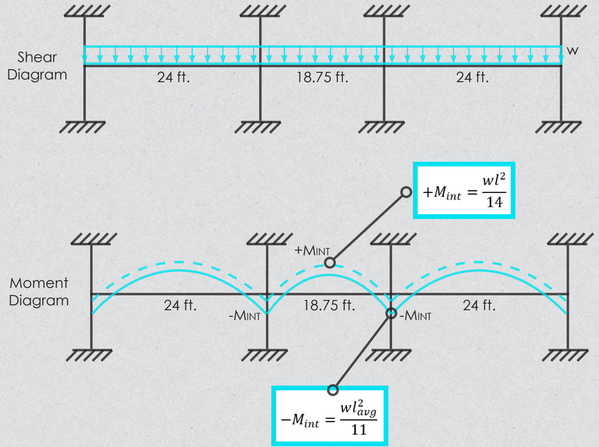
The Apartment Building

MOMENT COEFFICIENT APPROXIMATION



4th Floor Slab Edge





The Apartment Building

ALLOWABLE STRESS ANALYSIS

Allowable Stress Analysis Equations

At Transfer at End of Beam

$$f_t = +\frac{Msw}{S} - \frac{P_i}{A} + \frac{P_i e}{S}$$

$$f_b = \frac{Msw}{S} - \frac{P_i}{A} - \frac{P_i e}{S}$$

$$\sigma_{ci} = 0.6 f'_{ci}$$

$$\sigma_t = 6\sqrt{f'_{ci}}$$

At Service at End of Beam

$$f_t = -\frac{Mtotal}{S} - \frac{P_e}{A} + \frac{P_e e}{S}$$

$$f_b = \frac{Mtotal}{S} - \frac{P_e}{A} - \frac{P_e e}{S}$$

$$\sigma_{ci} = 0.45 f'_c$$

$$\sigma_t = 7.5\sqrt{f'_c}$$

At Transfer at Mid-span of Beam

$$f_t = -\frac{Msw}{S} - \frac{P_i}{A} + \frac{P_i e}{S}$$

$$f_b = \frac{Msw}{S} - \frac{P_i}{A} - \frac{P_i e}{S}$$

$$\sigma_{ci} = 0.6 f'_c$$

$$\sigma_t = 6\sqrt{f'_c}$$

At Service at Mid-span of Beam

$$f_t = -\frac{Mtotal}{S} - \frac{P_e}{A} + \frac{P_e e}{S}$$

$$f_b = \frac{Mtotal}{S} - \frac{P_i}{A} - \frac{P_i e}{S}$$

$$\sigma_{ci} = 0.45 f'_c$$

$$\sigma_t = 7.5\sqrt{f'_c}$$

The Apartment Building

STRUCTURAL ANALYSIS OF EXISTING

Original Design Loads

		psf	plf
Live Loads	Private Rooms	40	600
		Total	**600**
Dead loads	SW of Conc		1312.5
	Brick Veneer	50	500
	Misc MEP	5	75
		Total	**1887.5**

Moment Coefficients Analysis

Selfweight		
w_{sw}	1.3125	klf
-Mint	68.73	ft.k
+Mint	32.96	ft.k
Total		
w_{total}	2.49	klf
-Mint	130.25	ft.k
+Mint	62.47	ft.k

Allowable Stress Analysis

Given		
f'c	3000	psi
f'ci	5000	psi
w_{total}	2.49	klf
SW	1.3125	klf
LL	0.6	klf
f_{pu}	270	ksi
f_{py}	243	ksi
transfer loss	35	ksi
(8) 1/2" dia. Tendons		
Eccentricity	0	in
f_{pi}	**199.26**	ksi
	199.8	ksi
f_{pe}	164.26	ksi
P_e	201.05	kips
P_i	243.89	kips

At Transfer At End				At Service At End			
f_t	-0.15	ksi	compression	f_t	-0.12	ksi	compression
f_b	-0.23	ksi	compression	f_b	-0.21	ksi	compression
σ_t	0.33	ksi		σ_t	0.53	ksi	
σ_{ci}	3.00	ksi		σ_{ci}	2.25	ksi	
$\sigma_{ci} > f_b, f_b$			PASS	$\sigma_{ci} > f_b, f_b$			PASS
At Transfer At Midspan				**At Service At Midspan**			
f_t	-0.17	ksi	compression	f_t	-0.18	ksi	compression
f_b	-0.16	ksi	compression	f_b	-0.19	ksi	compression
σ_t	0.09	ksi		σ_t	0.53	ksi	
σ_{ci}	1.80	ksi		σ_{ci}	2.25	ksi	
$\sigma_{ci} > f_b, f_b$			PASS	$\sigma_{ci} > f_b, f_b$			PASS

B. Kerem Demirci

Construction Option

The Apartment Building

STRUCTURAL ANALYSIS OF EXISTING

Original Design Loads

		psf	plf
Live Loads	Private Rooms	40	600
		Total	**600**
Dead loads	SW of Conc		1312.5
	Brick Veneer	50	500
	Misc MEP	5	75
		Total	**1887.5**

Moment Coefficients Analysis

Selfweight		
w_{sw}	1.3125	klf
-Mint	68.73	ft.k
+Mint	32.96	ft.k
Total		
w_{total}	2.49	klf
-Mint	130.25	ft.k
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Allowable Stress Analysis

Given		
f'c	3000	psi
f'ci	5000	psi
w_{total}	2.49	klf
SW	1.3125	klf
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(8) 1/2" dia. Tendons		
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$\sigma_{ci} > f_t, f_b$			PASS	$\sigma_{ci} > f_t, f_b$			PASS
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σ_t	0.09	ksi		σ_t	0.53	ksi	
σ_{ci}	1.80	ksi		σ_{ci}	2.25	ksi	
$\sigma_{ci} > f_t, f_b$			PASS	$\sigma_{ci} > f_t, f_b$			PASS

STRUCTURAL ANALYSIS WITH PBVSS SYSTEM

Original Design Loads

		psf	plf
Live Loads	Private Rooms	40	600
		Total	**600**
Dead loads	SW of Conc		1312.5
	PBVSS Panels	55	550
	Misc MEP	5	75
		Total	**1937.5**

Moment Coefficients Analysis

Selfweight		
w_{sw}	1.3125	klf
-Mint	68.73	ft.k
+Mint	32.96	ft.k
Total		
w_{total}	2.54	klf
-Mint	132.87	ft.k
+Mint	63.72	ft.k

Allowable Stress Analysis

Given		
f'c	3000	psi
f'ci	5000	psi
w_{total}	2.54	klf
SW	1.3125	klf
LL	0.6	klf
f_{pu}	270	ksi
f_{py}	243	ksi
transfer loss	35	ksi
(8) 1/2" dia. Tendons		
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σ_t	0.33	ksi		σ_t	0.53	ksi	
σ_{ci}	3.00	ksi		σ_{ci}	2.25	ksi	
$\sigma_{ci} > f_t, f_b$			PASS	$\sigma_{ci} > f_t, f_b$			PASS
At Transfer At Midspan				**At Service At Midspan**			
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σ_t	0.09	ksi		σ_t	0.53	ksi	
σ_{ci}	1.80	ksi		σ_{ci}	2.25	ksi	
$\sigma_{ci} > f_t, f_b$			PASS	$\sigma_{ci} > f_t, f_b$			PASS

Analysis 3

SIPS for Interior Fit-out

B. Kerem Demirci

Construction Option

The Apartment Building

PROBLEM IDENTIFICATION

RECONCILING FORCE
Short interval production scheduleing (SIPS) for interior fit-out

ACTIVATING FORCES
- Efficient turnover of floors
- Repetative process
- High level of quality
- Increased communication

RESTRAINING FORCES
- Phased occupancy
- Extended punchlist
- Separate quality control procedure

COMPROMISE
Rely on CPM schedule

B. Kerem Demirci
Construction Option

The Apartment Building

PROBLEM IDENTIFICATION

RECONCILING FORCE
Short interval production scheduleing (SIPS) for interior fit-out

Benefits
- Eliminate stacking of trades
- Minimize learning curve
- Increase production
- Increase quality control
- Increase communication
- Improve housekeeping

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Construction Option

The Apartment Building

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- Efficient turnover of floors
- Repetative process
- High level of quality
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RESTRAINING FORCES
- Phased occupancy
- Extended punchlist
- Separate quality control procedure

COMPROMISE
Rely on CPM schedule

METHODOLOGY

Research SIPS case studies → Create generalized SIPS process map → Apply SIPS to The Apartment Building

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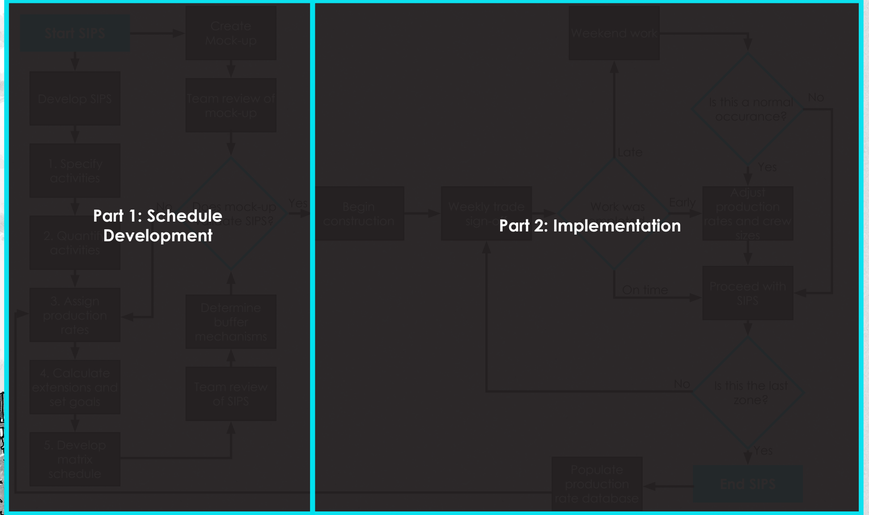
Construction Option

The Apartment Building

GENERALIZED SIPS PROCESS MAP



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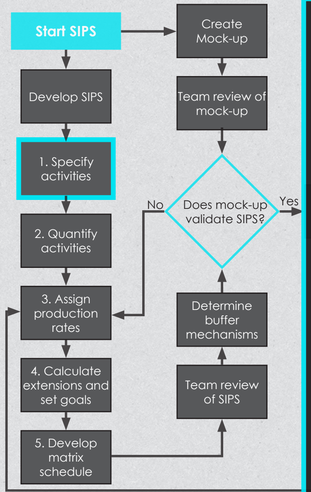
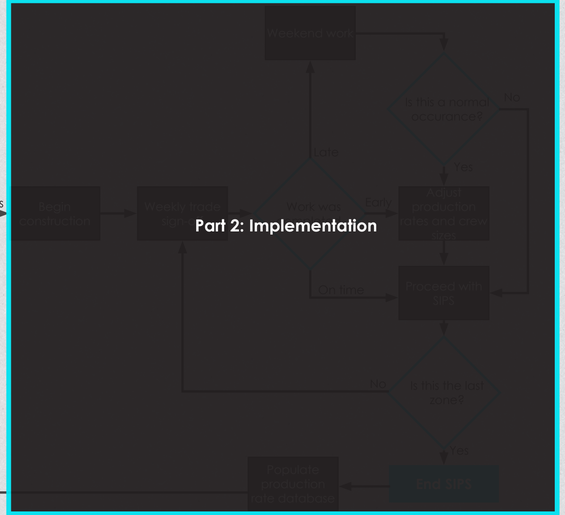
GENERALIZED SIPS PROCESS MAP





