Case Study Of The Work Envelope Requirement Among Piping And Steel Trades And The Influence Of The Population

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Thesis Defense

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Department of Civil, Environmental, and Architectural Engineering

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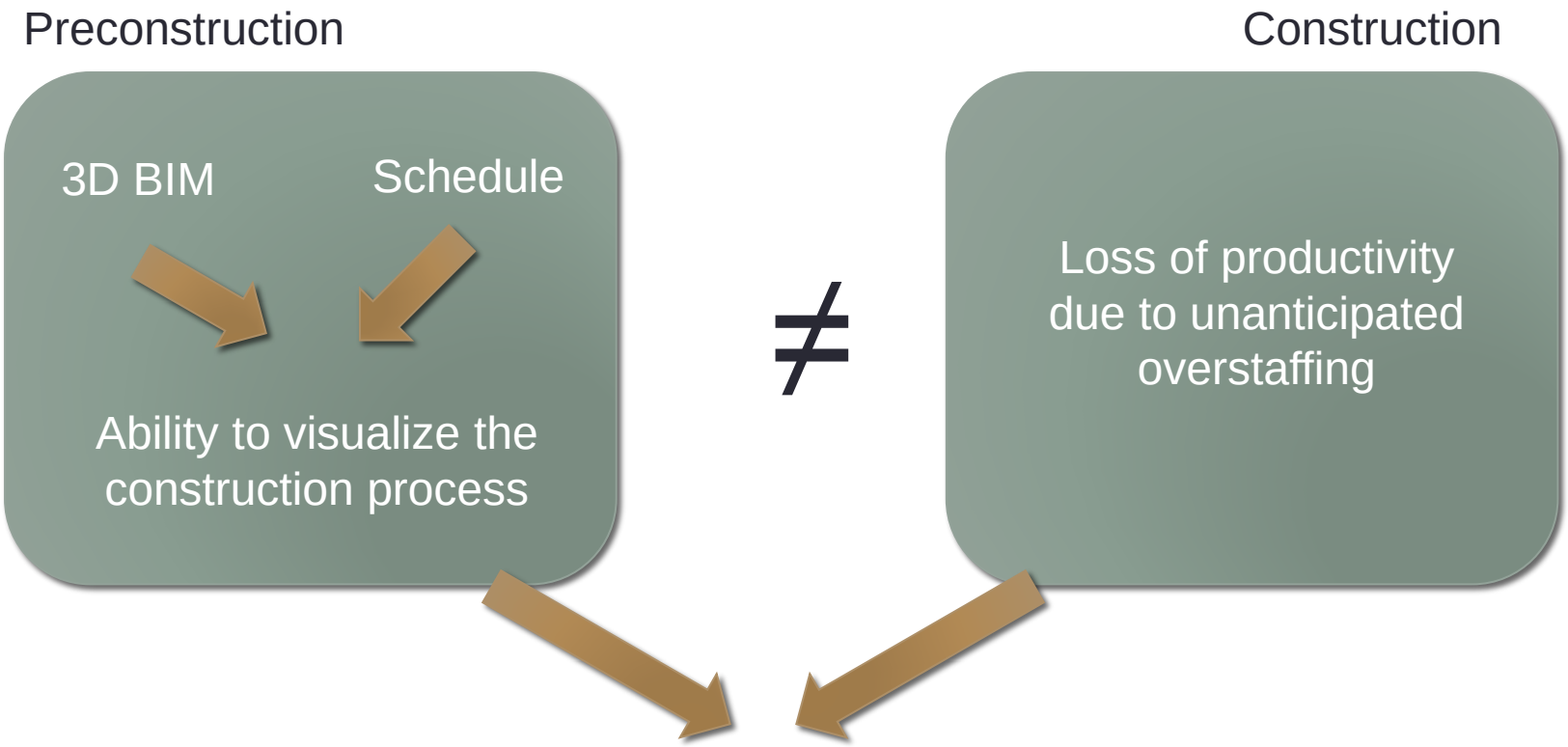
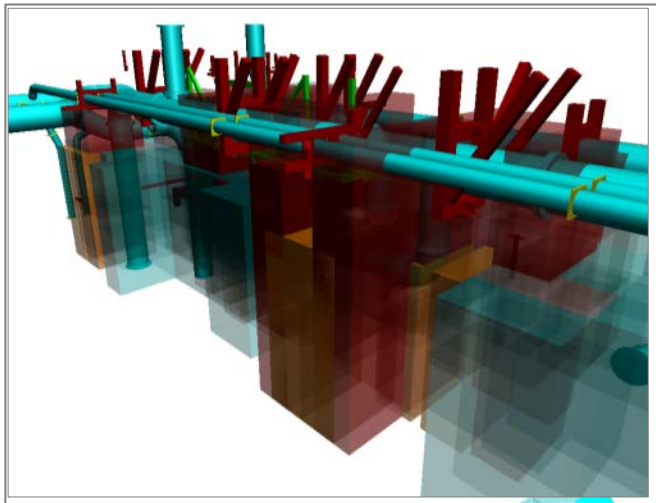
Background

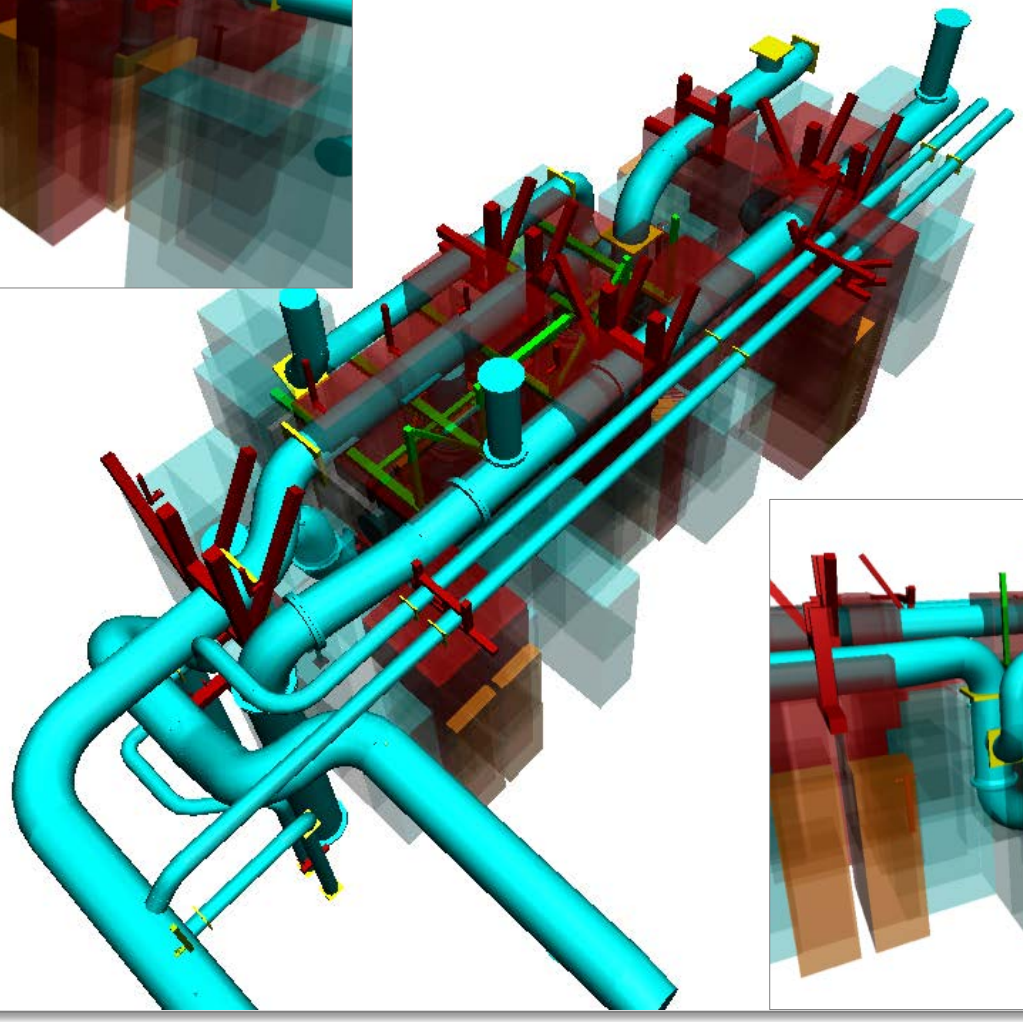


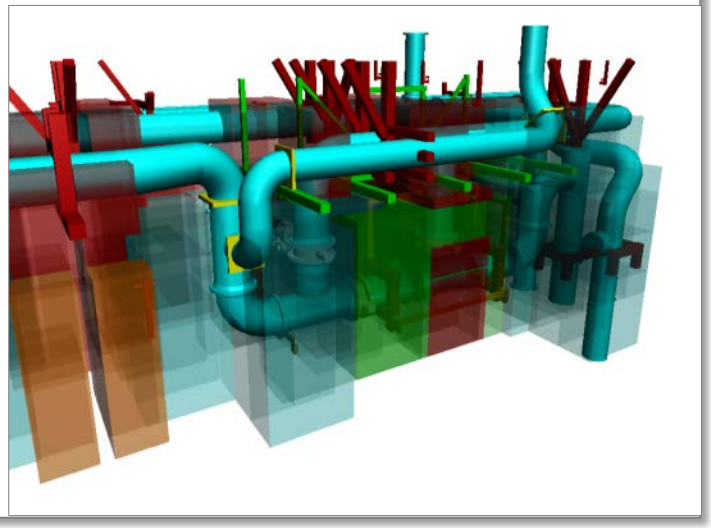
Integrate the knowledge of work envelope requirements to anticipate overstaffing & reduce productivity losses.

