

# ‘A Journey to Concrete Productivity in Brazil’

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  - ❖ Professor at the Graduate Program in Structures at UNIFOR;
- ❖ Deputy Director of the Ceará Regional Division of ABECE (Brazilian Association of Structural Engineering and Consulting).



# Session Outline:

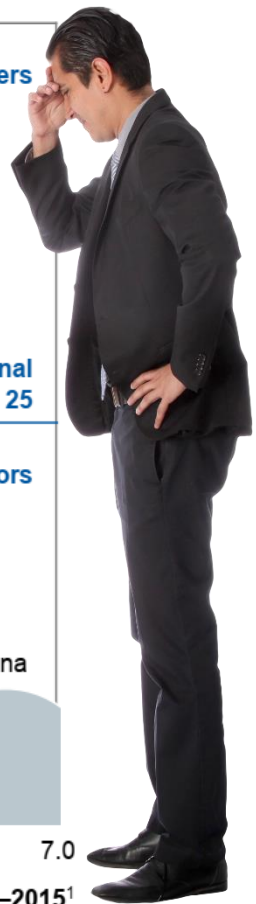
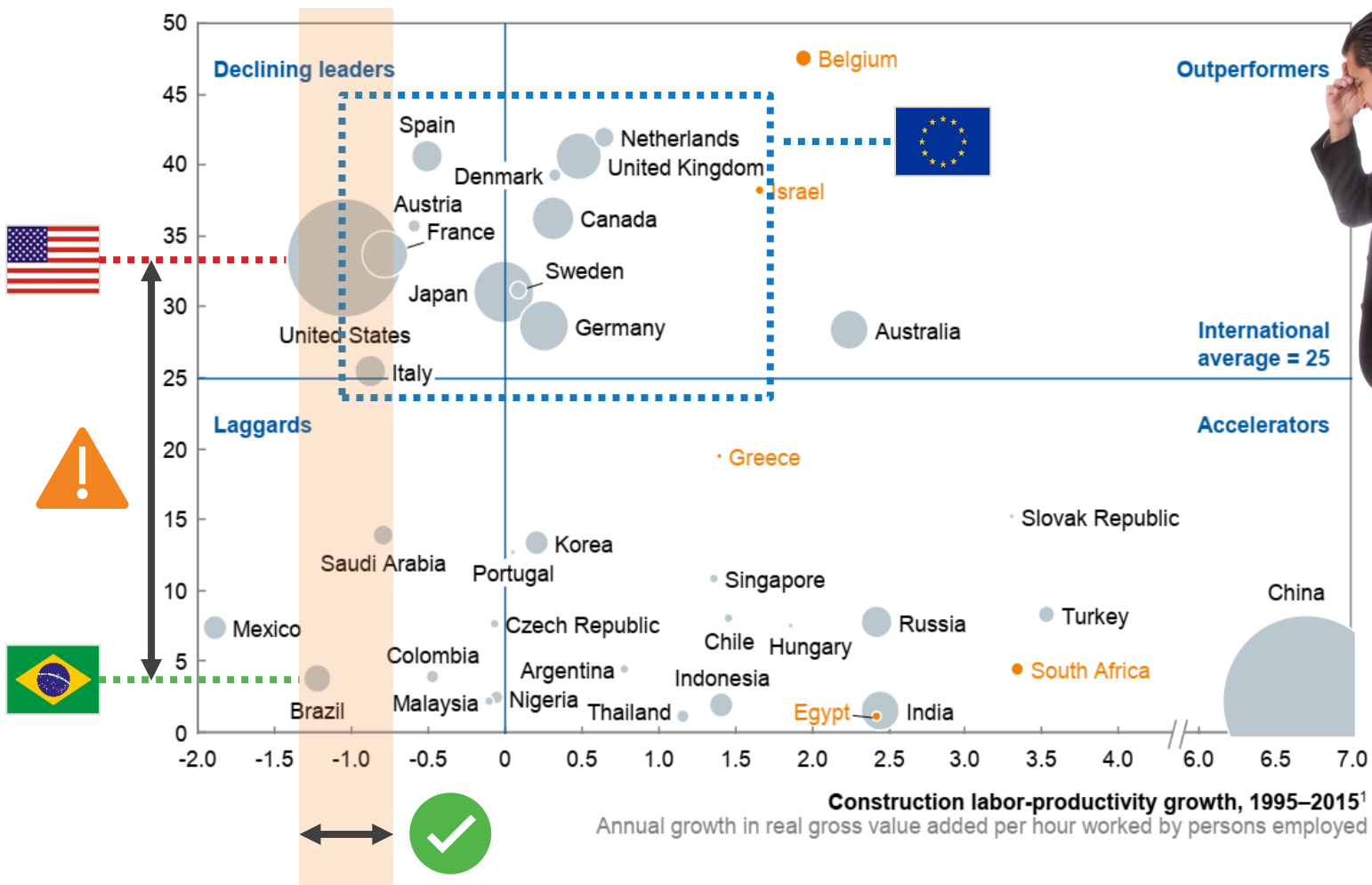
- ❖ A general overview of the Brazilian market
- ❖ Structural indexes, a simple and good idea!
- ❖ Measuring productivity using design inputs
- ❖ Let's enhance productivity!?
- ❖ Some real examples
- ❖ Ranking productivity: Data matter!
- ❖ Getting to 'NET Zero'!