PART 1: SCHEDULE DEVELOPMENT

1. Specify Activities

The Apartment Building

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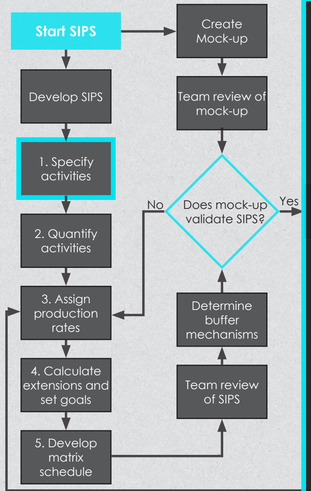
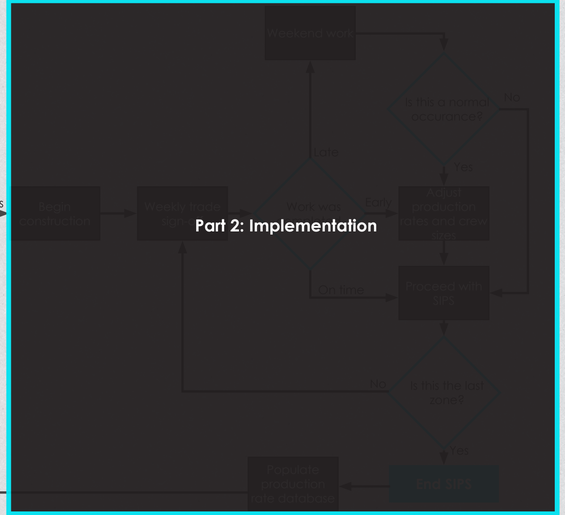
Construction Option

GENERALIZED SIPS PROCESS MAP



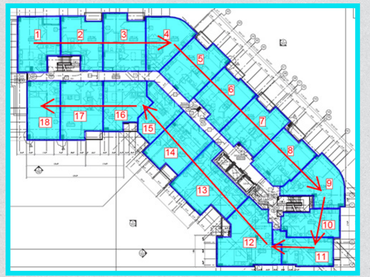


PART 1: SCHEDULE DEVELOPMENT

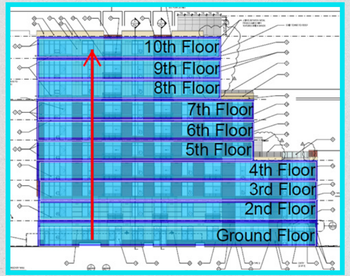
1. Specify Activities

Apartment Units per Floor

Floor	Square Footage	# of Units
Ground	16800	7
2	16800	18
3-4	16800	20
5	15000	16
6-7	15000	18
8-10	13500	16



6th and 7th floor zone breakdown and sequencing



Vertical sequencing (west elevation)

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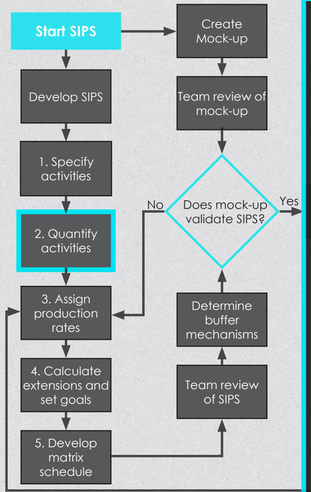
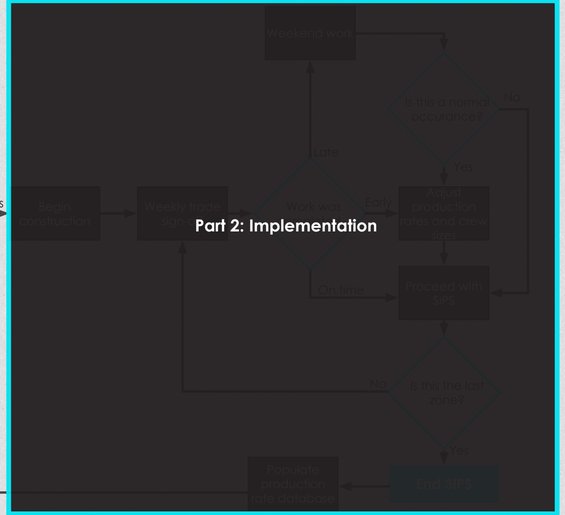
The Apartment Building

GENERALIZED SIPS PROCESS MAP





PART 1: SCHEDULE DEVELOPMENT

2. Quantify Activities

Typical Unit Quantities (One Bedroom B9)

ID	Activity	Quantity	Unit
A1	Frame metal studs	169	LF
A2	Duct rough-in	741	SF
A3	Sprinkler rough-in	741	SF
A4	Plumbing rough-in	741	SF
A5	Electrical rough-in	741	SF
A6	Insulate walls	169	LF
A7	Hang and finish drywall	2043	SF
A8	Paint textured Ceilings	741	SF
A9	Prime paint	2043	SF
A10	Install prehungs	5	ea
A11	Install kitchen cabinets and counters	90	SF face
A12	Install ceramic tile	40	SF
A13	Finish Paint	2043	SF
A14	Lay flooring	700	SF
A15	Install appliances, mirrors and shelving	6	ea
A16	Install entry doors	1	ea

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Construction Option

The Apartment Building

Introduction

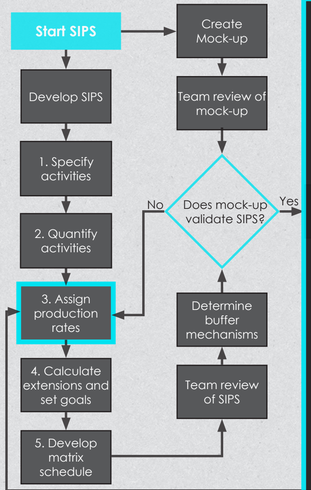
Analysis 2:
Exterior Enclosure Acceleration

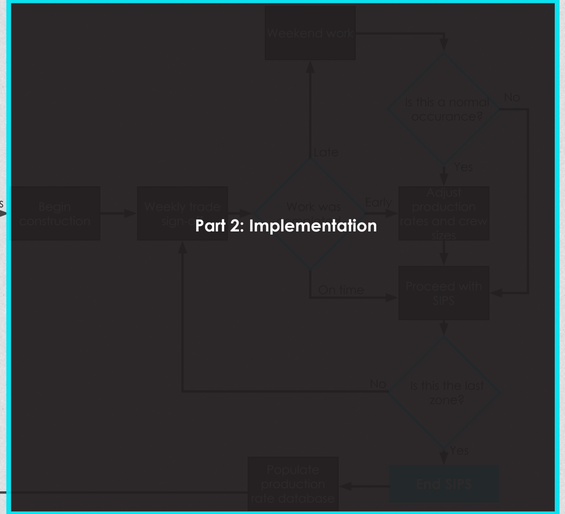
Analysis 3:
SIPS for Interior Fit-out

Analysis 4:
Tools to Support SIPS Implmentation

Final Recommendation

GENERALIZED SIPS PROCESS MAP





PART 1: SCHEDULE DEVELOPMENT

3. Assign production rates

Budget Production of Activities (2nd Floor)

ID	Activity	Quantity	Unit	Budget Duration	Units	Budget Production
A1	Frame metal studs	3042	LF	5	Days	608
A2	Duct rough-in	13338	SF	5	Days	2668
A3	Sprinkler rough-in	13338	SF	5	Days	2668
A4	Plumbing rough-in	13338	SF	5	Days	2668
A5	Electrical rough-in	13338	SF	5	Days	2668
A6	Insulate walls	3042	LF	5	Days	608
A7	Hang and finish drywall	36774	SF	5	Days	7355
A8	Paint textured Ceilings	13338	SF	5	Days	2668
A9	Prime paint	36774	SF	5	Days	7355
A10	Install prehungs	90	ea	5	Days	18
A11	Install kitchen cabinets and counters	1620	SF face	5	Days	324
A12	Install ceramic tile	720	SF	5	Days	144
A13	Finish Paint	36774	SF	5	Days	7355
A14	Lay flooring	12600	SF	5	Days	2520
A15	Install appliances and shelving	108	ea	5	Days	22
A16	Install entry doors	18	ea	5	Days	4

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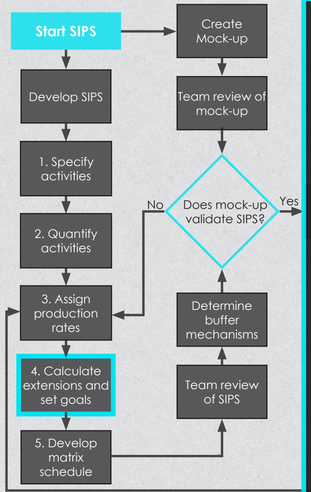
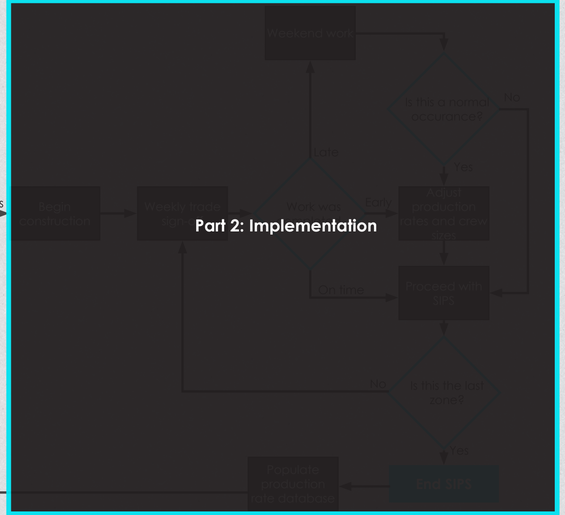
Construction Option

The Apartment Building

GENERALIZED SIPS PROCESS MAP





PART 1: SCHEDULE DEVELOPMENT

4. Calculate Extensions and Set Goals

Required Crew Size for Activities (2nd Floor, 18 units)

ID	Activity	Quantity	Unit	Budget Duration	Units	Budget Production	Worker Production	Units	Required Crew Size
A1	Frame metal studs	3042	LF	5	Days	608	75	LF/Day	9
A2	Duct rough-in	13338	SF	5	Days	2668	400	SF floor area/Day	7
A3	Sprinkler rough-in	13338	SF	5	Days	2668	470	SF floor area/Day	6
A4	Plumbing rough-in	13338	SF	5	Days	2668	320	SF floor area/ Day	9
A5	Electrical rough-in	13338	SF	5	Days	2668	300	SF floor area/ Day	9
A6	Insulate walls	3042	LF	5	Days	608	2000	SF/Day	1
A7	Hang and finish drywall	36774	SF	5	Days	7355	750	SF/Day	10
A8	Paint textured Ceilings	13338	SF	5	Days	2668	1000	SF/Day	3
A9	Prime paint	36774	SF	5	Days	7355	1800	SF/Day	5
A10	Install prehungs	90	ea	5	Days	18	16	Units/Day	2
A11	Install kitchen cabinets and counters	1620	SF face	5	Days	324	80	SF cabinet face/ Day	5
A12	Install ceramic tile	720	SF	5	Days	144	62.5	SF/Day	3
A13	Finish Paint	36774	SF	5	Days	7355	1800	SF/Day	5
A14	Lay flooring	12600	SF	5	Days	2520	600	SF/Day	5
A15	Install appliances and shelving	108	ea	5	Days	22	8	Units/Day	3
A16	Install entry doors	18	ea	5	Days	4	16	Units/Day	1