To **limit site overcrowding** we need to know the **space requirement** for each activity

3D Scaffolding planning for a plant







Selected previous researches

1979
U.S. Army Corps of Engineers

1997
Thabet & Beliveau

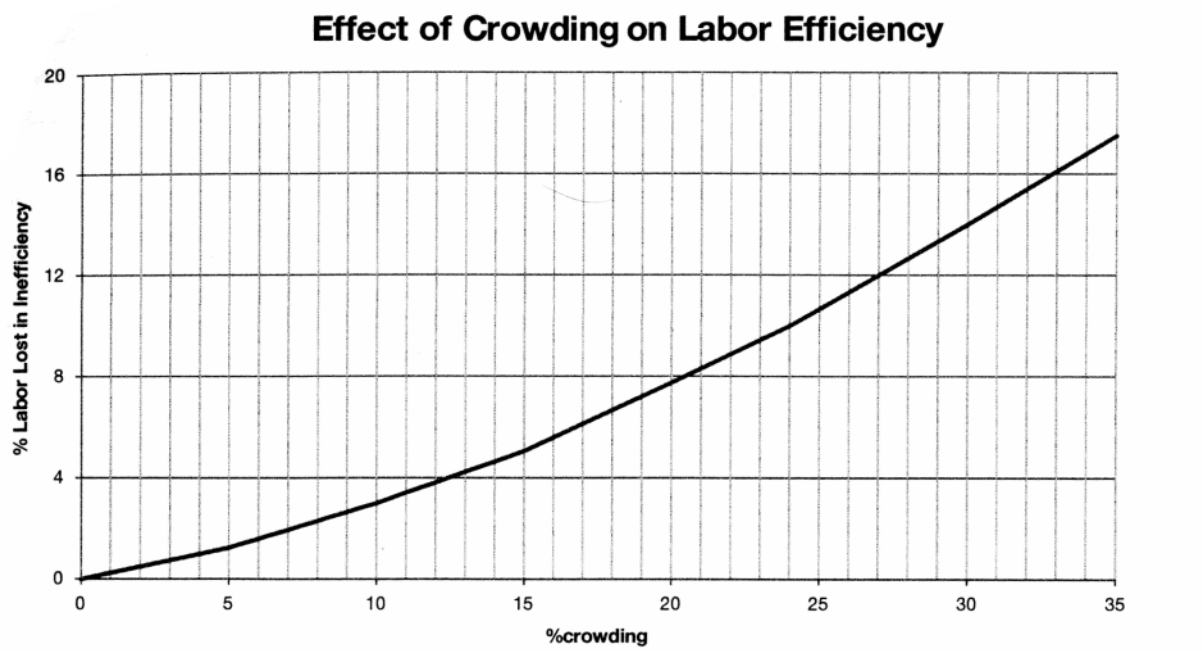
1997
Riley & Sanvido

2002
Burcu Akinci et al

2005
Zaki Mallasi

2011
Nashwan & Chavada

Overcrowding causes efficiency loss and cost increase



Source: *Modification Impact Evaluation Guide*, U.S. Army Corps of Engineers (1979)

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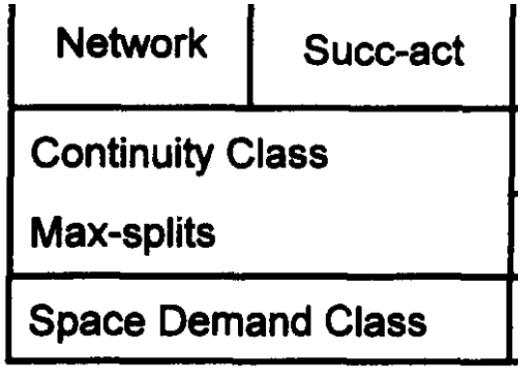
Zaki Mallasi

2011
Nashwan & Chavada

Space-Constrained and Resources-constrained scheduling for high-rise

Productivity and Space usage are linked with a curve



(a) Table-1 Ac

Table-2 Values are Based on Step Functio

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2011
Nashwan & Chavada

Schedule optimization through work-patterns

Macro level process

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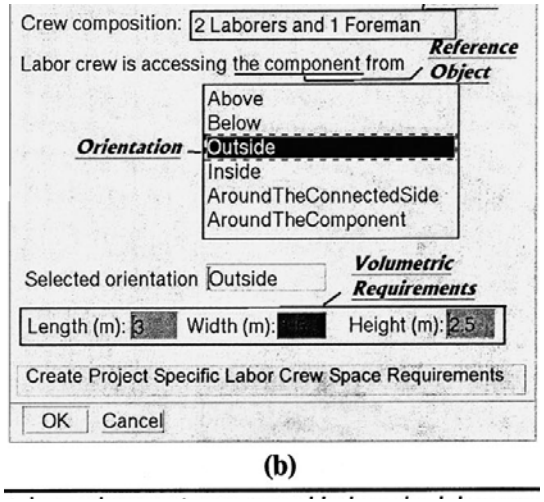
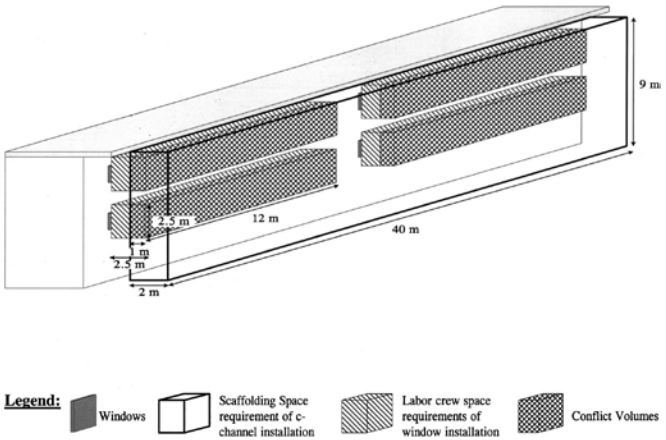
2011
Nashwan & Chavada

Developed a software: 4D WorkPlanner Time-Space Conflict Analyzer

Conflict ratio for prioritization

Limited automation of the work envelope drawing





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Developed a simulation environment for time-space conflicts

Optimization of work-pattern via genetic algorithm

Selected previous researches

1979 — U.S. Army Corps of Engineers

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1997 — Riley & Sanvido

2002 — Burcu Akinci et al

2005 — Zaki Mallasi

2011 — Nashwan & Chavada

Workspaces classification: personnel, storage, path…

Construction simulation software

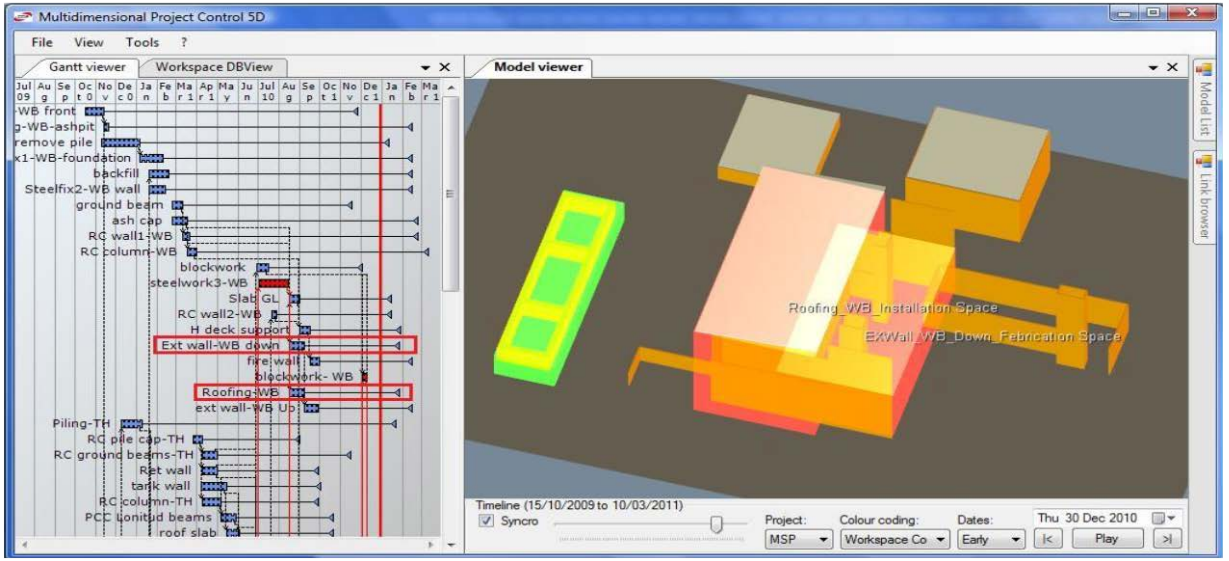


FIG 17: Detection of a conflict between 2 workspaces associated with 2 conflicting activities (i.e. Roofing WB and Ext wall-WB down)

The challenges

- Many possible usages of having known work envelopes mentioned in the literature
- But lack of initial data to perform the analysis

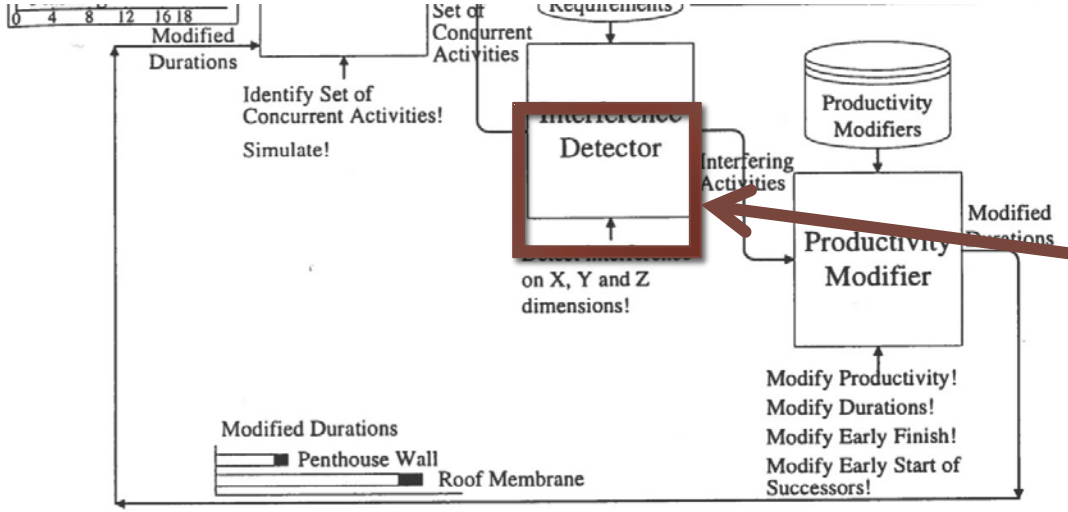


Figure 4. 4D WorkPlanner

Current reasoning process incorporated in 4D WorkPlanner accommodates only the productivity impacts of time-space conflicts. We are working on incorporation of constructability, safety and damage impacts of time-space conflicts

In interpreting the output of 4D WorkPlanner, the quantitative results such as

Unknown input data

From Akinci *et al.* (1998)

The challenges

How to define the work envelope?