# A general overview of the Brazilian market:

## Construction labor productivity, 2015<sup>1</sup>

2005 \$ per hour worked by persons employed, not adjusted for purchasing power parity<sup>2</sup>



Source:



THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

aci CONCRETE CONVENTION

# A general overview of the Brazilian market:

Productivity at **MACROECONOMIC LEVEL:**

$$\text{Productivity} = \text{GVA}/\text{MH}$$

- ❖ **'MH'** is the amount of labor in hours.
- ❖ **'GVA'** is the result of difference between the 'Product Value' (**PV**) and the following inputs named 'Intermediate Costs' (**IC**): Labor and material cost, equipment and others.

$$\text{GVA} = \text{PV} - \text{IC} \approx 20\% \text{ of the Total Capital!}$$

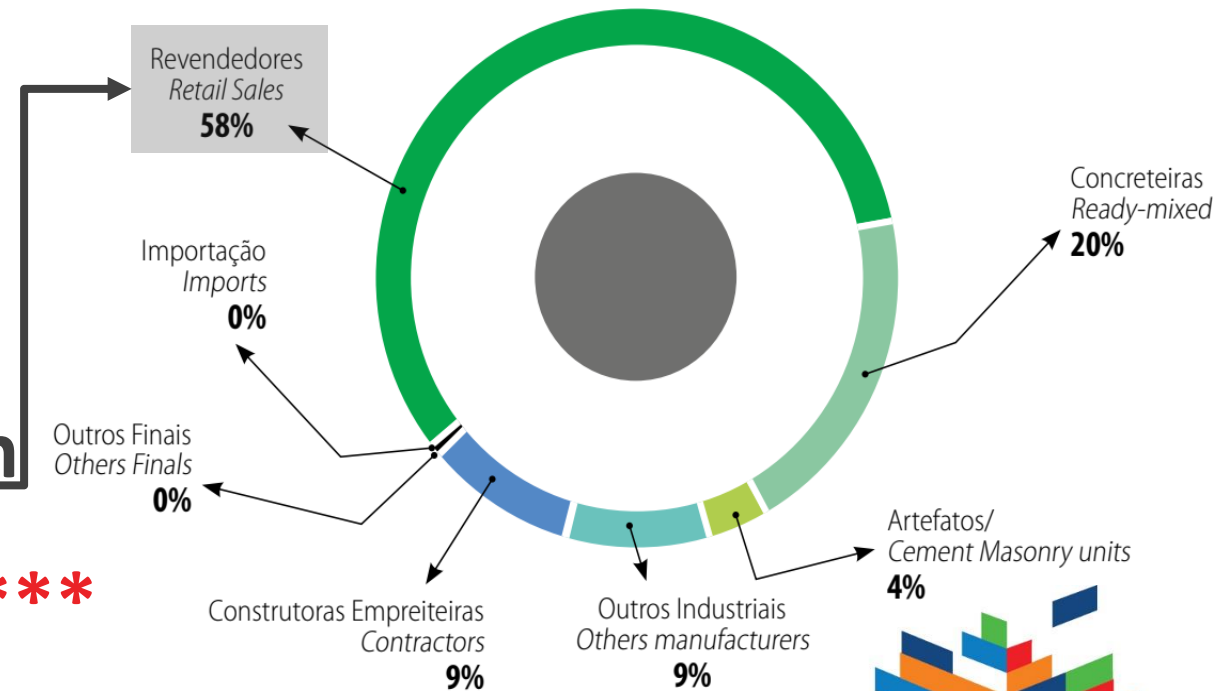


# A general overview of the Brazilian market:

- ❖ Low economic growth
- ❖ Governmental inefficiency
- ❖ Bureaucracy
- ❖ Low public investment
- ❖ Amount of small construction
- ❖ **Purchase Power Parity (PPP)\*\*\***
- ❖ **Ratio Labor Cost x Material Cost**

## Consumption of Portland Cement by intermediate cement destination in Brazil - 2021

Source: Annual Report of the National Cement Industry Syndicate



# A general overview of the Brazilian market:

## ❖ Purchase Power Parity (PPP):

Various measures of purchasing power parity that we investigated for construction seemed incongruent and not very robust, **so we chose to NOT adjust for different price levels among countries.**

Source: MGI Report.



VS



**Fortaleza-Brazil: \$ 235.00/sqft**

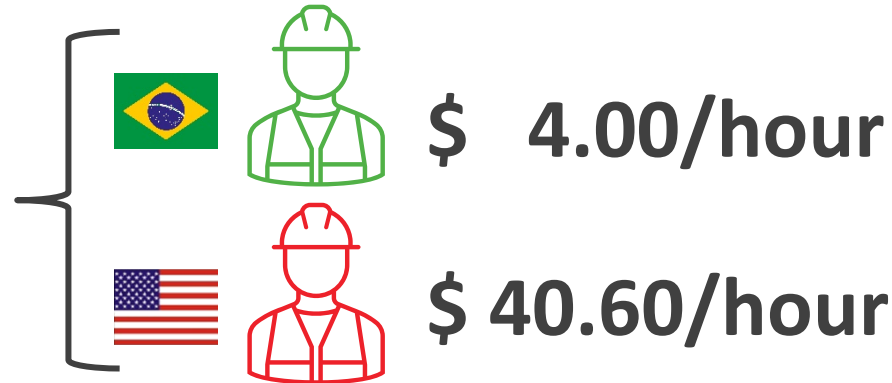
**San Francisco-CA: \$ 2,995.00/sqft ≈ 13 times more!**