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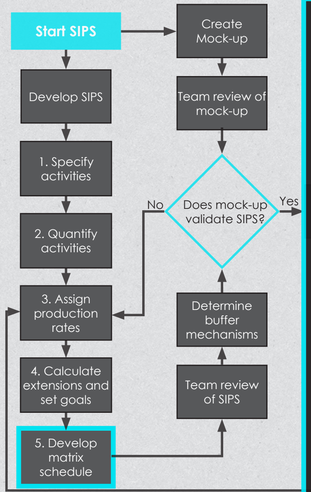
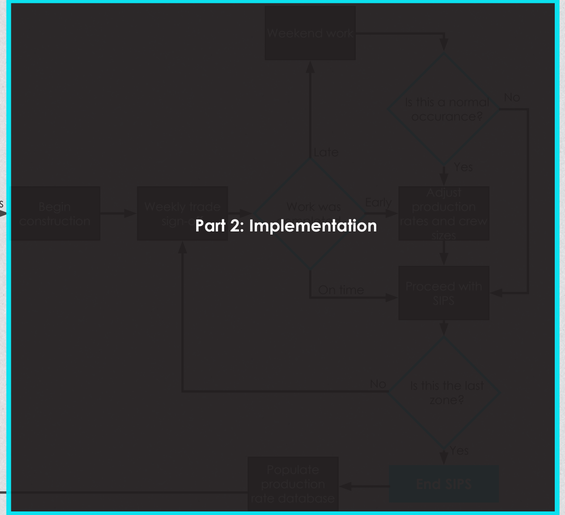
Construction Option

The Apartment Building

GENERALIZED SIPS PROCESS MAP





PART 1: SCHEDULE DEVELOPMENT

5. Develop Matrix Schedule

Matrix Schedule for 2nd through 10th Floor

Floor	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2	9	7	6	9	9	1	10	3	5	2	5	3	5	5	3	1								
3		10	8	7	10	10	1	11	3	5	2	5	3	5	5	3	1							
4			10	8	7	10	10	1	11	3	5	2	5	3	5	5	3	1						
5				8	6	6	8	8	1	9	3	4	1	4	3	4	4	3	1					
6					9	7	6	9	9	1	10	3	5	2	5	3	5	5	3	1				
7						9	7	6	9	9	1	10	3	5	2	5	3	5	5	3	1			
8							8	6	6	8	8	1	9	3	4	1	4	3	4	4	3	1		
9								8	6	6	8	8	1	9	3	4	1	4	3	4	4	3	1	
10									8	6	6	8	8	1	9	3	4	1	4	3	4		3	1
Total labor	9	17	24	32	41	43	50	52	58	49	48	44	40	37	39	29	25	22	20	15	12	8	4	1

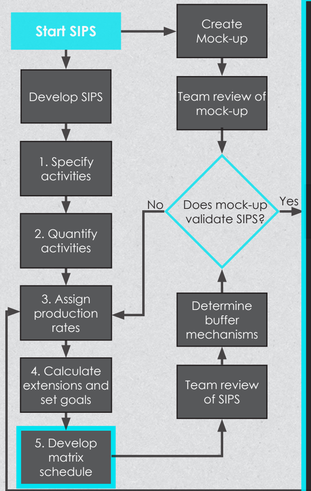
SIPS Legend

- Frame metal studs
- Duct rough-in
- Sprinkler rough-in
- Plumbing rough-in
- Electrical rough-in
- Insulate walls
- Hang and finish drywall
- Paint textured Ceilings
- Prime paint
- Install prehungs
- Install kitchen cabinets and counters
- Install ceramic tile
- Finish Paint
- Lay flooring
- Install appliances, mirrors and shelving
- Install entry doors

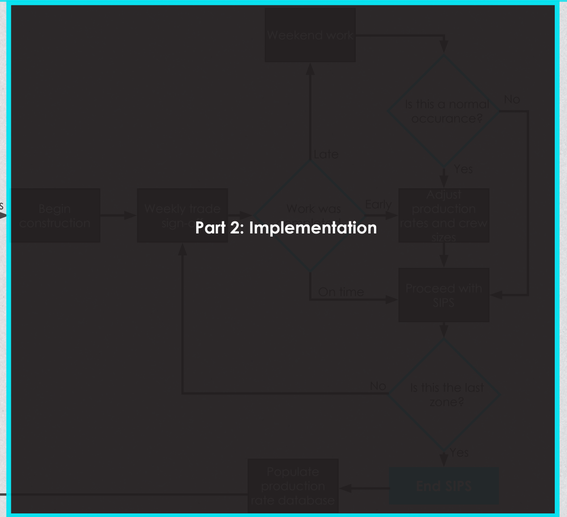
B. Kerem Demirci
Construction Option

The Apartment Building

GENERALIZED SIPS PROCESS MAP



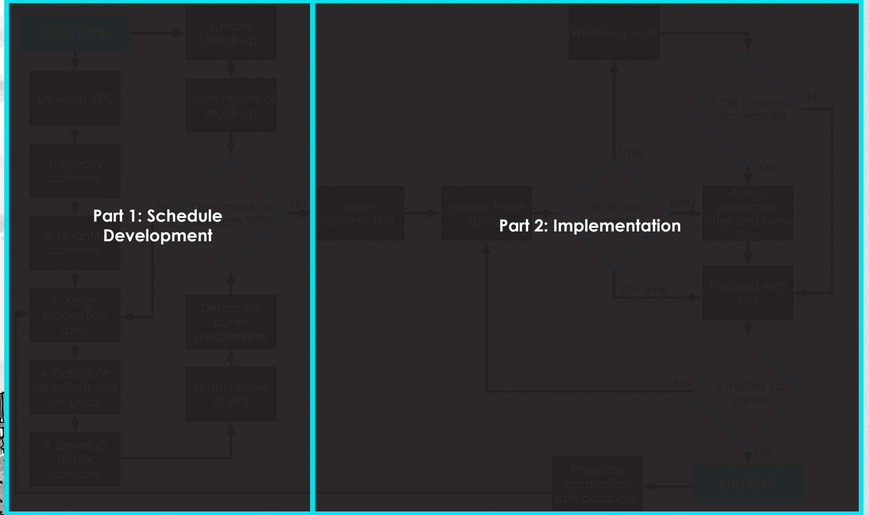
PART 1: SCHEDULE DEVELOPMENT



B. Kerem Demirci
Construction Option

The Apartment Building

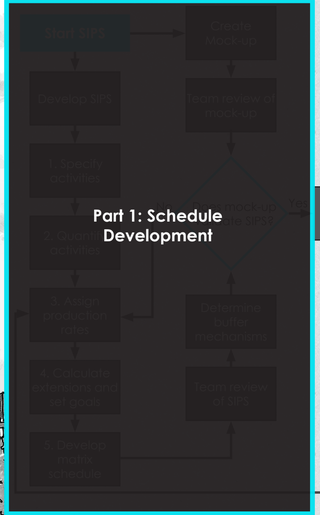
GENERALIZED SIPS PROCESS MAP

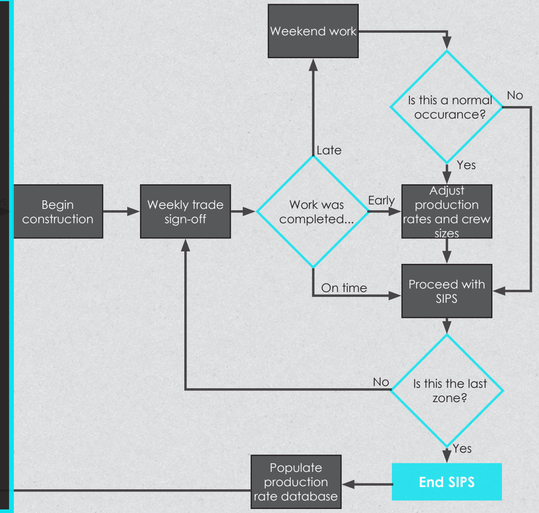


B. Kerem Demirci
Construction Option

The Apartment Building

GENERALIZED SIPS PROCESS MAP





PART 2: IMPLEMENTATION

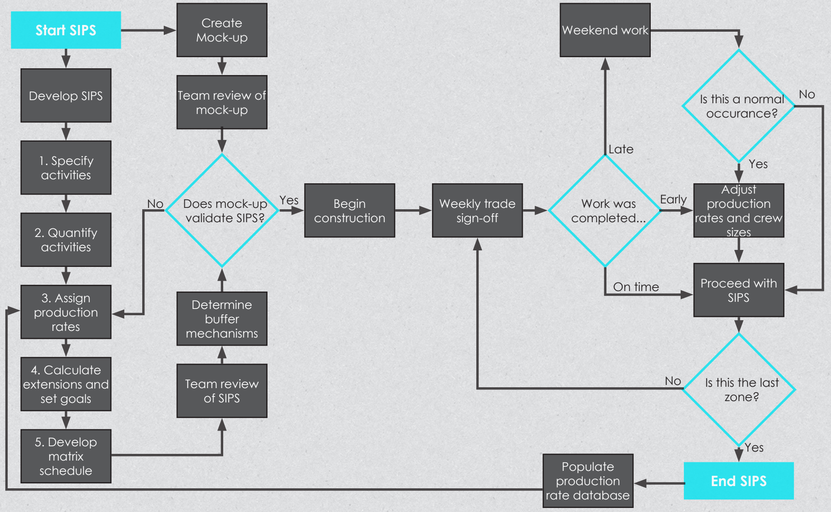
Continuous Improvement

B. Kerem Demirci

Construction Option

The Apartment Building

GENERALIZED SIPS PROCESS MAP



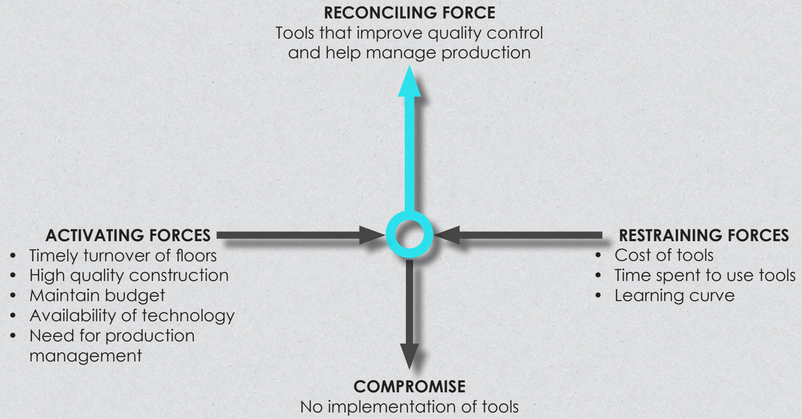
Analysis 4

Tools to Support SIPS Implementation

B. Kerem Demirci
Construction Option

The Apartment Building

PROBLEM IDENTIFICATION



B. Kerem Demirci

Construction Option

The Apartment Building

PROBLEM IDENTIFICATION

RECONCILING FORCE
Tools that improve quality control and help manage production

Benefits
- Improve quality control
- Help track production
- Aid the iterative SIPS process
- Improve communication