- The planner doesn’t have the field knowledge
- The superintendent is not available
- Lengthy and Costly process

Heavily relies on subjective assessment

Research Methodology

1

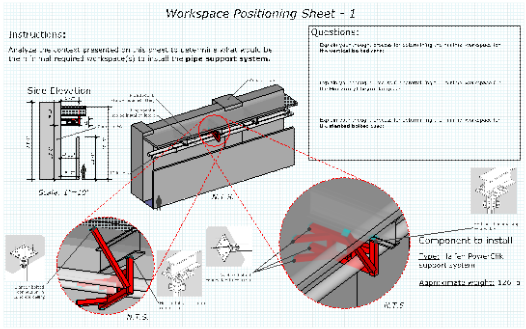
- Work envelope definition
  - In-depth interviews with Piping Superintendents
  - Relative definition
  - Developed decision trees
  - Focused on scaffolding

2

- Work envelope dimensioning
  - Anthropomorphic characteristics for various populations
  - Absolute definition

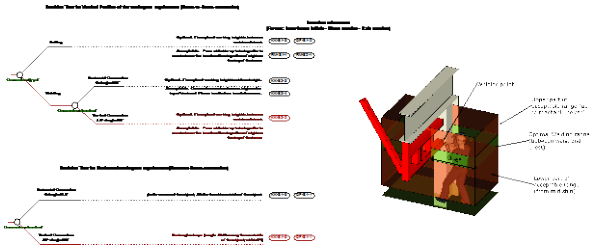
1 – Work Envelope Definition

Sample worksheet design → Professional's input gathering → Decision trees design



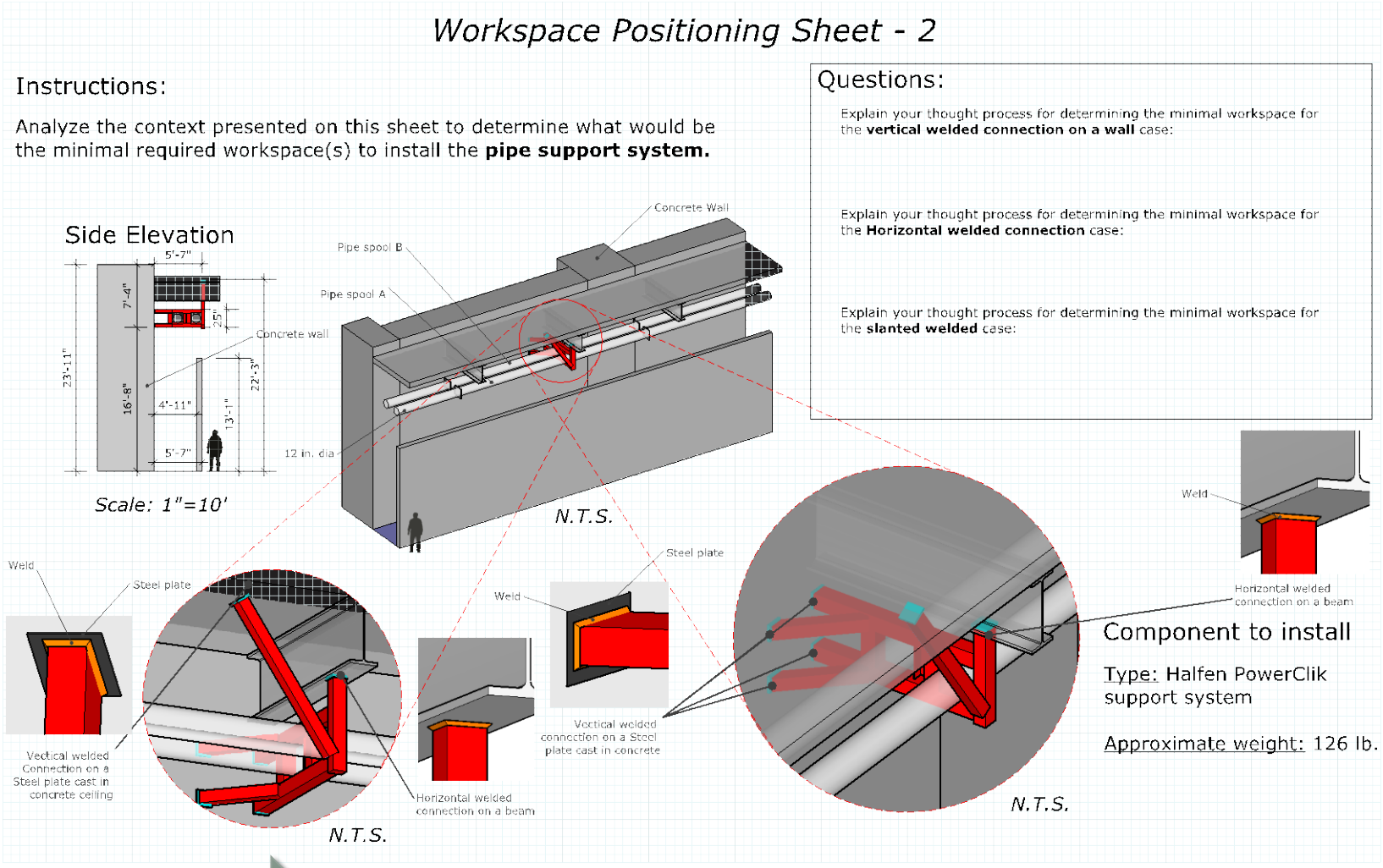
9 worksheets

- Sample of 5 Superintendents
- Experienced in steel and piping trades on oil and & gas projects
- Mainly in the U.S. Gulf Coast
- 2 Ex-superintendents Consultants from Bentley Systems Inc.



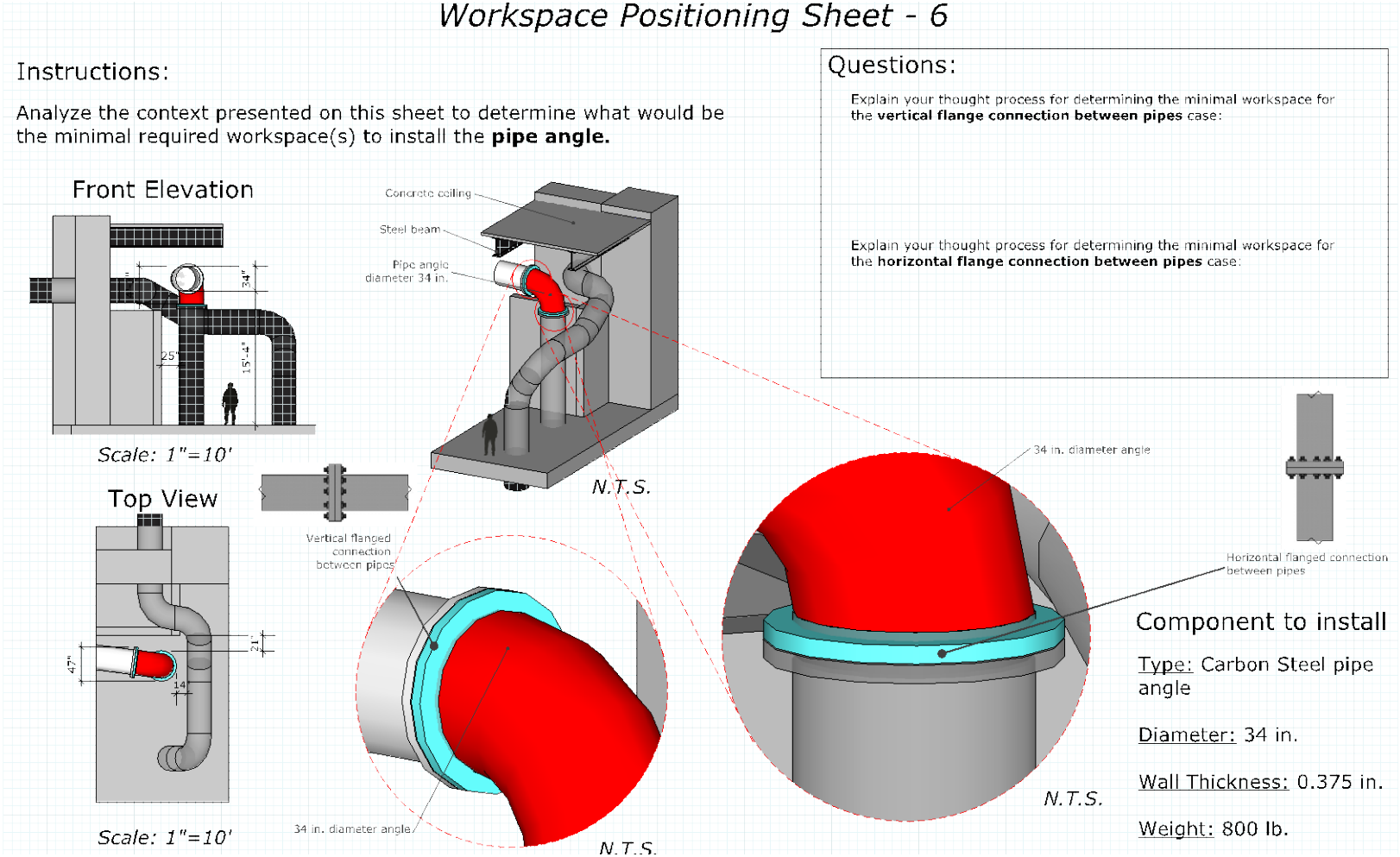
16 Decision trees

1 – Work Envelope Definition



9 Worksheets have been developed

1 – Work Envelope Definition



9 Worksheets have been developed

1 – Work Envelope Definition

Workspace Positioning Sheet - 7

Instructions:

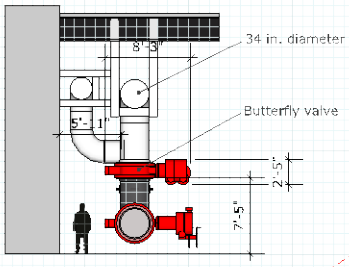
Analyze the context presented on this sheet to determine what would be the minimal required workspace(s) to install the **butterfly valve with large accuator.**

Questions:

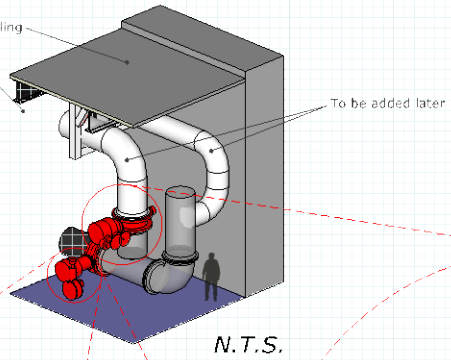
Explain your thought process for determining the minimal workspace for the **vertical butterfly valve** case:

Explain your thought process for determining the minimal workspace for the **horizontal butterfly valve** case:

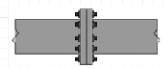
Side Elevation



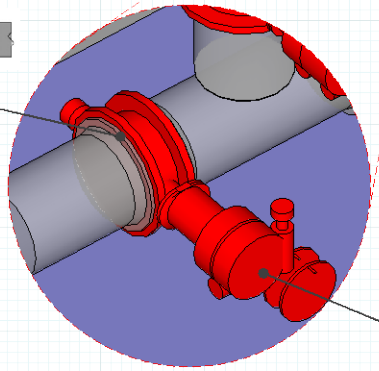
Scale: 1"=10'



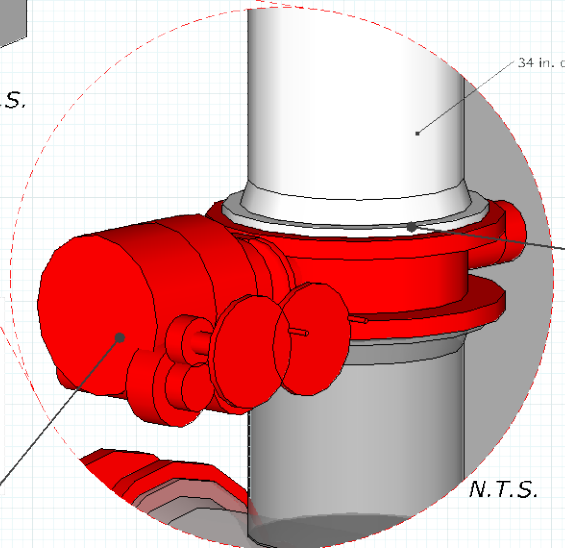
N.T.S.

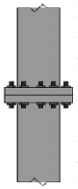


Vectical Flanged Connection with pipe



Butterfly valve





Component to Install

Type: Butterfly valve with large accuator

Diameter: 34 in.