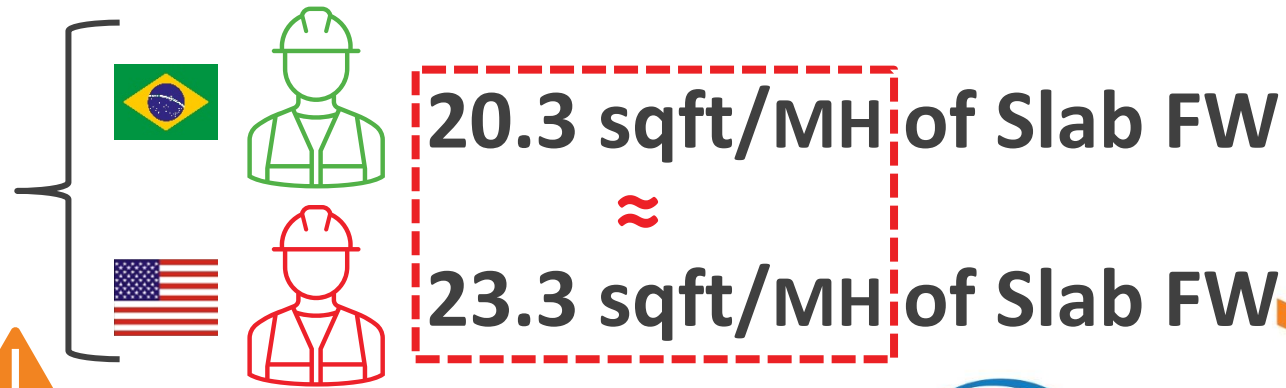
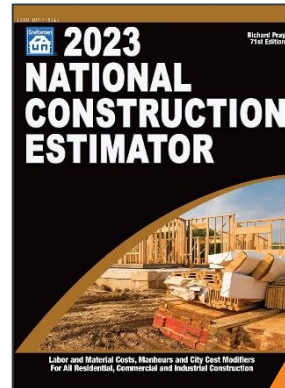
# A general overview of the Brazilian market:

## ❖ Ratio Labor Cost x Material Cost:

Labor rates by:



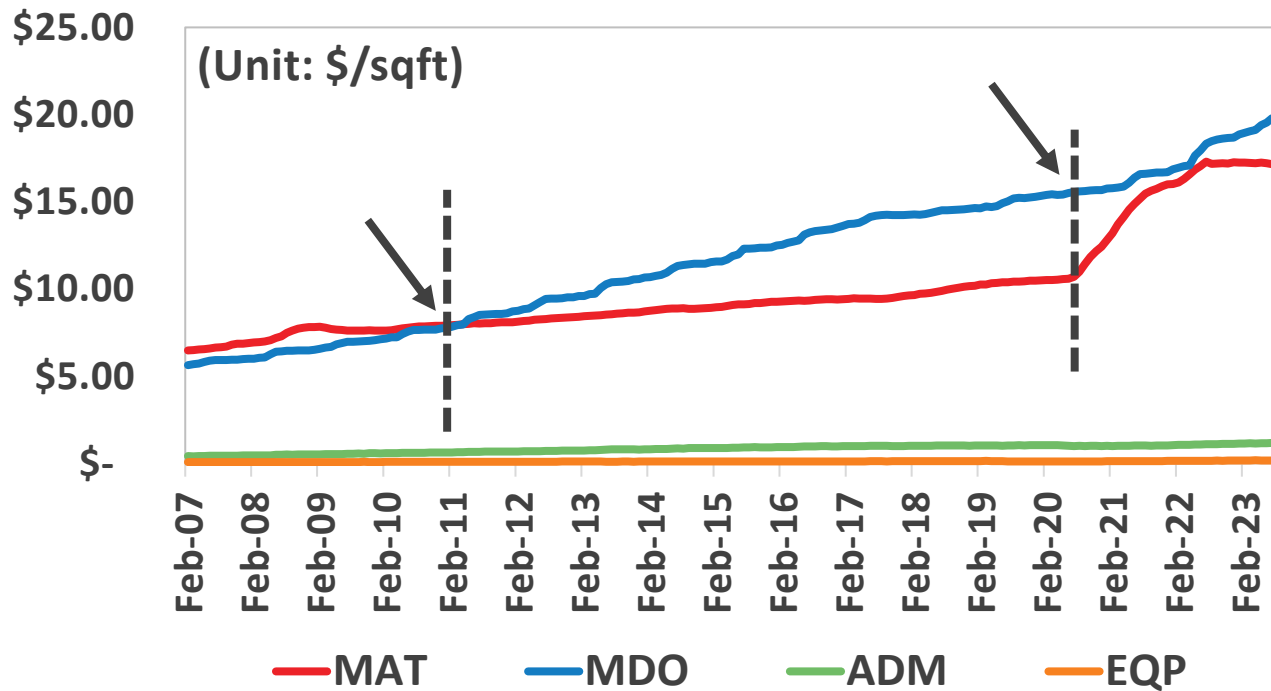
A CARPENTER production by:



# A general overview of the Brazilian market:

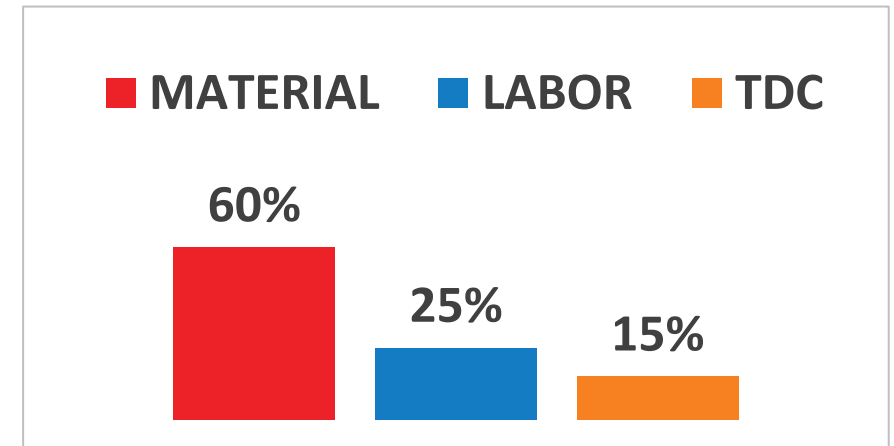
## ❖ Ratio Labor Cost x Material Cost:

Evolution of the Brazilian Average Construction Cost | 2007 to 2023



Source: Brazilian Chamber of the Construction Industry (CBIC).