ACTIVATING FORCES
- Timely turnover of floors
- High quality construction
- Maintain budget
- Availability of technology
- Need for production management

RESTRAINING FORCES
- Cost of tools
- Time spent to use tools
- Learning curve

COMPROMISE
No implementation of tools

B. Kerem Demirci

Construction Option

The Apartment Building

PROBLEM IDENTIFICATION

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RESTRAINING FORCES
- Cost of tools
- Time spent to use tools
- Learning curve

COMPROMISE
No implementation of tools

METHODOLOGY

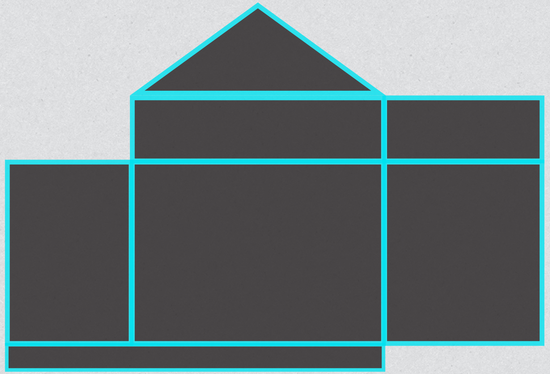
Review House of Quality → Complete a House of Quality → Review available tools → Use House of Quality to select tools → Update SIPS process map

B. Kerem Demirci

Construction Option

The Apartment Building

HOUSE OF QUALITY

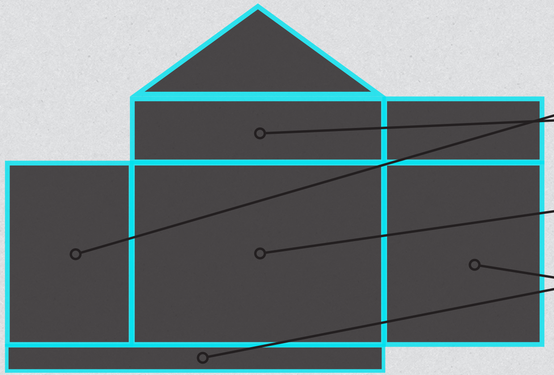


B. Kerem Demirci

Construction Option

The Apartment Building

HOUSE OF QUALITY



1.Customer Requirements

2.Technical Requirements

3. Interrelationship Matrix

4. Importance Benchmarks

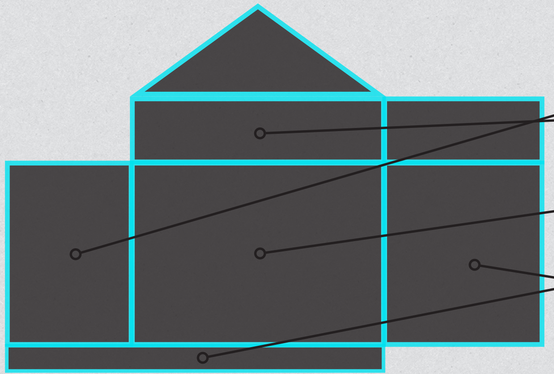
5. Planning Matrix

B. Kerem Demirci

Construction Option

The Apartment Building

HOUSE OF QUALITY



- 1.Customer Requirements
- 2.Technical Requirements
- 3. Interrelationship Matrix
- 4. Importance Benchmarks
- 5. Planning Matrix

- Finish under budget
- Finish on budget
- Finish on time
- Efficient phased turnover of floors
- Improved quality control
- Increased communication between trades
- Easily integrated with SIPS
- Easy to use
- Easy to learn
- Cost effective

- Cost of technology
- Management labor cost
- Time spent prior to construction
- Time spend during construction
- Learning curve of process
- Design issues prevented
- Rework time saved
- Quality issues prevented
- Training required
- Visuals produced to aid construction
- Labor efficiency and production
- Wasted labor time
- Problem areas of construction process identified
- Intervals of iterations
- Time spent per iteration

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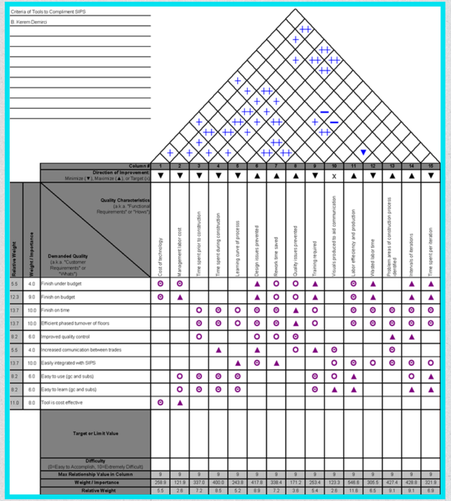
Construction Option

The Apartment Building

HOUSE OF QUALITY FOR THE APARTMENT BUILDING



Importance Benchmarks		
Technical Requirement	**Relative Weight**	**Direction of Improvement**
Labor efficiency and production	11.6	Increase
Intervals of iterations	9.1	-
Problem areas of construction process identified	9.1	Increase
Design issues prevented	8.9	Increase
Time spent during construction	8.5	Decrease

B. Kerem Demirci

Construction Option

The Apartment Building

AVAILABLE BIM TOOLS

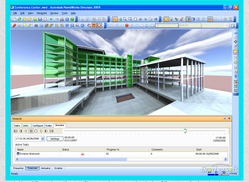
Design Authoring

http://sicad-sa.com/Revit/3D%20View-%20NorthWest.jpg

Design Reviews

http://www.engr.psu.edu/ae/cic/facilities/fCon/

4D Modeling



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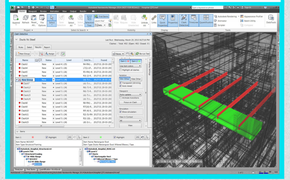
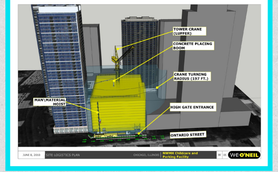
3D Coordination



http://static-dc.autodesk.net/content/dam/autodesk/www/products/autodesk-navisworks-family/images/screenshots/clash-detective-large-1152x720.jpg

Site Utilization Planning



http://www.agdworks.com/assets/images/site-skp4.jpg

Field Tracking

http://beyonddesign.typepad.com/.a/6a0114e87fbd82d970d017c3264b518970b-pi

B. Kerem Demirci

Construction Option

The Apartment Building

AVAILABLE BIM TOOLS

Design Authoring

http://sicad-sa.com/Revit/3D%20View-%20NorthWest.jpg

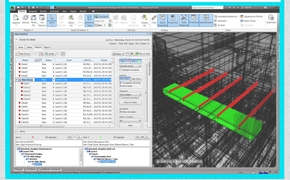
Design Reviews

http://www.engr.psu.edu/ae/cic/facilities/ICon/

4D Modeling

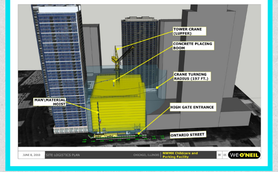
http://img.brothersoft.com/screenshots/softimage/a/autodesk_navisworks-175054-2.jpeg

3D Coordination



http://static-dc.autodesk.net/content/dam/autodesk/www/products/autodesk-navisworks-family/images/screenshots/clash-detective-large-1152x720.jpg

Site Utilization Planning



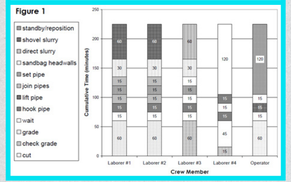
http://www.agdworks.com/assets/images/site-skp4.jpg

Field Tracking

http://beyonddesign.typepad.com/.a/6a0144e87fbd82d970d017c3264b518970b-pi

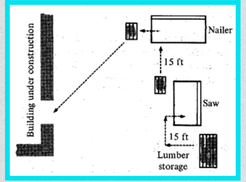
AVAILABLE DATA COLLECTION TOOLS

Crew Balance Charts



(Kuprenas and Fakouri 2001)

Flow Diagrams and Process Charts



(Leicht 2014)

Activity Sampling

	Effective Work	Contributory Work	Non-Contributory Work
Day 1	72	66	20
Day 2	55	35	22
Day 3	57	55	27
Sum	184	156	69

Labor Utilization Factors

$$LUF = \frac{(effective\ work + 0.25 \times contributory\ work)}{total\ observed}$$

$$LUF = \frac{effective\ work}{total\ observed}$$

Trade	Effective	Contributory	Non-Contributory
Carpenter	29	38	33
Electrician	28	35	37
Insulator	45	28	27
Laborer	44	26	30
Painter	46	26	28

Foreman Delay Survey

Record Workforce

https://www.harbortronics.com/Products/TimeLapsePackage/web/TLP-F-2700-Open,1000.jpg

B. Kerem Demirci

Construction Option

The Apartment Building

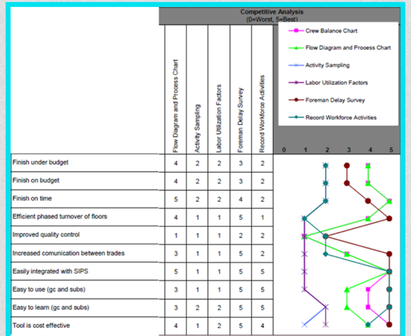
PLANNING MATRIX

BIM Tools

	Design Authoring	Design Reviews	4D Modeling	3D Coordination	Site Utilization Planning	Field and Management Tracking
Finish under budget	3	3	3	4	2	1
Finish on budget	4	3	3	5	3	2
Finish on time	4	2	5	5	3	2
Efficient phased turnover of floors	2	2	5	5	3	3
Improved quality control	4	4	2	4	1	5
Increased comunication between trades	3	3	4	5	4	1
Easily integrated with SIPS	3	3	5	5	3	5
Easy to use (gc and subs)	3	2	4	4	3	3
Easy to learn (gc and subs)	2	2	3	3	3	3
Tool is cost effective	4	4	3	3	3	2

Data Collection Tools

	Flow Diagram and Process Chart	Activity Sampling	Labor Utilization Factors	Foreman Delay Survey	Record Workforce Activities
Finish under budget	4	2	2	3	2
Finish on budget	4	2	2	3	2
Finish on time	5	2	2	4	2
Efficient phased turnover of floors	4	1	1	5	1
Improved quality control	1	1	1	2	2
Increased comunication between trades	3	1	1	5	2
Easily integrated with SIPS	5	1	1	5	5
Easy to use (gc and subs)	3	1	1	5	5
Easy to learn (gc and subs)	3	2	2	5	5
Tool is cost effective	4	1	2	5	4



B. Kerem Demirci

Construction Option

The Apartment Building

PLANNING MATRIX

BIM Tools

Competitive Analysis (0=Worst, 5=Best)