Weight: 3'500 lb.

9 Worksheets have been developed

2 – Work envelope dimensioning

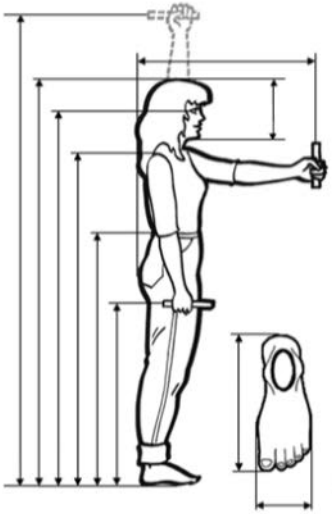
- The work envelope definition obtained is relative to body parts:
  - “at face height” (mainly for welding)
  - “between chest and waist” (mainly for bolting)
- How to translate this in practical dimensions (feet and inches)?
- Are work envelope different for different populations?

2 – Work envelope dimensioning

- Anthromorphic Data sources used:

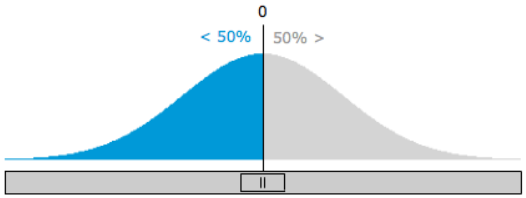
DINED

Data from: “International data on anthropometry” (1990)
International Labor Office Geneva



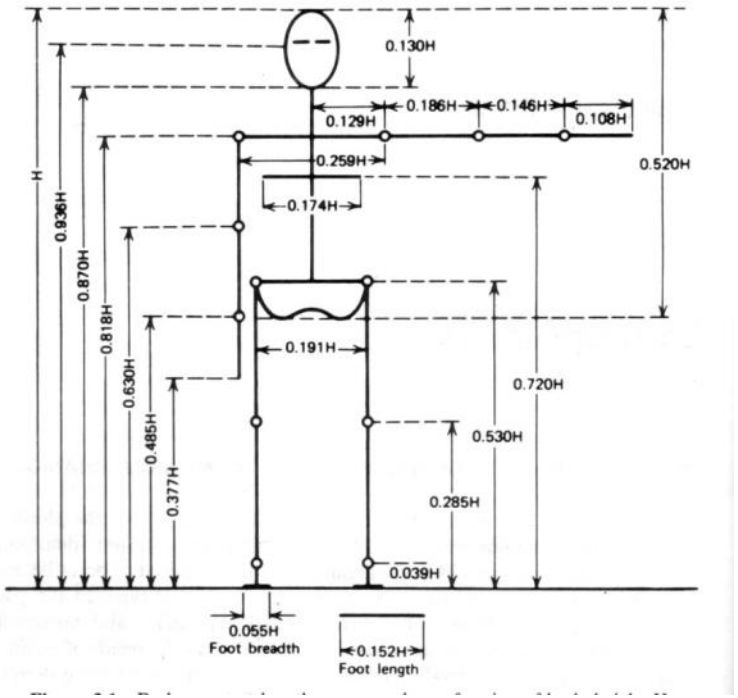
measure: stature
population: man

mean: 1660
standard deviation: 30



Drills & Contini

“Body segments parameters, Part II” (1970)



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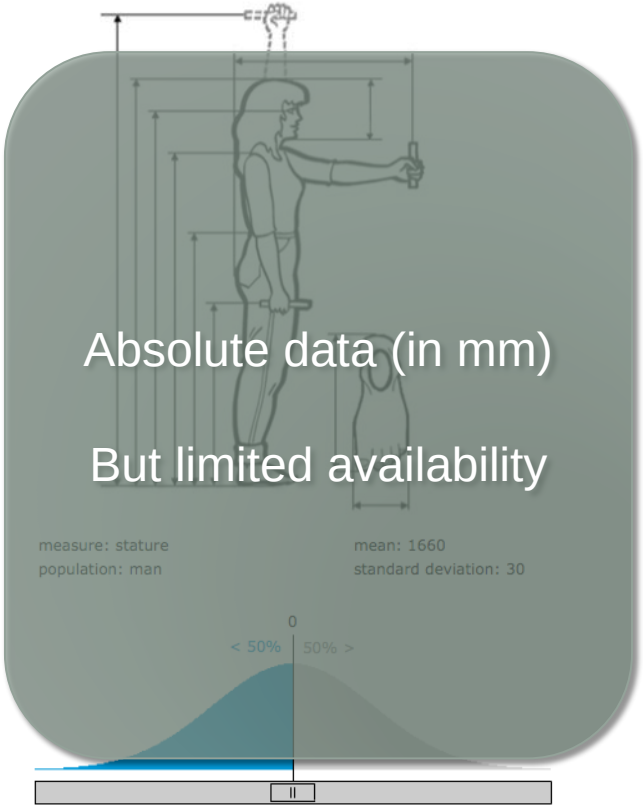

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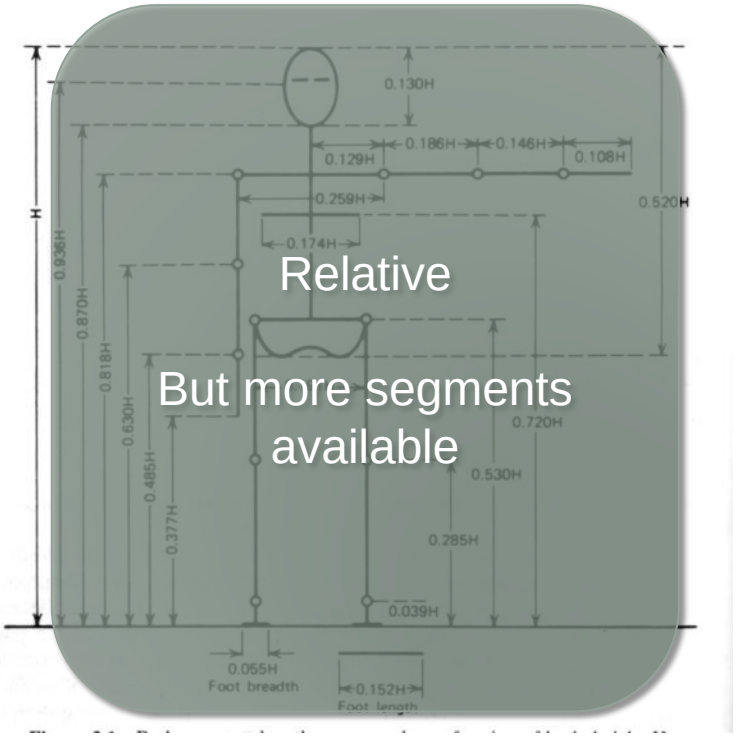
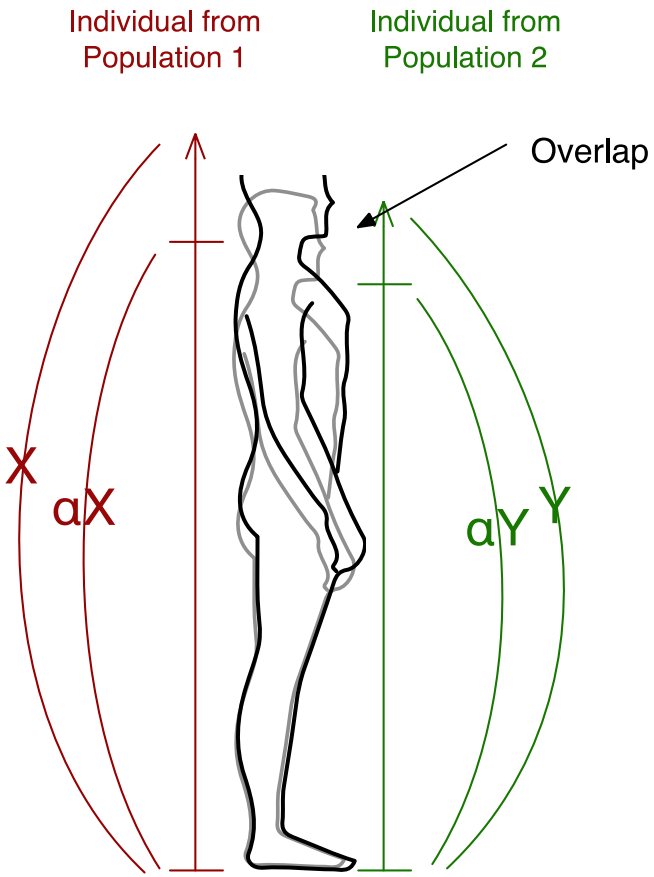


2 – Work envelope dimensioning

- Comparing populations

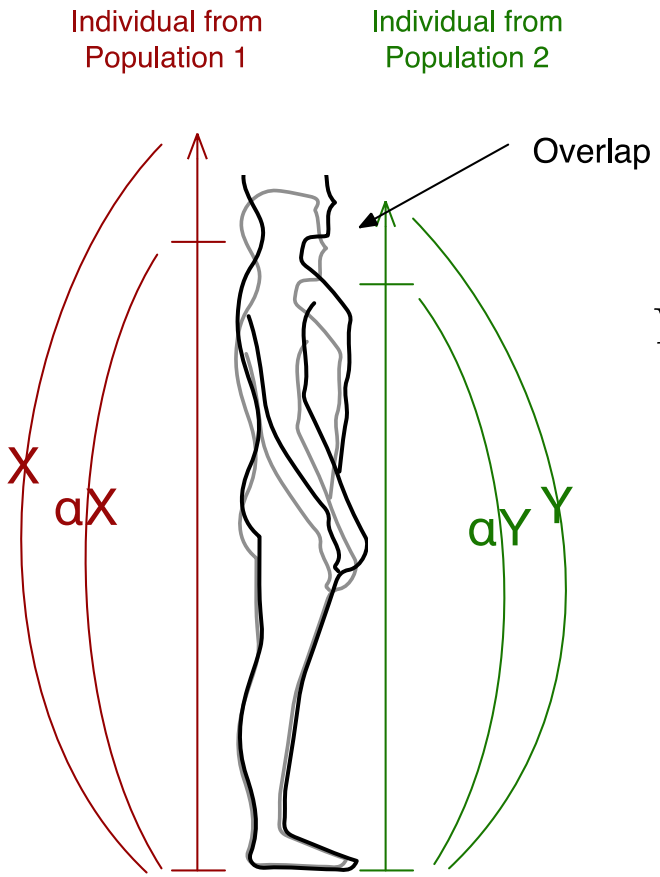


Population	Stature	
	Mean (mm)	Std Deviation
International	1780	79
North American	1790	70
Latin American (Rest)	1750	61
North Europe	1810	61
Eastern Europe	1750	58
North India	1670	58
South China	1660	30

Data from International Labor Office (1990)