Cost Distribution RC/PT Concrete Structures in Brazil



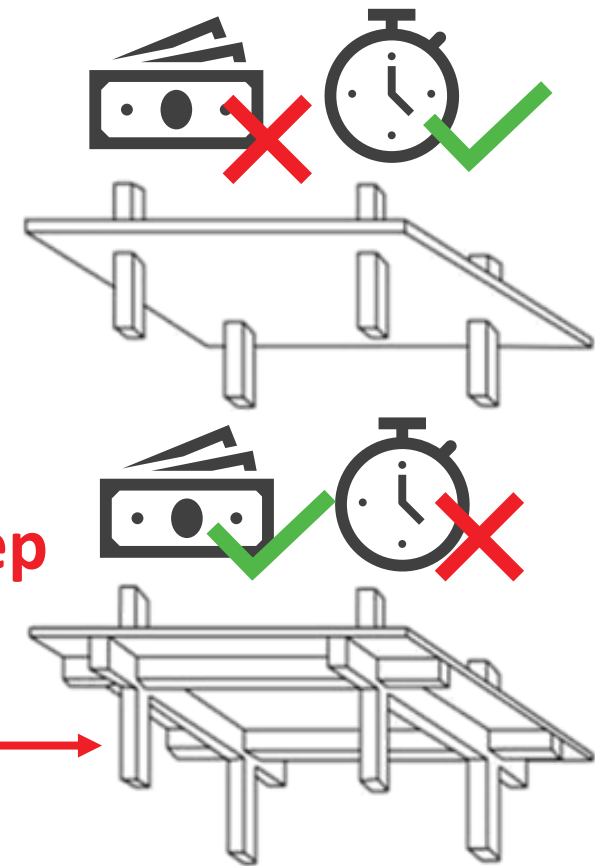
Source: Author surveys.



# A general overview of the Brazilian market:

## ❖ Ratio Labor Cost x Material Cost:

- Formwork is **NOT** the higher cost
- Non-structural elements using cementitious and ceramic materials increasing **Dead Loads and Creep**
- Two-way concrete slab with beams as the main structural solution .: **Low Productivity!**
- Significant number of **conflicts** between structural elements (beams) and MEP systems

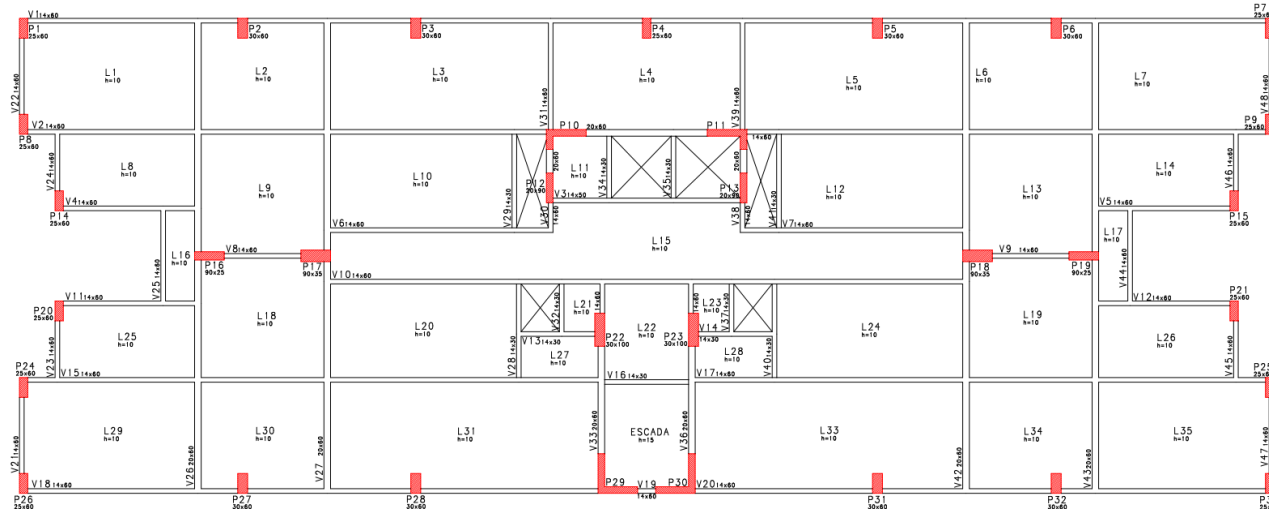


# Structural indexes, a simple and good idea!

- ❖ **Structural Area (SA):** Floor area excluding openings bigger than 5 sqft.
- ❖  $i1 = \text{Concrete Volume} / \text{SA} \therefore \text{'Average Slab Thickness'}$
- ❖  $i2 = \text{Formwork Area} / \text{SA} \therefore \text{It means, (Constructability)}^{-1}$
- ❖  $i3 = \text{Rebar Consumption} / \text{SA}$
- ❖  $i4 = \text{Post-tension Consumption} / \text{SA}$