	Design Authoring	Design Reviews	4D Modeling	3D Coordination	Site Utilization Planning	Field and Management Tracking
Finish under budget	3	3	3	4	2	1
Finish on budget	4	3	3	5	3	2
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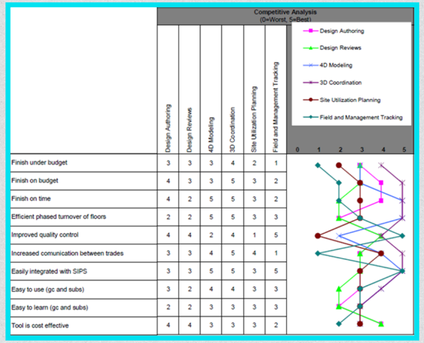

Data Collection Tools

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	Flow Diagram and Process Chart	Activity Sampling	Labor Utilization Factors	Foreman Delay Survey	Record Workforce Activities
Finish under budget	4	2	2	3	2
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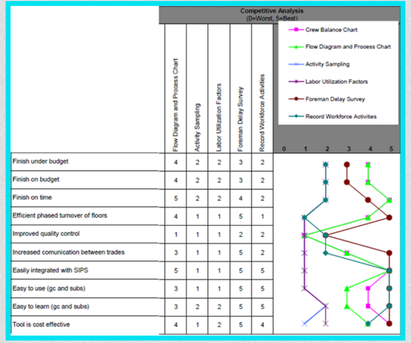
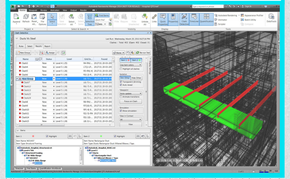


FINAL TOOL SELECTION

Design Authoring

http://sicad-sa.com/Revit/3D%20View-%20NorthWest.jpg

3D Coordination



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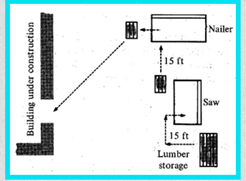
Flow Diagrams and Process Charts

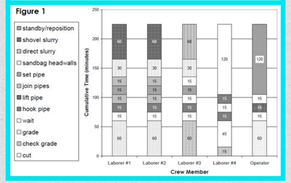


(Leicht 2014)

Foreman Delay Survey

	Electrical	Mechanical	Framing	Drywall	Insulation	Casework	Flooring	Total	Percent
Changes/ redo (design error or change)									
Changes/ redo (fabrication error)									
Changes/ redo (field error or damage)									
Waiting for material(s) (warehouse)									
Waiting for materials (vendor delay)									
Waiting for tools									
Waiting for construction equipment									
Construction equipment breakdown									
Waiting for information									
Waiting for other crews									
Waiting for fellow crew members									

Crew Balance Charts



(Kuprenas and Fakouri 2001)

Record Workforce

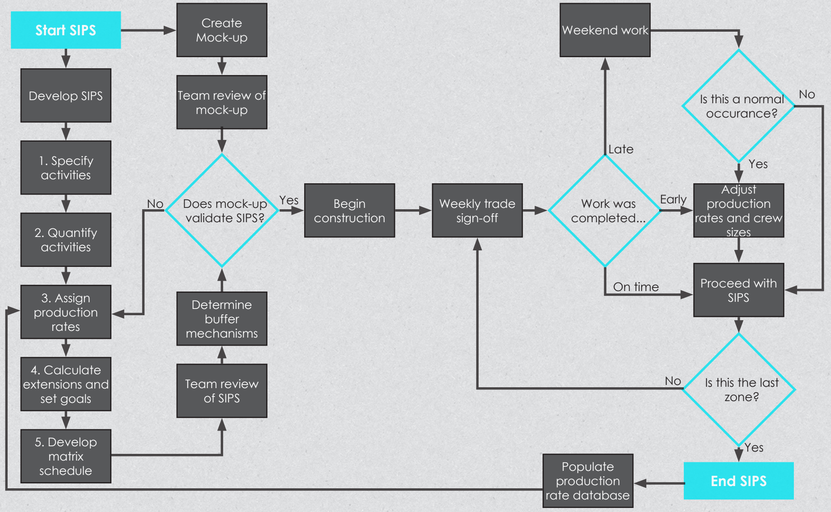
https://www.harbortronics.com/Products/TimeLapsePackage/web/TLP-F-2700-Open.1000.jpg

B. Kerem Demirci

Construction Option

The Apartment Building

ORIGINAL SIPS PROCESS MAP FOR INTERIOR FIT-OUT



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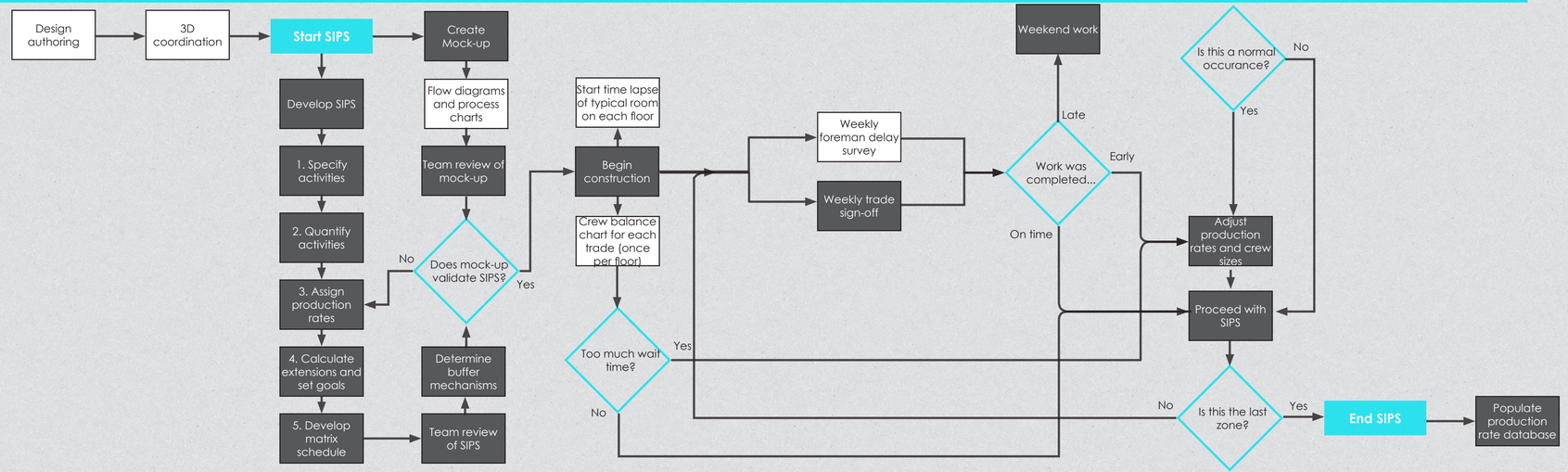
Construction Option

The Apartment Building

UPDATED SIPS PROCESS MAP FOR INTERIOR FIT-OUT



B. Kerem Demirci

Construction Option

The Apartment Building

FINAL RECOMMENDATIONS

ANALYSIS 1
Effect of Eco Certifications of Marketability

ANALYSIS 2
Exterior Enclosure Acceleration

ANALYSIS 3
SIPS for Interior Fit-out

ANALYSIS 4
Tools to Support SIPS Implementation

B. Kerem Demirci

Construction Option

The Apartment Building

FINAL RECOMMENDATIONS

ANALYSIS 1
Effect of Eco Certifications of Marketability

ANALYSIS 2
Exterior Enclosure Acceleration

ANALYSIS 3
SIPS for Interior Fit-out

ANALYSIS 4
Tools to Support SIPS Implementation

Upgrade to LEED Silver

- Rent premium for eco certifications exist
- Only 3 additional LEED points needed

B. Kerem Demirci

Construction Option

The Apartment Building

FINAL RECOMMENDATIONS

ANALYSIS 1
Effect of Eco Certifications of Marketability

ANALYSIS 2
Exterior Enclosure Acceleration

ANALYSIS 3
SIPS for Interior Fit-out

ANALYSIS 4
Tools to Support SIPS Implementation

Upgrade to LEED Silver
- Rent premium for eco certifications exist
- Only 3 additional LEED points needed

Implement PBVSS System
- 44 day onsite schedule reduction justifies $70,000 increase in cost
- Improved safety
- Improved quality

B. Kerem Demirci

Construction Option

The Apartment Building

FINAL RECOMMENDATIONS

ANALYSIS 1
Effect of Eco Certifications of Marketability

ANALYSIS 2
Exterior Enclosure Acceleration

ANALYSIS 3
SIPS for Interior Fit-out

ANALYSIS 4
Tools to Support SIPS Implementation

- Upgrade to LEED Silver
  - Rent premium for eco certifications exist
  - Only 3 additional LEED points needed
- Implement PBVSS System
  - 44 day onsite schedule reduction justifies $70,000 increase in cost
  - Improved safety
  - Improved quality
- Implement SIPS for Inteior Fit-out and follow the SIPS process map
  - Ensures timely turnover of floors
  - Increased productivity
  - Increased quality control

B. Kerem Demirci

Construction Option

The Apartment Building

FINAL RECOMMENDATIONS

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Effect of Eco Certifications of Marketability

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Exterior Enclosure Acceleration

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ANALYSIS 4
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  - Rent premium for eco certifications exist
  - Only 3 additional LEED points needed
- Implement PBVSS System
  - 44 day onsite schedule reduction justifies $70,000 increase in cost
  - Improved safety
  - Improved quality
- Implement SIPS for Inteior Fit-out and follow the SIPS process map
  - Ensures timely turnover of floors
  - Increased productivity
  - Increased quality control
- Supplement SIPS process with:
  - Design authoring
  - 3D coordination
  - Crew balance charts
  - Flow diagram and process charts
  - Foreman delay surveys
  - Time lapse video
  - Selected tools meet the customer's requirements
  - Are easily implemented into SIPS process

ACADEMIC

Dr. Messner

Dr. Solnosky

Dr. Memari

Acknowledgments

Mom, Dad, Deniz and Arif

INDUSTRY

John Moriarty and Associates

BMPI, LLC

B. Kerem Demirci
Construction Option

The Apartment Building

East Coast, USA

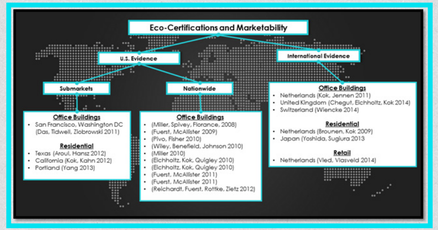
The Pennsylvania State University
Advisor: Dr. Messner