2 – Work envelope dimensioning

- Comparing populations



α: Body parameter (0.870 for chin)
R: Overlap requirement

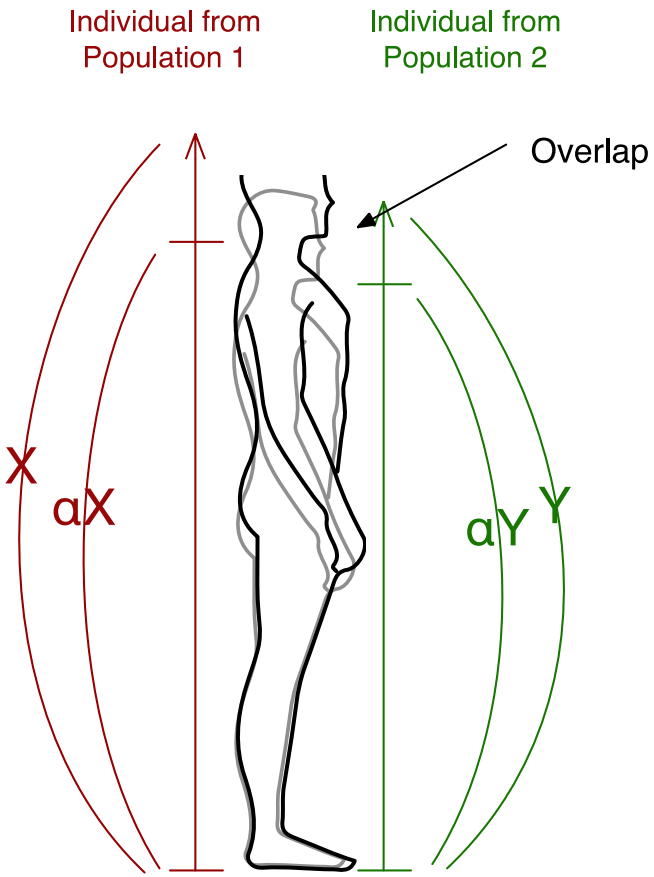
$$Y - \alpha X \geqslant (X - \alpha X)R \iff Y \geqslant (X - \alpha X)R + \alpha X$$
$$\iff Y \geqslant X(R - \alpha R + \alpha)$$
$$\iff Y - X(R - \alpha R + \alpha) \geqslant 0$$

Normal Normal

Normal

2 – Work envelope dimensioning

- Comparing populations



α: Body parameter (0.870 for chin)
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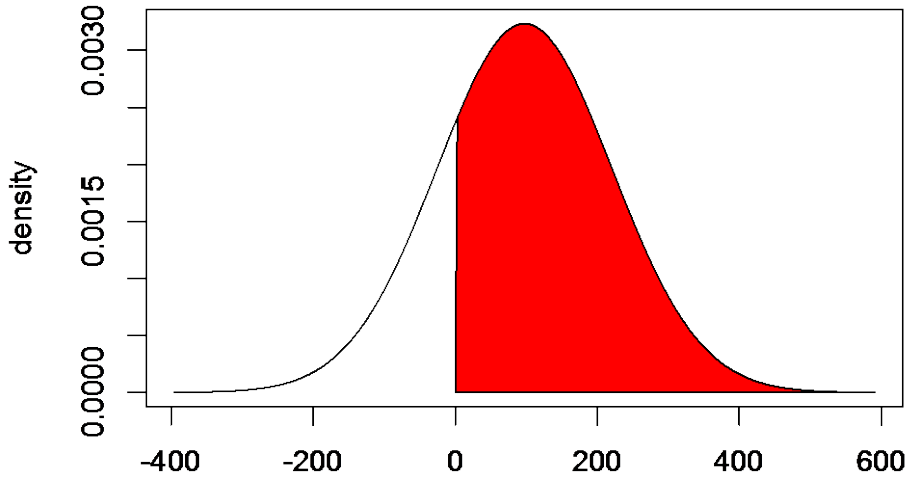
$$P(Y - X(R - \alpha R + \alpha) \geqslant 0$$



Results

1

- Work envelope definition
  - Interviews analysis
  - Decision Trees making

2

- Work envelope dimensioning
  - Anthropomorphic characteristics for various populations
  - Absolute definition

1 – Work Envelope Definition

Interviewee	Company	Drawing sheet	Rules mentioned	Reference Code
John Doe	Bentley	Sheet 1 – Bolted support system	The railing height on a scaffold is 3ft. Nothing should hit this threshold.	KK-S1-1
			The height of the platform is set using the highest elevation connection	KK-S1-2
			The optimal height for bolding is above waist and below chest (3-4ft above the platform)	KK-S1-3
			The number of levels of platform needed will be set given the vertical distance between the connections	KK-S1-4
			For a bolted connection to the wall there should be 3ft 6in from the wall	KK-S1-5
			3ft 6in space around the outside of the object is optimal (**in any situation**)	KK-S1-6
		Sheet 2 – Welded support system	The comfortable welding position is just below the chest to above the waist	KK-S2-1
			For vertical welds with sufficient clearence: just above the waist. (ie. 3ft from the platform for a 5'10" worker)	KK-S2-2
			Horizontal weld with sufficient head clearance: At face height (5'5")	KK-S2-3
			Horizontal weld with insufficient head clearance: comfortable reaching arm extension above the head	KK-S2-4
		Sheet 3 – Vertical pipe weld	For the vertical connection the width of the workspace can be 4ft. 4ft is the standard width of a scaffold and is about what is required to bolt/weld	KK-S3-1
		Sheet 4 – Other pipe weld	The bigger the pipe, the bigger the scaffold	KK-S4-1
		Sheet 5 – Other pipe weld (alternate phasing)		
		Sheet 6 – Flange connection	The worker need to see the top of the flange connection. Sometime he can "feel" the hole but it's not advisable for safety reasonts	KK-S6-1
		Sheet 7 – Butterfly valves	The larger the component the more workers	KK-S7-1
			8"-12" Bolted valve: 2 workers	KK-S7-2
			14"-24" Bolted valve: 3 to 4 workers	KK-S7-3
			Dont don't necessarly bigger workspace around. Stick with the 3ft 6in around.	KK-S7-4
		Sheet 8 – Small Butterfly valves	You will need to add another level of scaffold if the connection(s) are in a range bigger than between the "sweet spot" (between waist and chest) and the eyes (Applicable to all pipe connections)	KK-S8-1
			The "workable range for a worker is from 4-5in from the ground up to the eye level. (applicable broadly)	KK-S8-2
			The worker should be able to work on the actuator	KK-S8-3
			The actuator won't always fit in the 3ft 6in range so you have make sure that this space is still available even with the actuator	KK-S8-4
		Sheet 9 – Pipe Rack	Avoid to have people working below someone else for safety reasons. Try to stagger scaffolds	KK-S9-1
		Sheet 1 – Bolted support system	When bolting above head platform should be 5ft below connection	RM-S1-1
		Sheet 2 – Welded support system	When welding overhead from below the platform should be 5ft below connection	RM-S2-1
		Sheet 3 – Vertical pipe weld	For a pipe welding the worker should be able to see the top of the weld	RM-S3-1

1 – Work Envelope Definition

Interview analysis:

Removed unsafe suggested practices from analysis

“workers can stand on a bucket to perform welding”

Found that there was **optimal** and **acceptable** work envelope

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Identified “breakpoints” that have an impact on the work envelope

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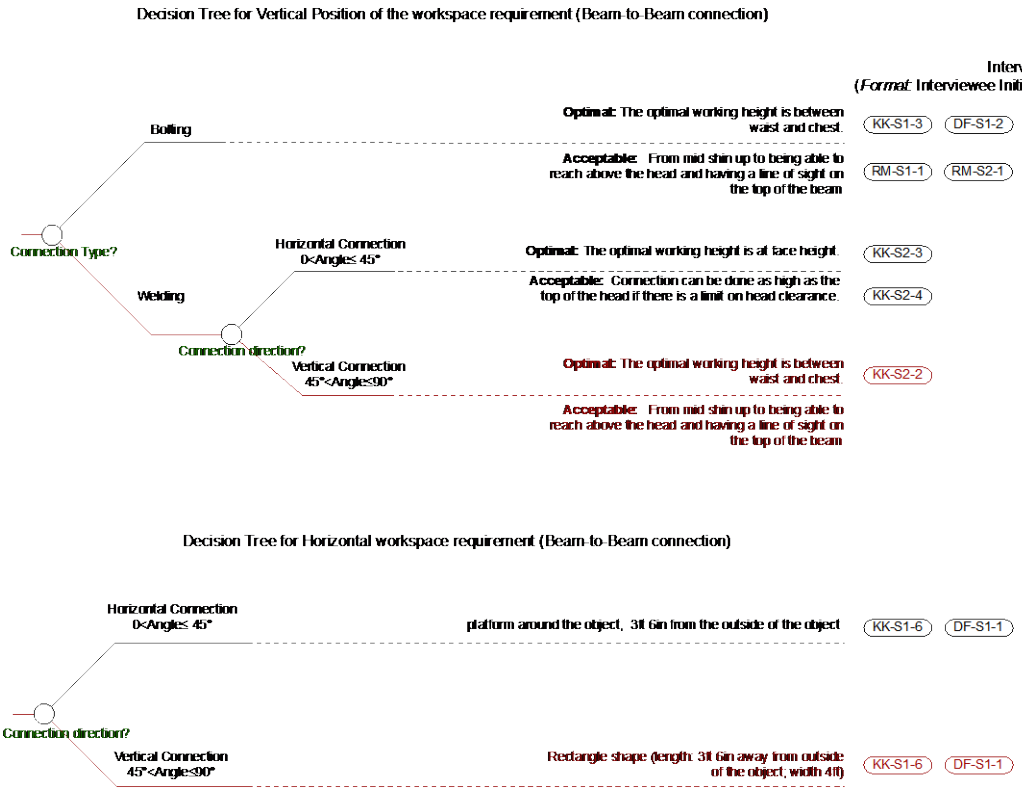
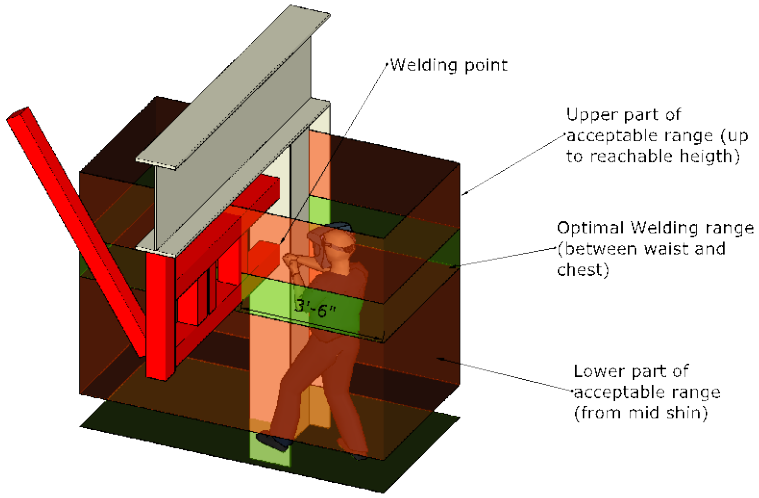
High level of agreement between the interviewee → High level of confidence