**Units: lbs, sqft and cuft.**

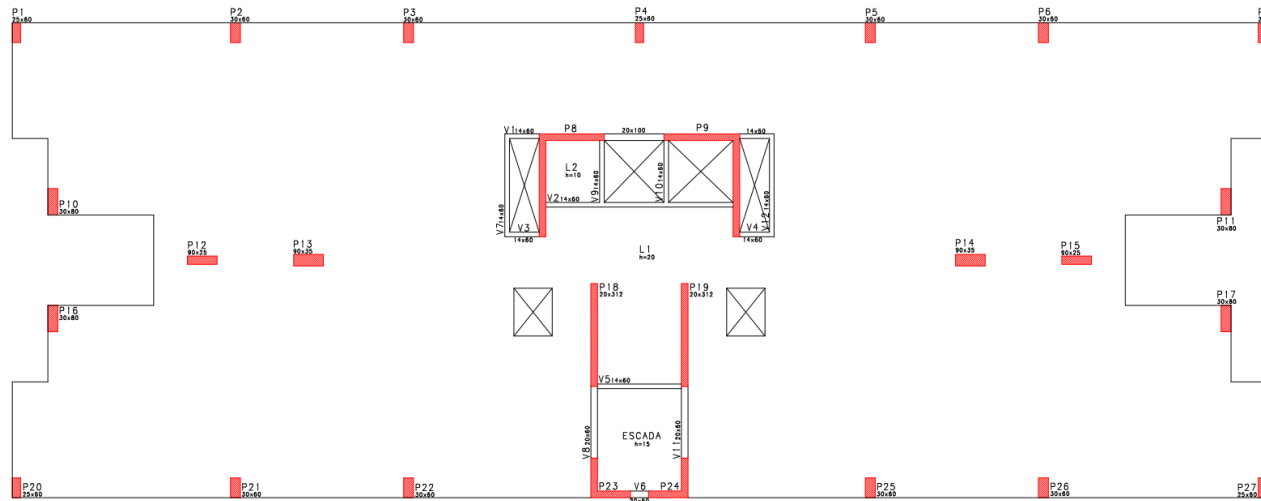
# Structural indexes, a simple and good idea!



QUANTITY				
SA (ft2)	CC (ft3)	FW (ft2)	RF (lb)	PT (lb)
5382	3320	11033	18519	0

INDEXES			
i1(ft3/ft2)	i2 (ft2/ft2)	i3 (lb/ft2)	i4 (lb/ft2)
0.62	2.05	3.44	0.00

**\$ 9.00/sqft**



QUANTITY				
SA (ft2)	CC (ft3)	FW (ft2)	RF (lb)	PT (lb)
5382	4414	8417	16449	4131

INDEXES			
i1(ft3/ft2)	i2 (ft2/ft2)	i3 (lb/ft2)	i4 (lb/ft2)
0.82	1.56	3.06	0.77

**\$ 12.00/sqft ≈ +30%!!!**



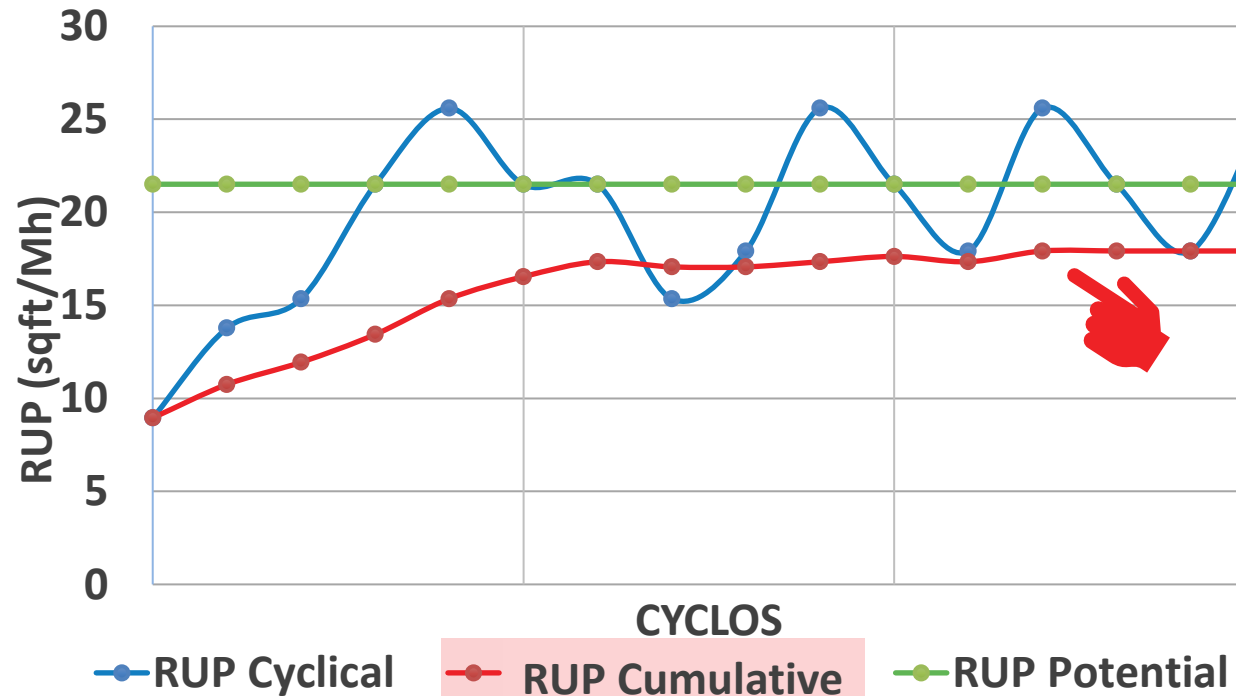
THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

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# Measuring productivity using design inputs