B. Kerem Demirci

Construction Option

The Apartment Building

ANALYSIS 1: EFFECTS OF ECO CERTIFICATIONS ON MARKETABILITY

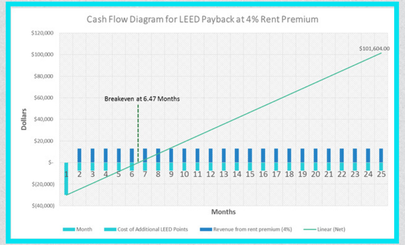


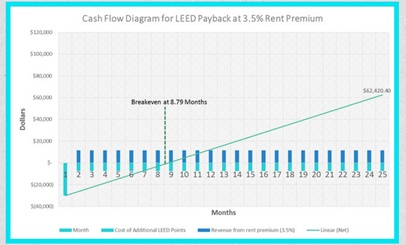
Existing Literature Results

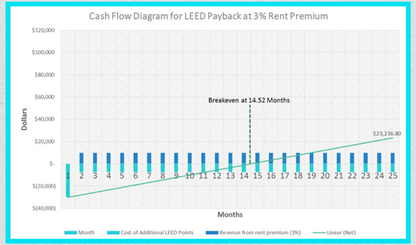
	Publication Year	Author(s)	Location	Data Period	Data Source	Sample	Rent Premium	Sales Premium
Office Buildings	2014	Wiencke	Switzerland	-	University of Zurich	Survey	3%	4.75%
	2014	Chegut, Eichholtz, Kok	UK	2000-2009	CoStar Database	BREEAM	20%	15%
	2012	Reichardt, Fuerst, Rottke,	US	2004-2008	CoStar Database	Energy Star	2.50%	-
				2008-2009		LEED	2.90%	-
	2011	Das, Tidwell, Ziobrowski	San Francisco and DC, US	2007-2010	CoStar Database	LEED/Energy Star	0.1% - 2.4%	-
	2011	Fuerst, McAllister	US	-	CoStar Database	Energy Star	4%	26%
						LEED	5%	25%
	2011	Fuerst, McAllister	US	-	CoStar Database	Energy Star	3-4%	18%
						LEED	4-5%	25%
	2011	Kok, Jennen	Netherlands	-	-	Energy Labels	7%	-
	2010	Eichholtz, Kok, Quigley	US	?	CoStar Database	Energy Star	2%	13%
						LEED	6%	11%
	2010	Eichholtz, Kok, Quigley	US	2007	CoStar Database	Energy Star	3%	16%
						LEED	5%	16%
	2010	Miller	US	2008-2010	CoStar Database	LEED	12%	15%
	2010	Wiley, Benefield, and Johnson	US	2008	CoStar Database	Energy Star	7%-9%	-
						LEED	16%-17%	-
	2010	Pivo, Fisher	US	-	CoStar Database	Energy Star	3%	3%
	2009	Fuerst, McAllister	US	2009	CoStar Database	Energy Star	5%	31%
						LEED	6%	35%
	2008	Miller, Spivey, Florance	US	2003-2007	CoStar Database	Energy Star	8%	6%
						LEED	8%	10%
Retail	2014	Veld, Vlasveld	Netherlands	1820 - 2007	CBRE Global Investors	Energy Performance Certificate	-0.52%	-0.60%
Residential	2013	Yoshida, Sugiura	Tokyo, Japan	2002-2009	TPIS	14	-	-
	2013	Yang	Portland, US	2009-2012	-	LEED NC Certified	-	5.80%
						LEED ND Certified	-	3%
	2012	Kok, Kahn	California, US	2007-2012	DataQuick	Energy Star / LEED / GreenPoint	-	9%
	2012	Aroul, Hansz	Texas, US	2002-2009	NTREIS	Green Buildings	-	2%-4%
	2011	Brounen, Kok	Netherlands	2009	Agentschap NL	Energy Labels	-	4%

Credit	Points	Cost
Green Power	2	$181,865
Mechanical System Flush	1	$30,000
Total (over two years)	**3**	**$211,865**

Unit type	SF	Quantity	Average Rent
Studio	523	26	$1,600
Jr. One Bedroom	669	40	$1,700
One Bedroom	738	37	$1,780
One Bedroom + Den	811	38	$2,290
Two Bedroom	956	15	$2,545
Two Bedroom +Den	1054	9	$2,875
Total monthly revenue			$326,530







B. Kerem Demirci

Construction Option

The Apartment Building

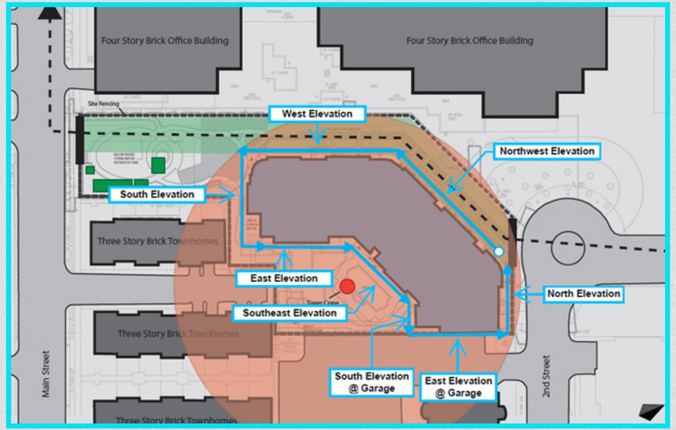
ANALYSIS 2: EXTERIOR ENCLOSURE ACCELERATION

Weight of PBVSS System

Item		Quantity	Unit	Weight (psf)
Brick Veneer	3-5/8"		SF	39
Rigid Insulation	1"		SF	0.75
Air Barrier			SF	0.7
Rigid Insulation	1"		SF	0.75
Plywood Sheathing	1/2"		SF	1
Batt Insulation	3-5/8"		SF	1.1
GWB	5/8"		SF	2
Steel Studs	12 gauge 3-5/8"		LF	4
Steel Relieving Angle	6x6x3/8		LF	1.5
Stud Shear Connector Ties			ea	1
Embeds with two stud (1/2" dia)	1/2x8x8			1
Steel Frame				2
		Total Weight		54.8

Maximum Panel Dimensions and Weight

Max panel height	10 ft.
Max panel length	38 ft.
Max panel weight	20,948 lbs.

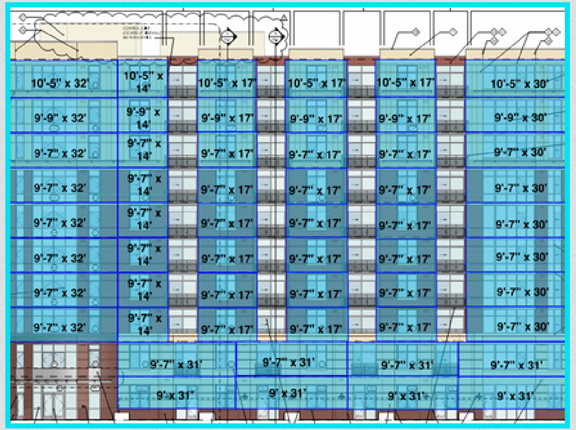


Total Panel Count

Elevation	# of Panels
North Elevation	26
East Elevation	31
East Elevation @ Garage	28
Southeast Elevation	31
South Elevation	17
South Elevation @ Garage	10
West Elevation	35
Northwest Elevation	56
Total	234

NW Elevation Panel Count

	Panel Height	Panel Length	Quantity
Northwest Elevation	10'-5"	32'	1
		30'	1
		17'	3
		14'	1
	9'-9"	32'	1
		30'	1
		17'	3
		14'	1
	9'-7"	32'	6
		31'	4
		30'	6
		17'	18
		14'	6
	9'	31'	4
		Total	56



NW Elevation Panel Breakdown

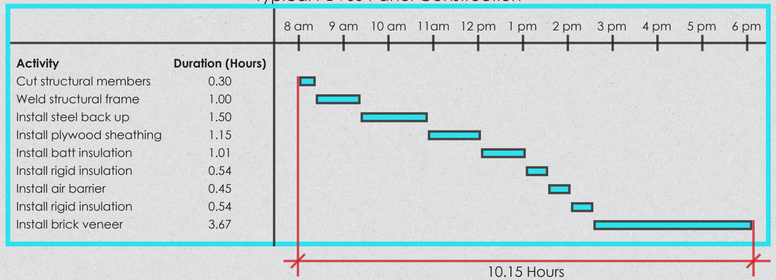
The Apartment Building

ANALYSIS 2: EXTERIOR ENCLOSURE ACCELERATION

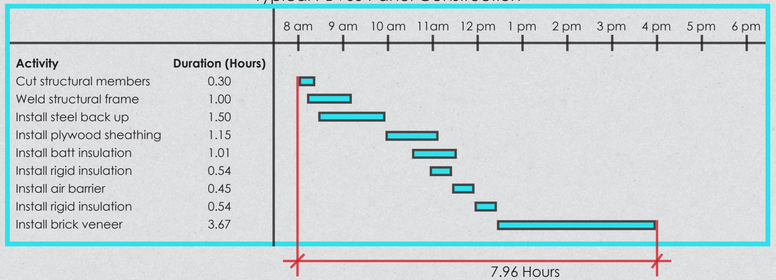
Construction Duration of a Typical PBVSS Panel

	Activity	Quantity	Unit	Total Duration (Hours
Offsite Work	Cut structural members	4	EA	0.30
	Weld structural frame	24	LF	1.00
	Install Steel Backup	150	LF	1.50
	Install Batt Insul	201	SF	1.15
	Install Plywood Sheathing	201	SF	1.01
	Install Rigid Insul	201	SF	0.54
	Install Air Barrier	201	SF	0.45
	Install Rigid Insul	201	SF	0.54
	Install Brick Veneer	201	SF	3.67
Total Offsite Duration for One Panel				10.15
Totall Offiste Duration for One Panel With Sequencing				8
Total Offisite Duration for all 234 Panels				**59 days**
Onsite Work	Hoisting and installation	201	SF	1.12
Total Onsite Duration for One Panel				1.12
Totall Oniste Duration for all 234 Panels				**33 days**

Typical PBVSS Panel Construction



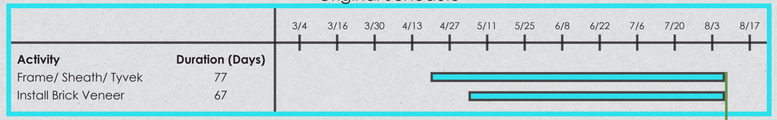
Typical PBVSS Panel Construction



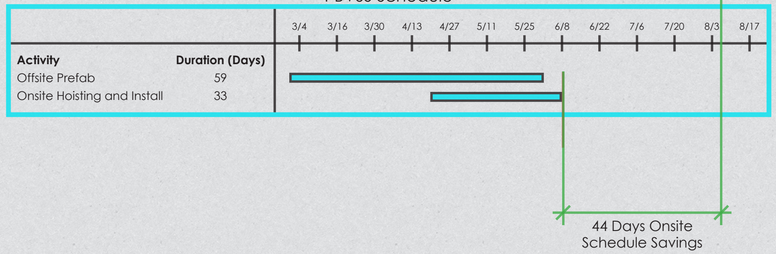
The Apartment Building

ANALYSIS 2: EXTERIOR ENCLOSURE ACCELERATION

Original Schedule



PBVSS Schedule



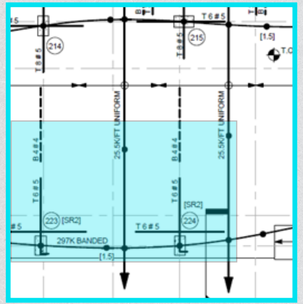
Original Brick Veneer Estimate

	Costcode	Item		Quantity	Unit	Unit Material	Unit Labor	Unit Equipment	Extended Total
04 21 13	132020	Brick Veneer	3-5/8"	201	SF	4.04	7.5		$ 2,319.54
07 21 13	102120	Rigid Insulation	1-1/2"	201	SF	0.48	0.49		$ 194.97
07 26 10	100700	Air Barrier		201	SF	0.0292	0.097		$ 25.37
09 29 10	302250	Gypsum Sheathing	5/8"	201	SF	0.47	0.74		$ 243.21
07 21 16	200080	Batt Insulation	3-5/8"	201	SF	0.32	0.27		$ 118.59
09 29 10	302090	GWB	5/8"	201	SF	0.37	0.93		$ 261.30
05 41 13	305140	Steel Studs	18 gauge 3-5/8"	150	LF	9.55	9.45		$ 2,850.00
05 12 23	400476	Steel Relieving Angle	6x6x3/8	20	LF	5.6	21.5	2.53	$ 592.60
04 05 19	161100	Adjustable Galvanized Brick Ties		105	ea	0.405	0.34		$ 78.23
05 12 23	650400	Embeds with two stud (1/2" dia)	1/2x8x8	6	ea	12.6632			$ 75.98
								Subtotal	**$ 6,759.78**
								Location Factor (0.93)	$ (473.18)
								Time Factor (1.04)	$ 270.39
								Tax (6% on Materials)	$ 168.63
								Subtotal	**$ 6,725.62**
								Extrapolated for Entire Brick Veneer	**$ 1,573,795.12**
01 54 26	500710	Swing Stage		6	mo	18000			$ 108,000.00
								Total Cost of Original Brick Veneer	**$ 1,681,795**