1 – Work Envelope Definition

Beam to Beam connection



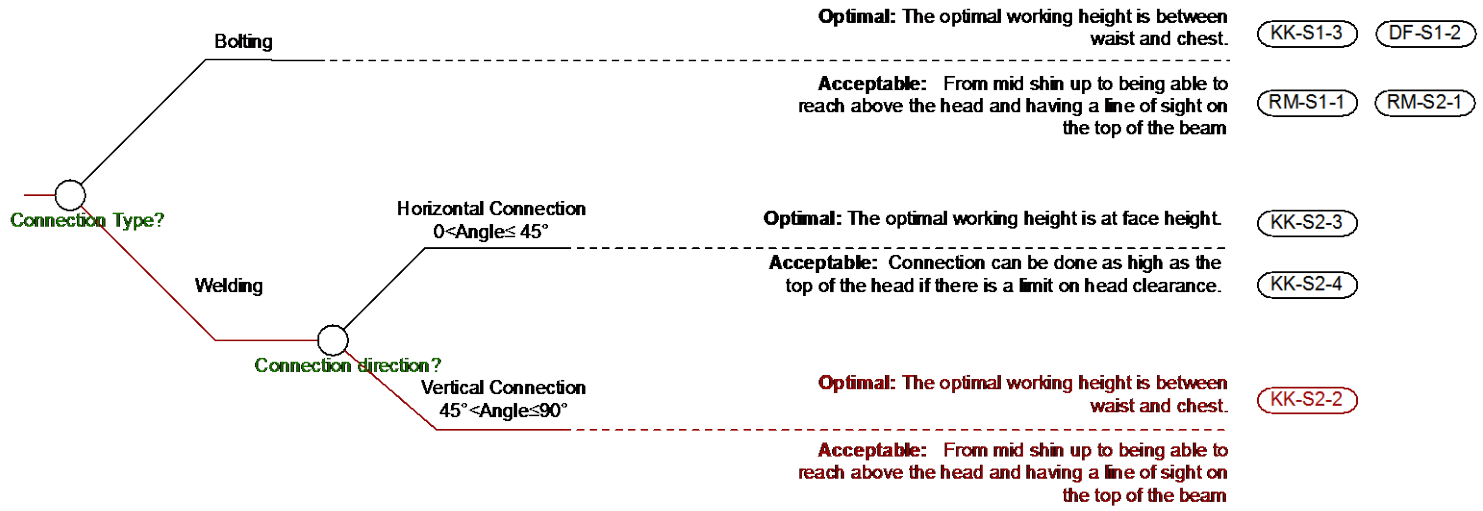


Decision Tree

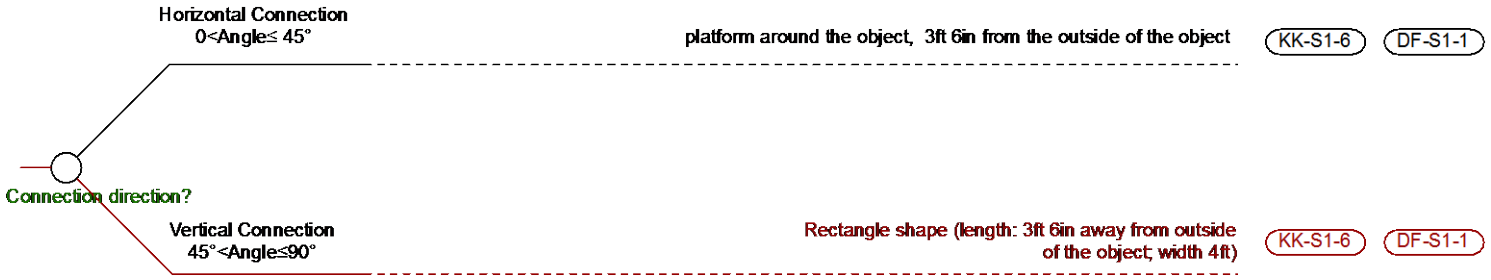
Application

1 – Work Envelope Definition

Beam to Beam connection

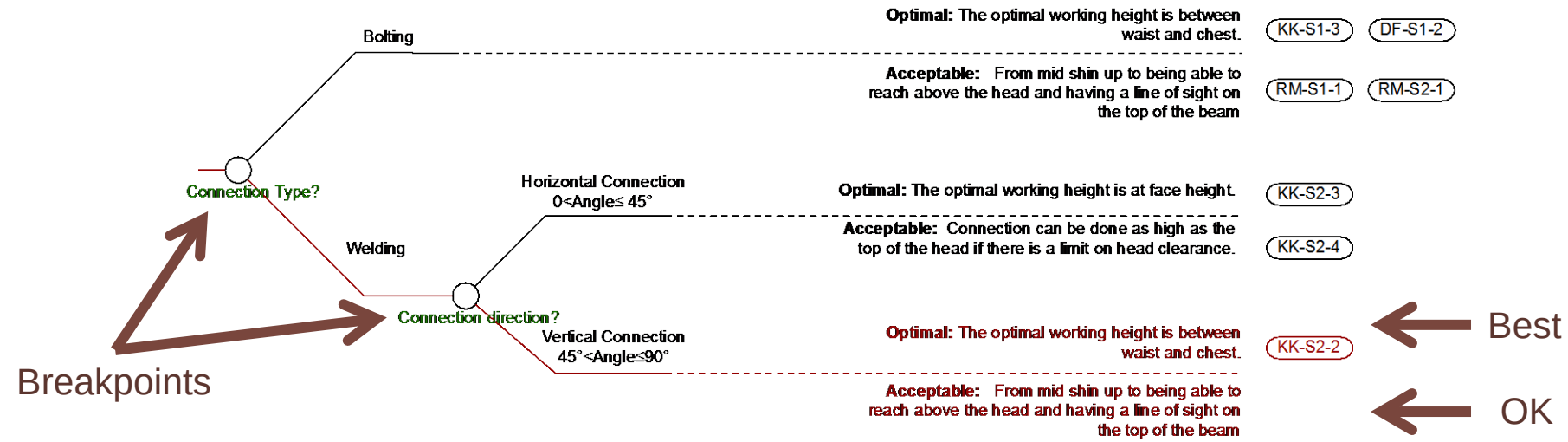


Decision Tree for Horizontal workspace requirement (Beam-to-Beam connection)



1 – Work Envelope Definition

Beam to Beam connection



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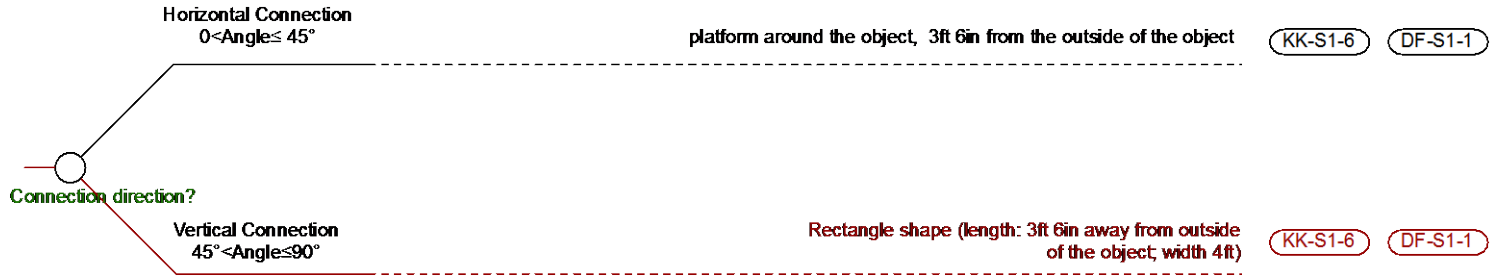
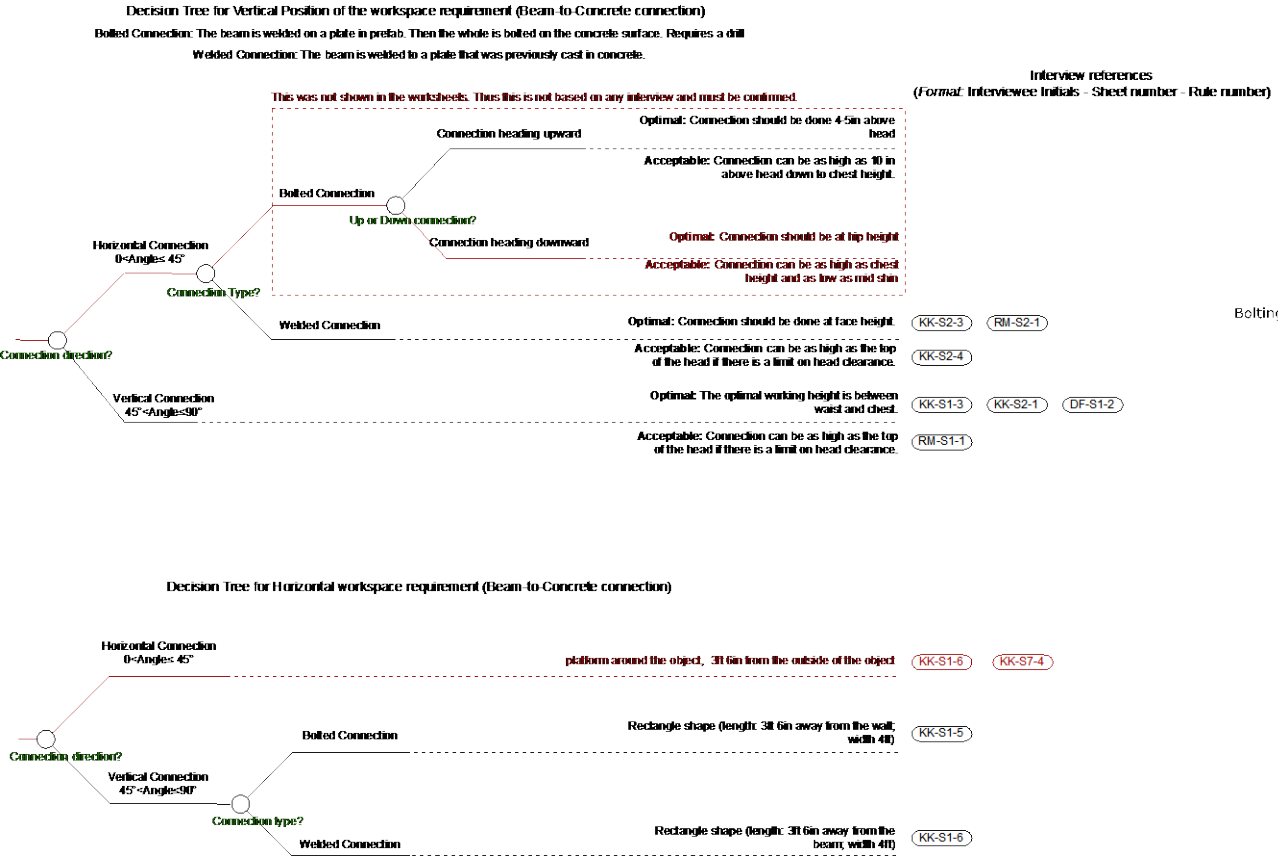
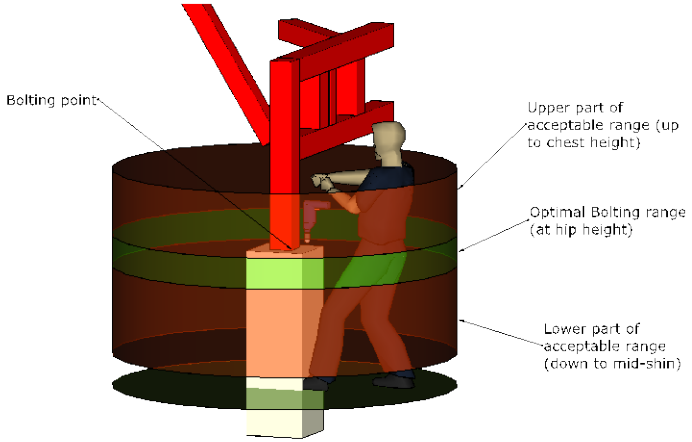