**'RUP': Output per Unit of Production.**

$$RUP = \frac{\text{Structural Area}}{MH}$$



**Manual Laborer**  
**Real  $\approx$  +30%**  
**in average.**



# Measuring productivity using design inputs

## RUPcum BY SERVICE:

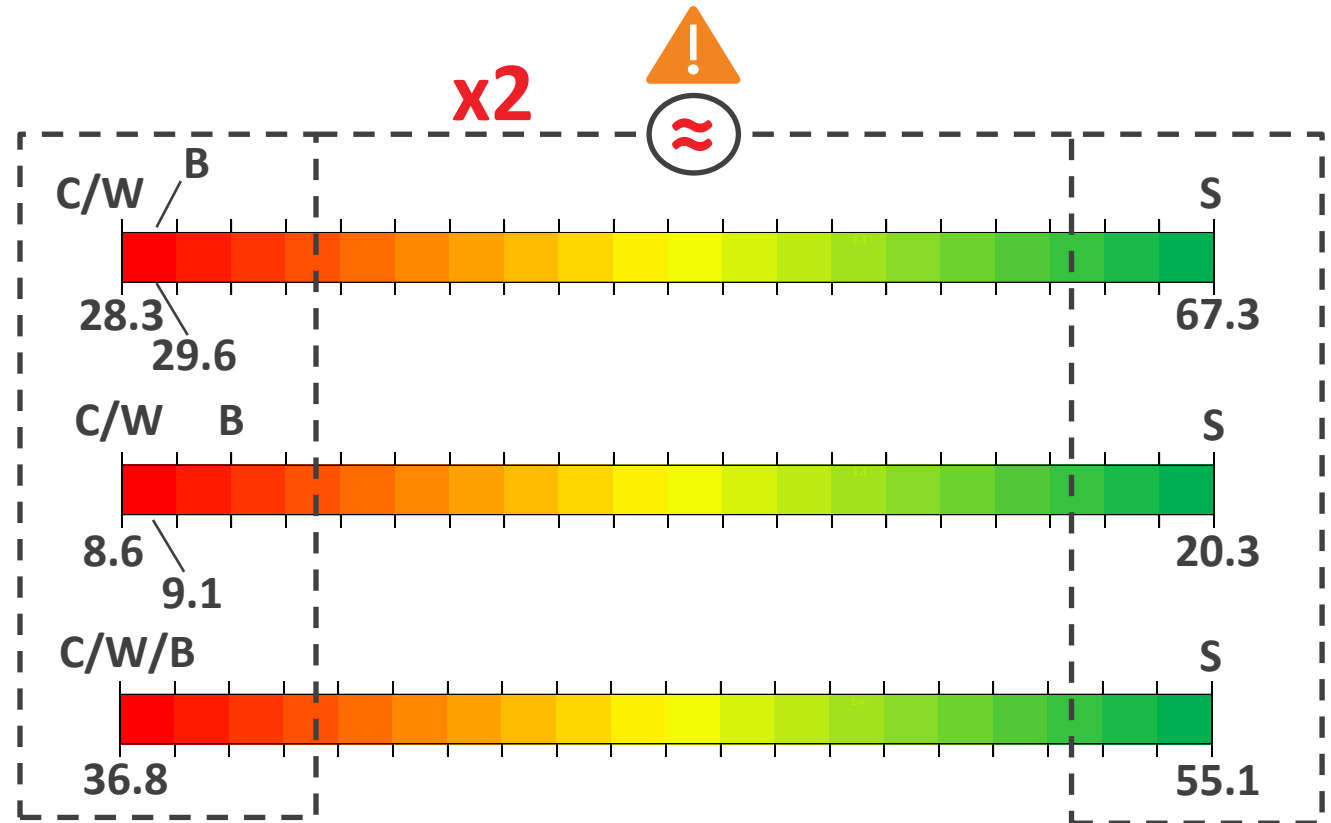
❖ Pouring concrete:

❖ Formwork assembly:

❖ Rebar installation:

❖ Post-tension (on site service): **55 lb/MH**

**Units: cuft, sqft and lbs by MH.**



# Measuring productivity using design inputs

Proposing the **'Index of Complexity' (iC)**:

❖ **FWC**: Formwork area of columns

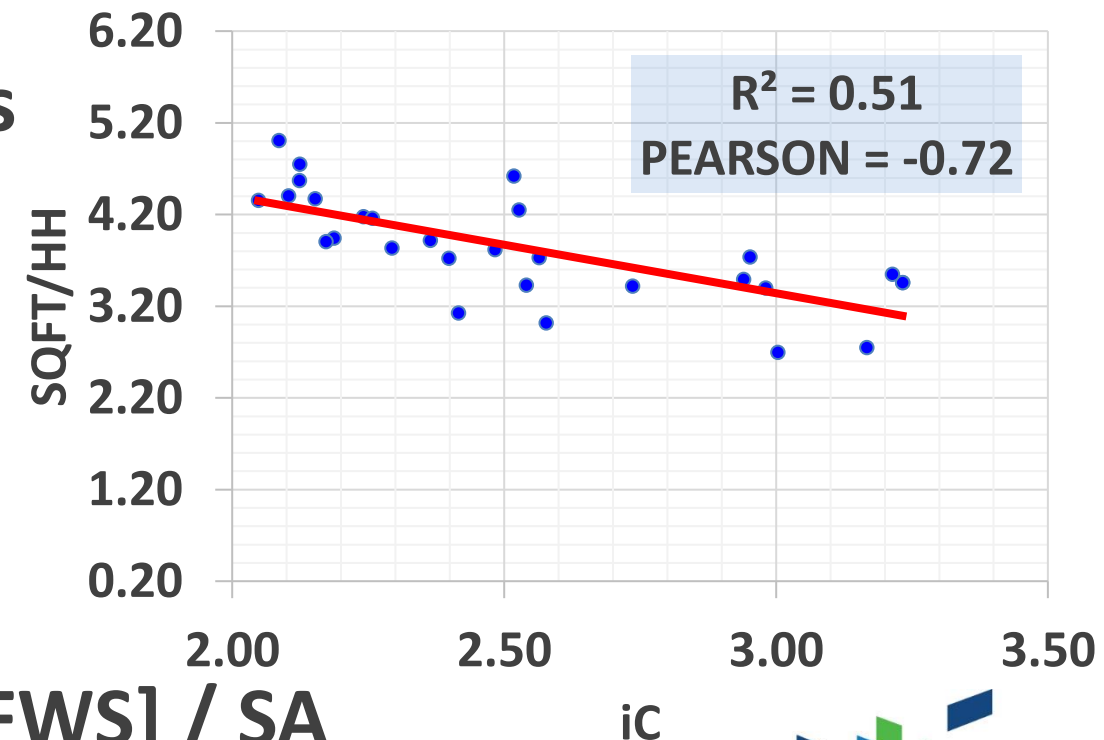
❖ **FWW**: Formwork area of walls

❖ **FWB**: Formwork area of beams

❖ **FWS**: Formwork area of slabs

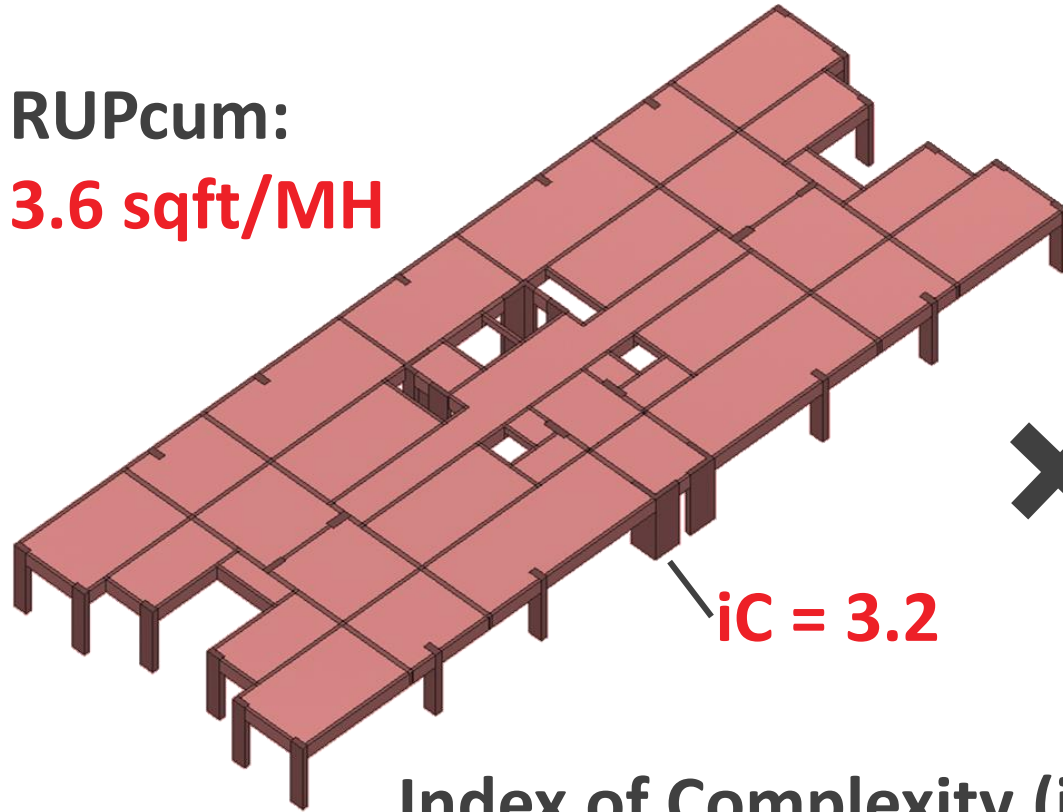
❖ **iC** =  $[2 \times (\text{FWC} + \text{FWW} + \text{FWB}) + \text{FWS}] / \text{SA}$

**Unit: sqft.**



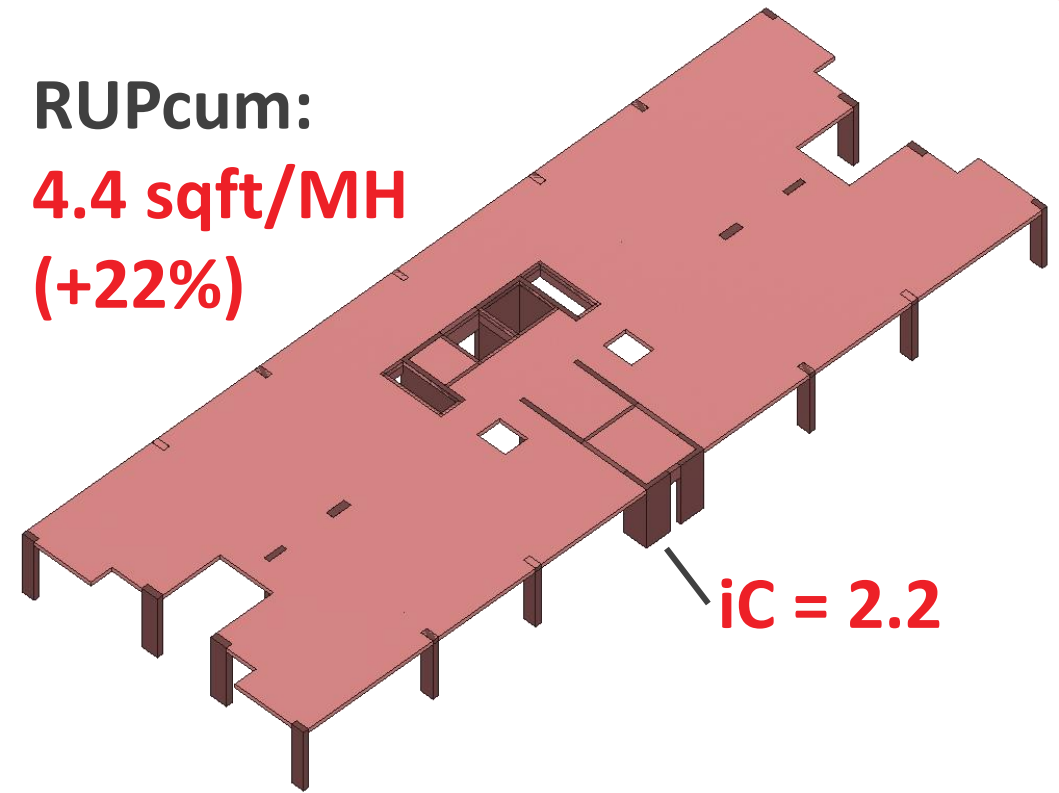
# Measuring productivity using design inputs