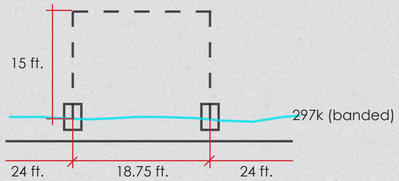
PBVSS Estimate

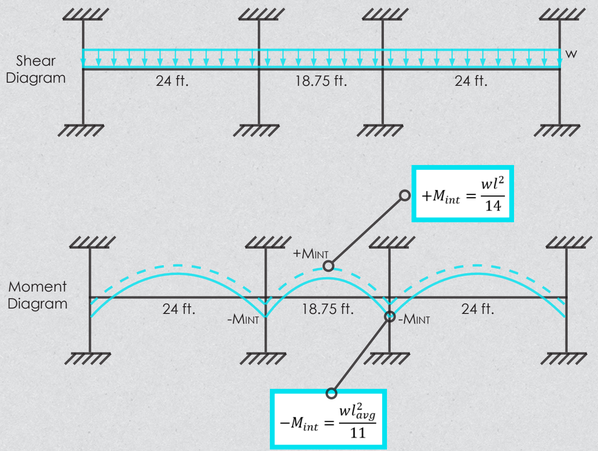
	Costcode	Item		Quantity	Unit	Unit Material	Unit Labor	Unit Equipment	Extended Total
04 21 13	132020	Brick Veneer	3-5/8"	201	SF	4.04	6		$ 2,018.04
07 21 13	102100	Rigid Insulation	1"	201	SF	0.24	0.36		$ 120.60
07 26 10	100700	Air Barrier		201	SF	0.0292	0.0776		$ 21.47
07 21 13	102100	Rigid Insulation	1"	201	SF	0.24	0.36		$ 120.60
07 46 29	101000	Plywood Sheathing	1/2"	201	SF	1.38	0.824		$ 443.00
07 21 16	200080	Batt Insulation	3-5/8"	201	SF	0.32	0.216		$ 107.74
09 29 10	302090	GWB	5/8"	201	SF	0.37	0.744		$ 223.91
05 41 13	308800	Steel Studs	18 gauge 3-5/8"	150	LF	9.55	7.56		$ 2,566.50
05 12 23	400476	Steel Relieving Angle	6x6x3/8	20	LF	5.6	17.2	2.53	$ 506.60
04 05 19	161100	Stud Shear Connector Ties		105	ea	0.405	0.272		$ 71.09
05 12 23	650400	Embeds with two stud (1/2" dia)	1/2x8x8	6	ea	12.6632	0		$ 75.98
05 12 23	400660	Steel frame		61.6	LF	1.39	8.48	1.25	$ 684.99
								Subtotal	**$ 6,960.52**
								Location Factor (0.93)	$ (487.24)
								Time Factor (1.04)	$ 298.60
								Tax (6% on Materials)	$ 184.75
								Subtotal	**$ 6,956.63**
								Total Onsite Construction Cost for all 234 Panels	**$ 1,627,850.31**
03 41 16	500050	Hoisting and Installation		234	ea		194.97	80.4	$ 64,436.58
		Warehouse Lease		3	month	12750			$ 38,250.00
		Transportation		78	trip	200			$ 15,600.00
		Forklift Rental		3	month	1,930			$ 5,790.00
								Total Offsite Construction Cost for all 234 Panels	**$ 124,076.58**
								Total Cost of PBVSS System	**$ 1,751,927**

The Apartment Building



4th Floor Slab Edge





B. Kerem Demirci

Construction Option

The Apartment Building

BREADTH 2: STRUCTURAL ANALYSIS OF PBVSS SYSTEM

Allowable Stress Analysis Equations

At Transfer at End of Beam

$$f_t = +\frac{Msw}{S} - \frac{P_i}{A} + \frac{P_i e}{S}$$

$$f_b = \frac{Msw}{S} - \frac{P_i}{A} - \frac{P_i e}{S}$$

$$\sigma_{ci} = 0.6 f'_{ci}$$

$$\sigma_t = 6\sqrt{f'_{ci}}$$

At Service at End of Beam

$$f_t = -\frac{Mtotal}{S} - \frac{P_e}{A} + \frac{P_e e}{S}$$

$$f_b = \frac{Mtotal}{S} - \frac{P_e}{A} - \frac{P_e e}{S}$$

$$\sigma_{ci} = 0.45 f'_c$$

$$\sigma_t = 7.5\sqrt{f'_c}$$

At Transfer at Mid-span of Beam

$$f_t = -\frac{Msw}{S} - \frac{P_i}{A} + \frac{P_i e}{S}$$

$$f_b = \frac{Msw}{S} - \frac{P_i}{A} - \frac{P_i e}{S}$$

$$\sigma_{ci} = 0.6 f'_{ci}$$

$$\sigma_t = 6\sqrt{f'_{ci}}$$

At Service at Mid-span of Beam

$$f_t = -\frac{Mtotal}{S} - \frac{P_e}{A} + \frac{P_e e}{S}$$

$$f_b = \frac{Mtotal}{S} - \frac{P_i}{A} - \frac{P_i e}{S}$$

$$\sigma_{ci} = 0.45 f'_c$$

$$\sigma_t = 7.5\sqrt{f'_c}$$

STRUCTURAL ANALYSIS OF EXISTING

Original Design Loads

		psf	plf
Live Loads	Private Rooms	40	600
		Total	**600**
Dead loads	SW of Conc		1312.5
	Brick Veneer	50	500
	Misc MEP	5	75
		Total	**1887.5**

Moment Coefficients Analysis

Selfweight		
w_{sw}	1.3125	klf
-Mint	68.73	ft.k
+Mint	32.96	ft.k
Total		
w_{total}	2.49	klf
-Mint	130.25	ft.k
+Mint	62.47	ft.k

Allowable Stress Analysis

Given		
f'c	3000	psi
f'ci	5000	psi
w_{total}	2.49	klf
SW	1.3125	klf
LL	0.6	klf
f_{pu}	270	ksi
f_{py}	243	ksi
transfer loss	35	ksi
(8) 1/2" dia. Tendons		
Eccentricity	0	in
f_{pi}	199.26	ksi
	199.8	ksi
f_{pe}	164.26	ksi
P_e	201.05	kips
P_i	243.89	kips

At Transfer At End				At Service At End			
f_t	-0.15	ksi	compression	f_t	-0.12	ksi	compression
f_b	-0.23	ksi	compression	f_b	-0.21	ksi	compression
σ_t	0.33	ksi		σ_t	0.53	ksi	
σ_{ci}	3.00	ksi		σ_{ci}	2.25	ksi	
$\sigma_{ci} > f_t, f_b$			PASS	$\sigma_{ci} > f_t, f_b$			PASS
At Transfer At Midspan				**At Service At Midspan**			
f_t	-0.17	ksi	compression	f_t	-0.18	ksi	compression
f_b	-0.16	ksi	compression	f_b	-0.19	ksi	compression
σ_t	0.09	ksi		σ_t	0.53	ksi	
σ_{ci}	1.80	ksi		σ_{ci}	2.25	ksi	
$\sigma_{ci} > f_t, f_b$			PASS	$\sigma_{ci} > f_t, f_b$			PASS

STRUCTURAL ANALYSIS WITH PBVSS SYSTEM

Original Design Loads

		psf	plf
Live Loads	Private Rooms	40	600
		Total	**600**
Dead loads	SW of Conc		1312.5
	PBVSS Panels	55	550
	Misc MEP	5	75
		Total	**1937.5**

Moment Coefficients Analysis

Selfweight		
w_{sw}	1.3125	klf
-Mint	68.73	ft.k
+Mint	32.96	ft.k
Total		
w_{total}	2.54	klf
-Mint	132.87	ft.k
+Mint	63.72	ft.k

Allowable Stress Analysis

Given		
f'c	3000	psi
f'ci	5000	psi
w_{total}	2.54	klf
SW	1.3125	klf
LL	0.6	klf
f_{pu}	270	ksi
f_{py}	243	ksi
transfer loss	35	ksi
(8) 1/2" dia. Tendons		
Eccentricity	0	in
f_{pi}	199.26	ksi
	199.8	ksi
f_{pe}	164.26	ksi
P_e	201.05	kips
P_i	243.89	kips

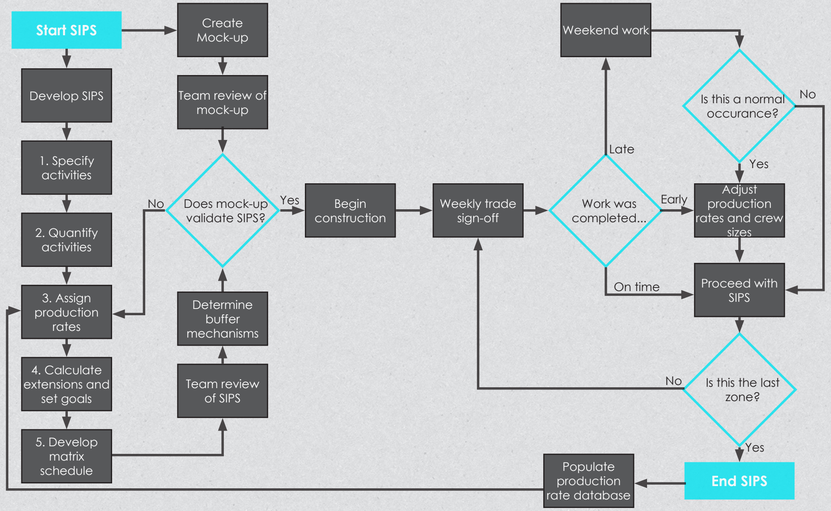
At Transfer At End				At Service At End			
f_t	-0.15	ksi	compression	f_t	-0.12	ksi	compression
f_b	-0.24	ksi	compression	f_b	-0.21	ksi	compression
σ_t	0.33	ksi		σ_t	0.53	ksi	
σ_{ci}	3.00	ksi		σ_{ci}	2.25	ksi	
$\sigma_{ci} > f_t, f_b$			PASS	$\sigma_{ci} > f_t, f_b$			PASS
At Transfer At Midspan				**At Service At Midspan**			
f_t	-0.17	ksi	compression	f_t	-0.18	ksi	compression
f_b	-0.16	ksi	compression	f_b	-0.19	ksi	compression
σ_t	0.09	ksi		σ_t	0.53	ksi	
σ_{ci}	1.80	ksi		σ_{ci}	2.25	ksi	
$\sigma_{ci} > f_t, f_b$			PASS	$\sigma_{ci} > f_t, f_b$			PASS