1 – Work Envelope Definition

Beam to Concrete connection





1 – Work Envelope Definition

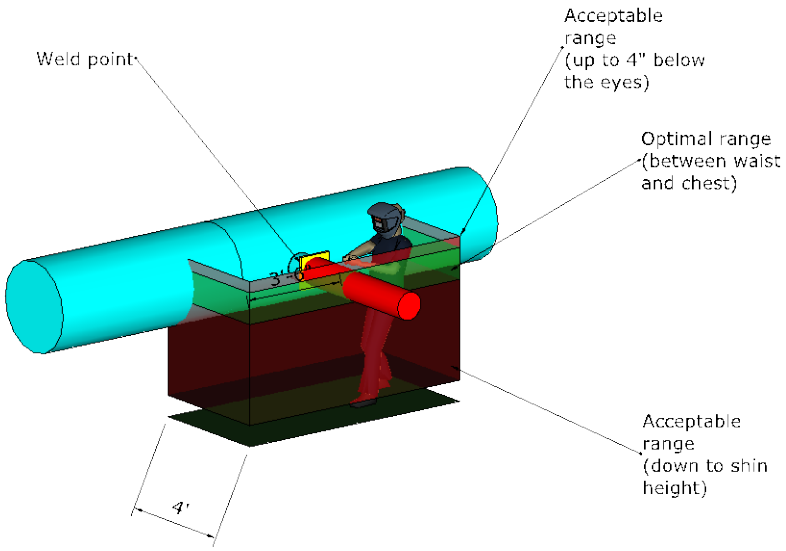
Pipe to Pipe connection

Decision Tree for Vertical Position of the workspace requirement (Pipe-to-pipe connection)

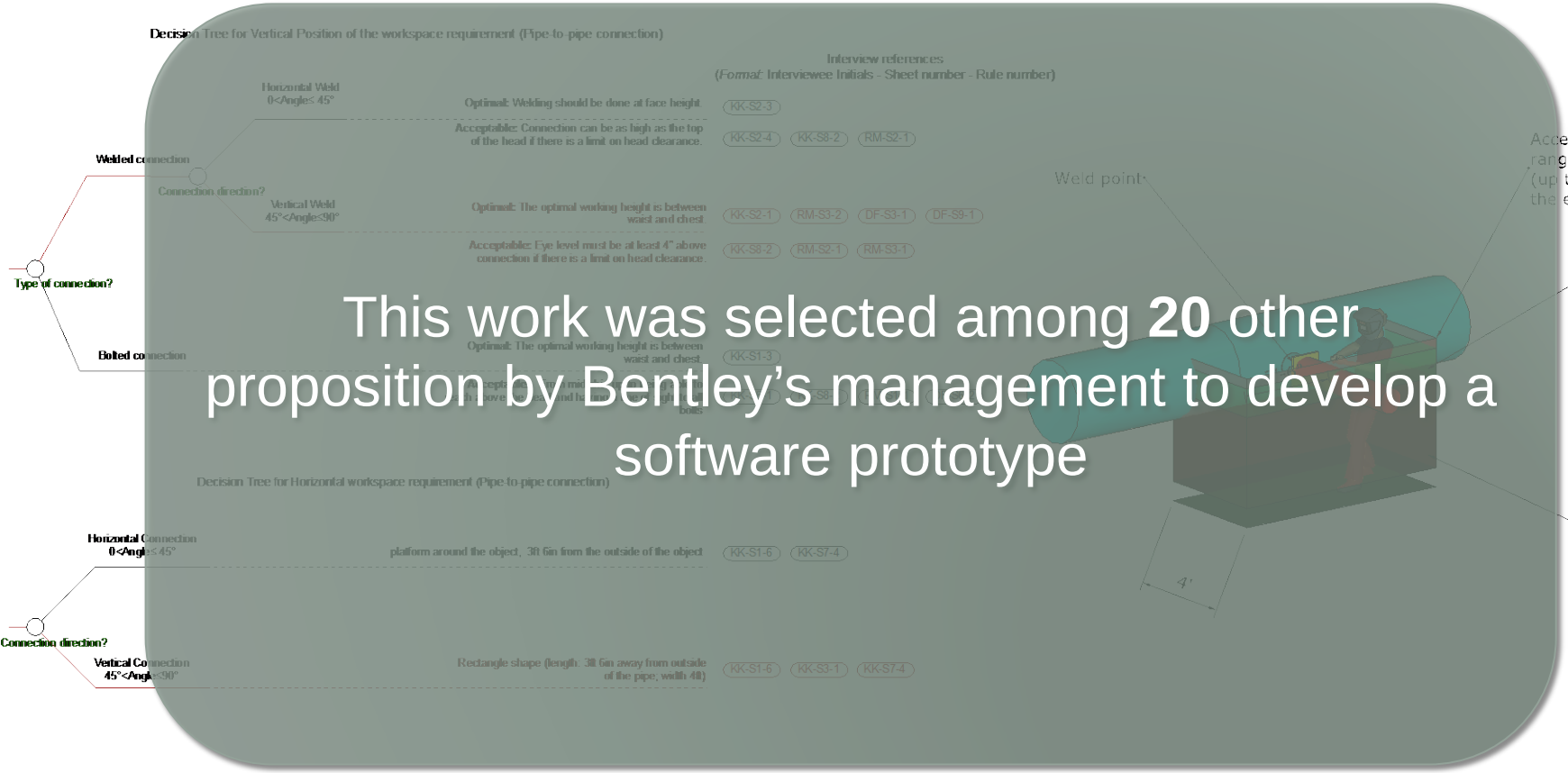
		Interview references (*Format*: Interviewee Initials - Sheet number - Rule number)
Type of connection? → Welded connection → Connection direction? → Horizontal Weld 0<Angle≤ 45°	**Optimal:** Welding should be done at face height.	KK-S2-3
	Acceptable: Connection can be as high as the top of the head if there is a limit on head clearance.	KK-S2-4 KK-S8-2 RM-S2-1
Connection direction? → Vertical Weld 45°<Angle≤90°	**Optimal:** The optimal working height is between waist and chest.	KK-S2-1 RM-S3-2 DF-S3-1 DF-S9-1
	Acceptable: Eye level must be at least 4" above connection if there is a limit on head clearance.	KK-S8-2 RM-S2-1 RM-S3-1
Type of connection? → Bolted connection	**Optimal:** The optimal working height is between waist and chest.	KK-S1-3
	Acceptable: From mid shin up to being able to reach above the head and having a line of sight to all bolts	KK-S6-1 KK-S8-2 RM-S1-1 DF-S6-2

Decision Tree for Horizontal workspace requirement (Pipe-to-pipe connection)

Connection direction? → Horizontal Connection 0<Angle≤ 45°	platform around the object, 3ft 6in from the outside of the object	KK-S1-6 KK-S7-4
Connection direction? → Vertical Connection 45°<Angle≤90°	Rectangle shape (length: 3ft 6in away from outside of the pipe; width 4ft)	KK-S1-6 KK-S3-1 KK-S7-4



1 – Work Envelope Definition



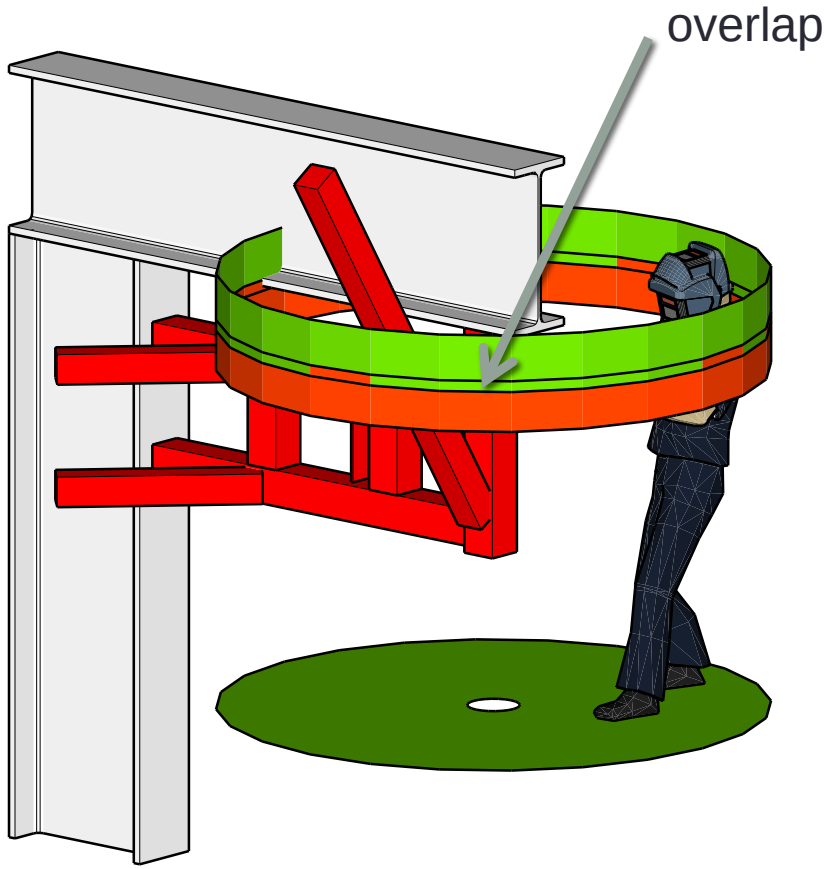
This work was selected among **20** other proposition by Bentley's management to develop a software prototype

2 – Work envelope dimensioning

- DINED:
  - International Male
    - Mean Stature: 1780mm
- Body Segment
  - Chin height: 0.870*H

→ Absolute chin height: 1549mm

→ Influence on the scaffolding setup



North Europe mean

South China mean

2 – Work envelope dimensioning

- Results
  - For “Face height”

Group 1

Group 2

Required overlap 50%

	nternational	North American	Latin American (Rest)	North Europe	Eastern Europ	North India	South China
International		0,776	0,745	0,746	0,75	0,510	0,48
North American			0,734	0,786	0,74	0,488	0,44
Latin American (Rest)				0,693	0,84	0,619	0,61
North Europe					0,69	0,420	0,34
Eastern Europe						0,622	0,61
North India							0,88
South China							

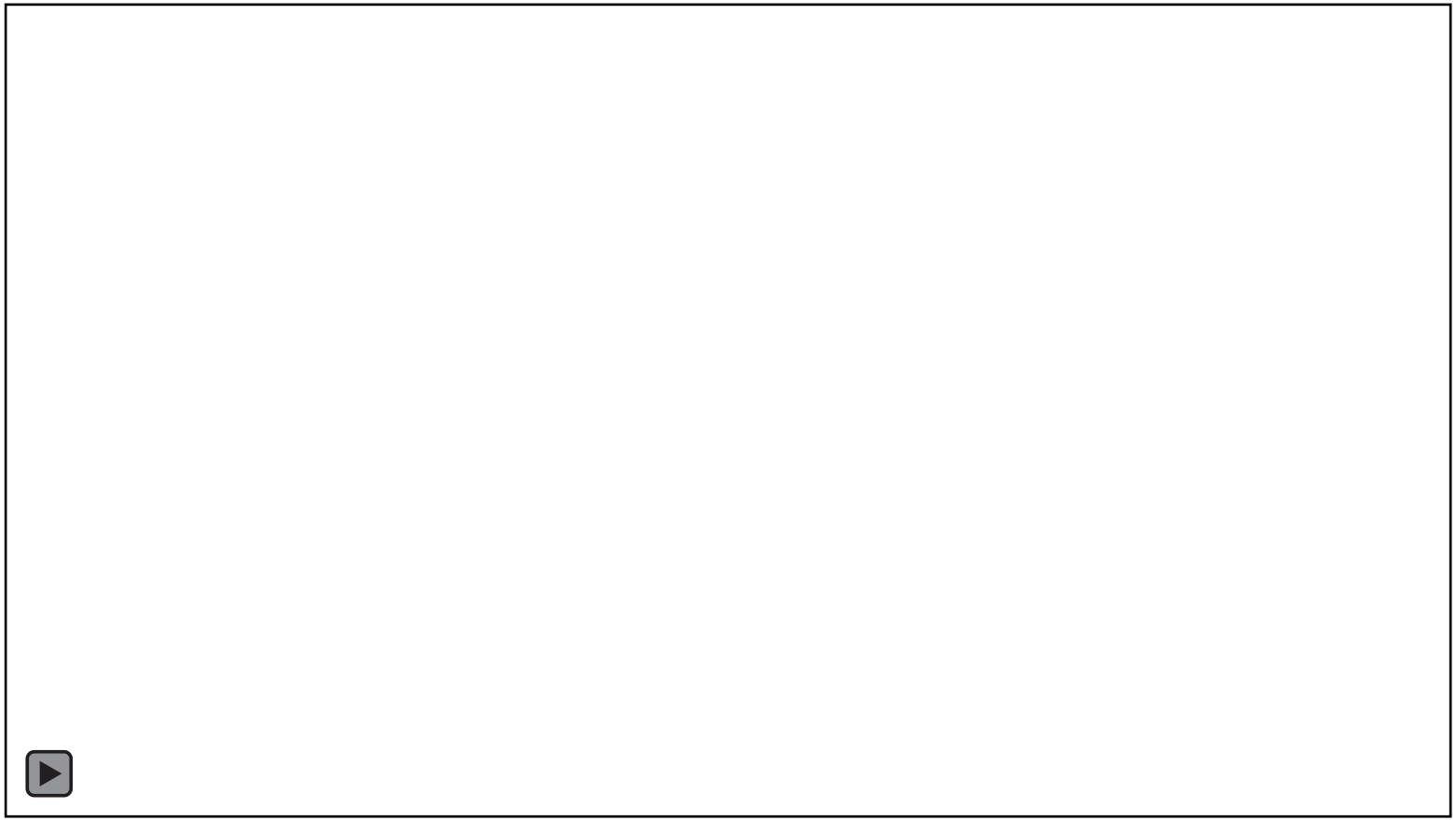
  - For “between waist and chest”

Required overlap 50%

	International	North American	Latin American (Rest)	North Europe	Eastern Europe	North India	South China
International		0,965	0,942	0,968	0,944	0,833	0,834
North American			0,952	0,977	0,953	0,840	0,842
Latin American (Rest)				0,954	0,986	0,925	0,933
North Europe					0,956	0,827	0,828
Eastern Europe						0,933	0,942
North India							0,990
South China							

2 – Work envelope dimensioning

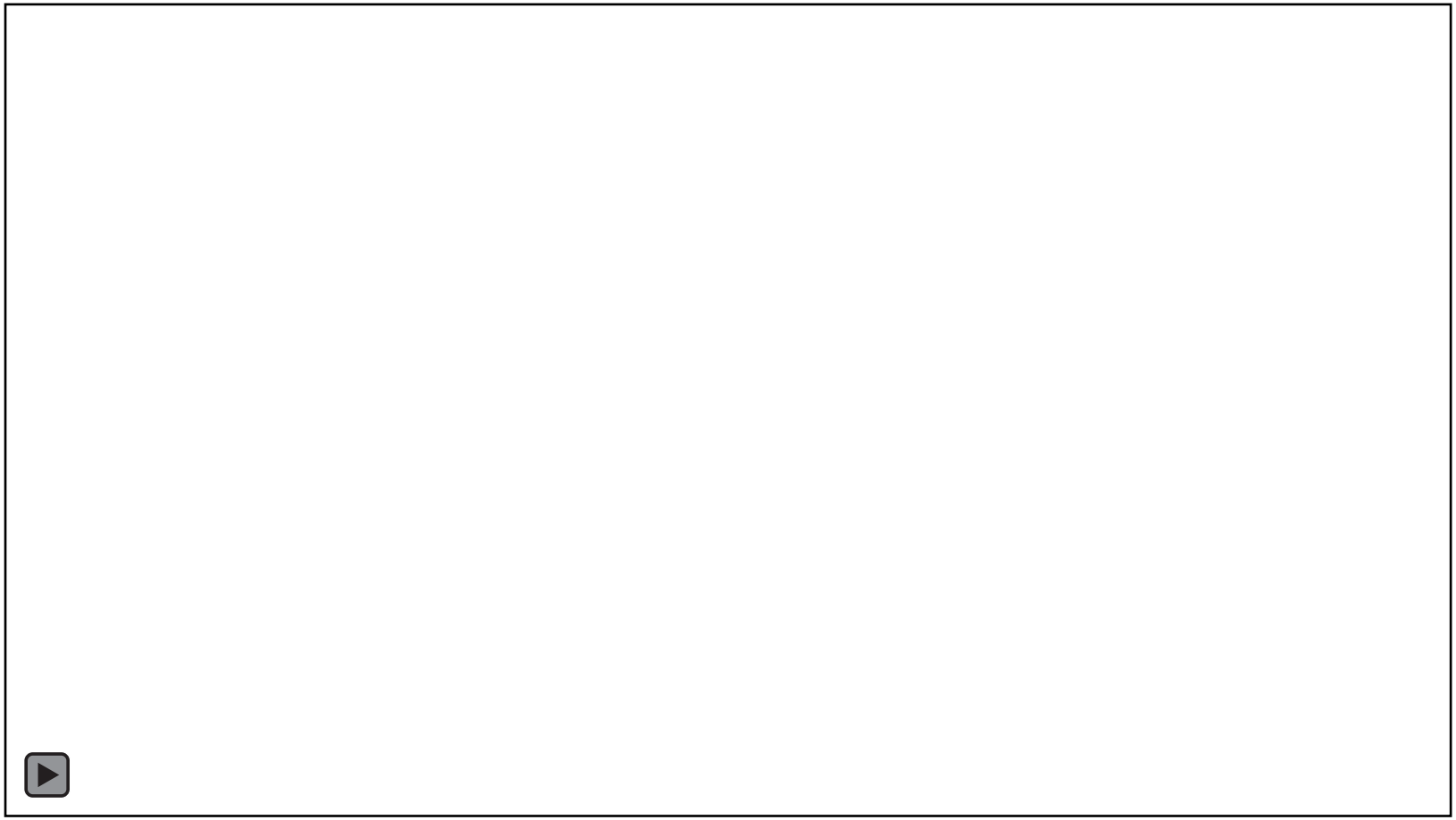
“Face Height”



Requires local adaptations

2 – Work envelope dimensioning

“Between Chest and Waist”

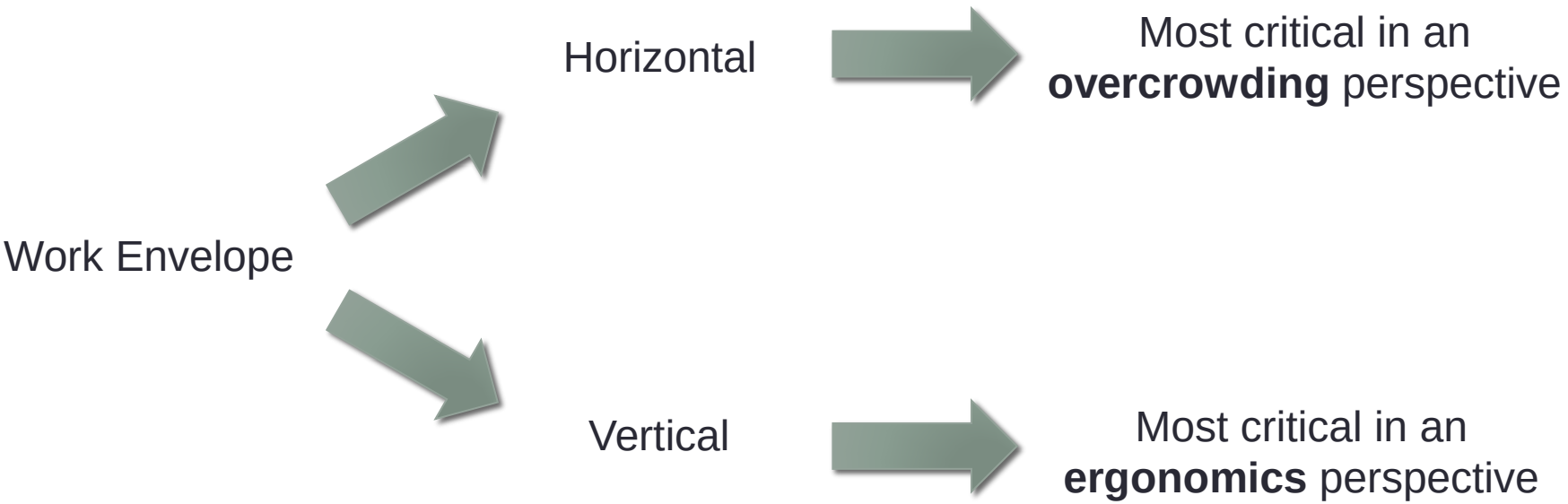


Does not require local adaptations

Contribution to the body of knowledge

1

2 components



Contribution to the body of knowledge

2

Main drivers of the work envelope shape:

- Bolted vs. Welded → "at face height" vs. "between chest and waist"
- Vertical vs. Horizontal → rectangular footprint vs. circular footprint
- Upward vs. Downward connection → "above head" vs. "at hip height"

Contribution to the body of knowledge

3

Impact of not considering the anthropomorphic data:

- Decreased ergonomics → Lower quality and safety
- No impact on the horizontal component → Limited overcrowding impact

Future Steps

- Expand the framework to other trades
- Apply the process on a real world project to asses its efficiency

Questions ?