B. Kerem Demirci

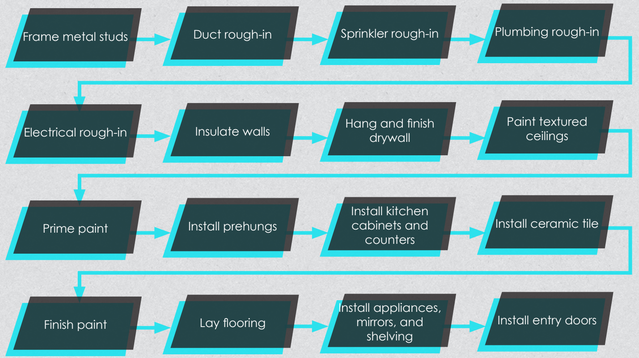
Construction Option

The Apartment Building

ANALYSIS 3: SIPS FOR INTERIOR FIT-OUT



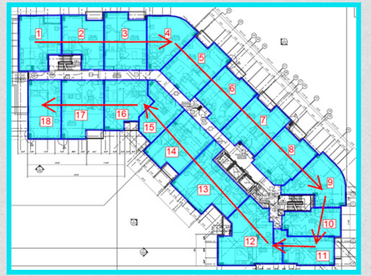
1. Specify Activities



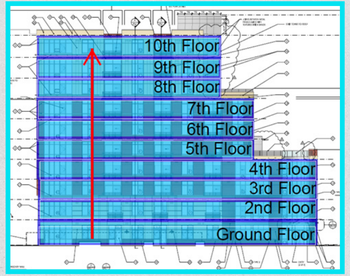
1. Specify Activities

Apartment Units per Floor

Floor	Square Footage	# of Units
Ground	16800	7
2	16800	18
3-4	16800	20
5	15000	16
6-7	15000	18
8-10	13500	16



6th and 7th floor zone breakdown and sequencing



Vertical sequencing (west elevation)

B. Kerem Demirci

Construction Option

The Apartment Building

ANALYSIS 3: SIPS FOR INTERIOR FIT-OUT

4. Calculate Extensions and Set Goals

Required Crew Size for Activities (2nd Floor, 18 units)

ID	Activity	Quantity	Unit	Budget Duration	Units	Budget Production	Worker Production	Units	Required Crew Size
A1	Frame metal studs	3042	LF	5	Days	608	75	LF/Day	9
A2	Duct rough-in	13338	SF	5	Days	2668	400	SF floor area/Day	7
A3	Sprinkler rough-in	13338	SF	5	Days	2668	470	SF floor area/Day	6
A4	Plumbing rough-in	13338	SF	5	Days	2668	320	SF floor area/ Day	9
A5	Electrical rough-in	13338	SF	5	Days	2668	300	SF floor area/ Day	9
A6	Insulate walls	3042	LF	5	Days	608	2000	SF/Day	1
A7	Hang and finish drywall	36774	SF	5	Days	7355	750	SF/Day	10
A8	Paint textured Ceilings	13338	SF	5	Days	2668	1000	SF/Day	3
A9	Prime paint	36774	SF	5	Days	7355	1800	SF/Day	5
A10	Install prehungs	90	ea	5	Days	18	16	Units/Day	2
A11	Install kitchen cabinets and counters	1620	SF face	5	Days	324	80	SF cabinet face/ Day	5
A12	Install ceramic tile	720	SF	5	Days	144	62.5	SF/Day	3
A13	Finish Paint	36774	SF	5	Days	7355	1800	SF/Day	5
A14	Lay flooring	12600	SF	5	Days	2520	600	SF/Day	5
A15	Install appliances and shelving	108	ea	5	Days	22	8	Units/Day	3
A16	Install entry doors	18	ea	5	Days	4	16	Units/Day	1

5. Develop Matrix Schedule

Matrix Schedule for 2nd through 10th Floor

Floor	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2	9	7	6	9	9	1	10	3	5	2	5	3	5	5	3	1								
3		10	8	7	10	10	1	11	3	5	2	5	3	5	5	3	1							
4			10	8	7	10	10	1	11	3	5	2	5	3	5	5	3	1						
5				8	6	6	8	8	1	9	3	4	1	4	3	4		3	1					
6					9	7	6	9	9	1	10	3	5	2	5	3	5	5	3	1				
7						9	7	6	9	9	1	10	3	5	2	5	3	5	5	3	1			
8							8	6	6	8	8	1	9	3	4	1	4	3	4	3	3	1		
9								8	6	6	8	8	1	9	3	4	1	4	3	4	4	3	1	
10									8	6	6	8	8	1	9	3	4	1	4	3	4	4	3	1
Total labor	9	17	24	32	41	43	50	52	58	49	48	44	40	37	39	29	25	22	20	15	12	8	4	1

SIPS Legend

- Frame metal studs
- Duct rough-in
- Sprinkler rough-in
- Plumbing rough-in
- Electrical rough-in
- Insulate walls
- Hang and finish drywall
- Paint textured Ceilings
- Prime paint
- Install prehungs
- Install kitchen cabinets and counters
- Install ceramic tile
- Finish Paint
- Lay flooring
- Install appliances, mirrors and shelving
- Install entry doors

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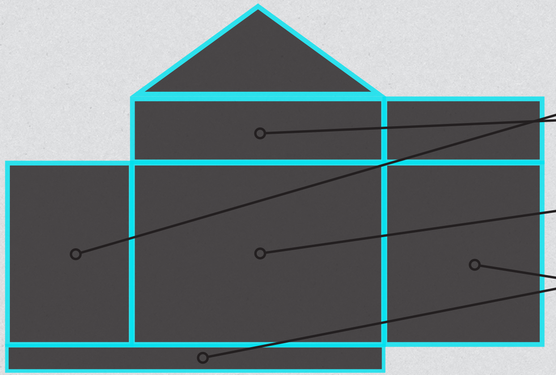
The Apartment Building

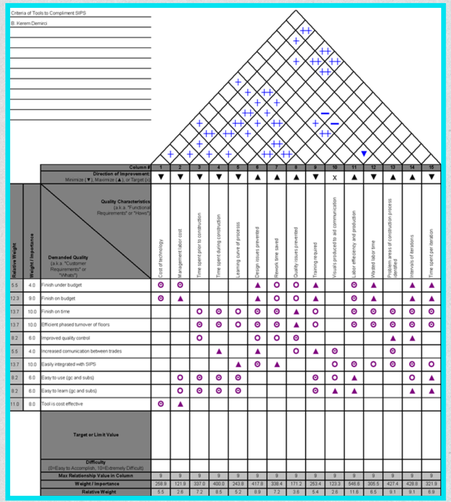
ANALYSIS 4: TOOLS TO SUPPORT SIPS IMPLEMENTATION



- 1.Customer Requirements
- 2.Technical Requirements
- 3. Interrelationship Matrix
- 4. Importance Benchmarks
- 5. Planning Matrix

- Finish under budget
- Finish on budget
- Finish on time
- Efficient phased turnover of floors
- Improved quality control
- Increased communication between trades
- Easily integrated with SIPS
- Easy to use
- Easy to learn
- Cost effective

- Cost of technology
- Management labor cost
- Time spent prior to construction
- Time spend during construction
- Learning curve of process
- Design issues prevented
- Rework time saved
- Quality issues prevented
- Training required
- Visuals produced to aid construction
- Labor efficiency and production
- Wasted labor time
- Problem areas of construction process identified
- Intervals of iterations
- Time spent per iteration



B. Kerem Demirci

Construction Option

The Apartment Building

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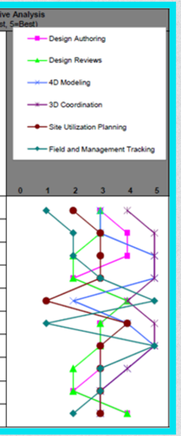
Importance Benchmarks		
Technical Requirement	**Relative Weight**	**Direction of Improvement**
Labor efficiency and production	11.6	Increase
Intervals of iterations	9.1	-
Problem areas of construction process identified	9.1	Increase
Design issues prevented	8.9	Increase
Time spent during construction	8.5	Decrease

BIM Tools

	Design Authoring	Design Reviews	4D Modeling	3D Coordination	Site Utilization Planning	Field and Management Tracking
Finish under budget	3	3	3	4	2	1
Finish on budget	4	3	3	5	3	2
Finish on time	4	2	5	5	3	2
Efficient phased turnover of floors	2	2	5	5	3	3
Improved quality control	4	4	2	4	1	5
Increased comunication between trades	3	3	4	5	4	1
Easily integrated with SIPS	3	3	5	5	3	5
Easy to use (gc and subs)	3	2	4	4	3	3
Easy to learn (gc and subs)	2	2	3	3	3	3
Tool is cost effective	4	4	3	3	3	2



Data Collection Tools

	Flow Diagram and Process Chart	Activity Sampling	Labor Utilization Factors	Foreman Delay Survey	Record Workforce Activities
Finish under budget	4	2	2	3	2
Finish on budget	4	2	2	3	2
Finish on time	5	2	2	4	2
Efficient phased turnover of floors	4	1	1	5	1
Improved quality control	1	1	1	2	2
Increased comunication between trades	3	1	1	5	2
Easily integrated with SIPS	5	1	1	5	5
Easy to use (gc and subs)	3	1	1	5	5
Easy to learn (gc and subs)	3	2	2	5	5
Tool is cost effective	4	1	2	5	4

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Construction Option

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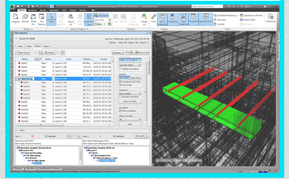
Design Authoring

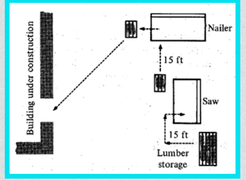
http://sicad-sa.com/Revit/3D%20View-%20NorthWest.jpg

3D Coordination



http://static-dc.autodesk.net/content/dam/autodesk/www/products/autodesk-navisworks-family/images/screenshots/clash-detective-large-1152x720.jpg

Flow Diagrams and Process Charts

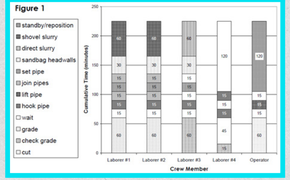


(Leicht 2014)

Foreman Delay Survey

	Electrical	Mechanical	Plumbing	Drywall	Insulation	Casework	Flooring	Total	Percent
Changes/ redo (design error or change)									
Changes/ redo (fabrication error)									
Changes/ redo (field error or damage)									
Waiting for materials (warehouse)									
Waiting for materials (vendor delay)									
Waiting for tools									
Waiting for construction equipment									
Construction equipment breakdown									
Waiting for information									
Waiting for other crews									
Waiting for fellow crew members									

Crew Balance Charts



(Kuprenas and Fakouri 2001)

Record Workforce

https://www.harbortronics.com/Products/TimeLapsePackage/web/TLP-F-2700-Open_1000.jpg