RUPcum:  
**3.6 sqft/MH**

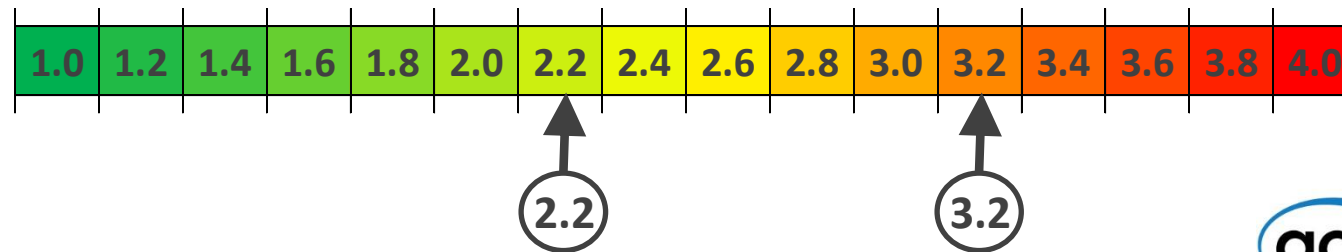


×

RUPcum:  
**4.4 sqft/MH**  
**(+22%)**



Index of Complexity (iC):



# Let's enhance productivity!?

Designing for **CONSTRUCTABILITY** but **SAVING MATERIAL!**

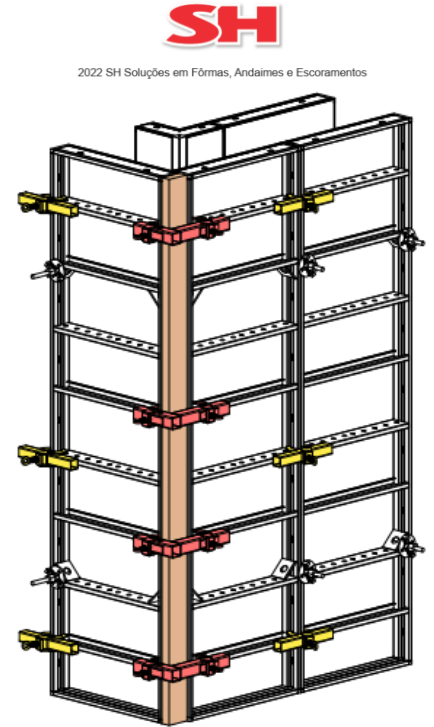
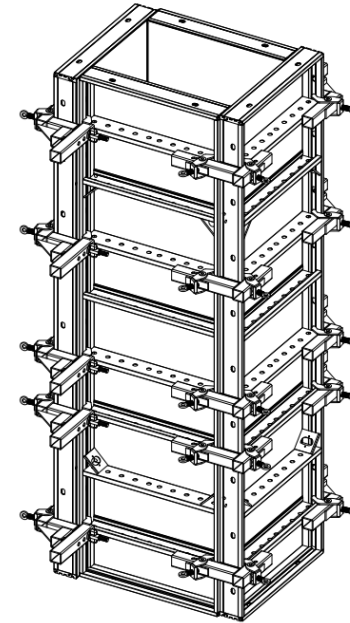
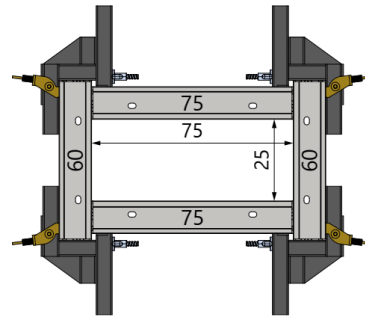
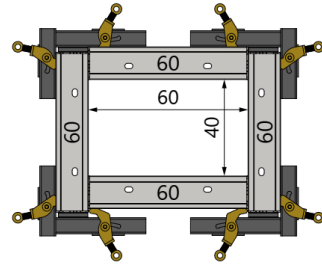
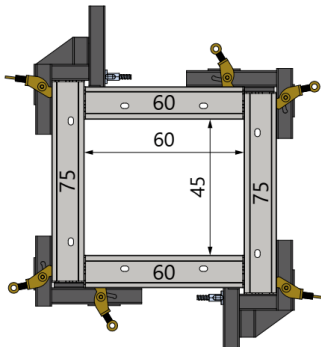
- ❖ Structural Concept/Formwork Systems
- ❖ Concrete options and definitions
- ❖ Rebar detailing
- ❖ Post-tensioning (PT)
- ❖ Innovation
- ❖ BIM
- ❖ Office/Construction site communication



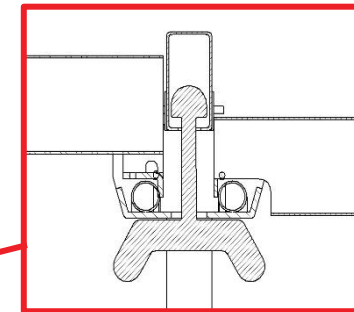
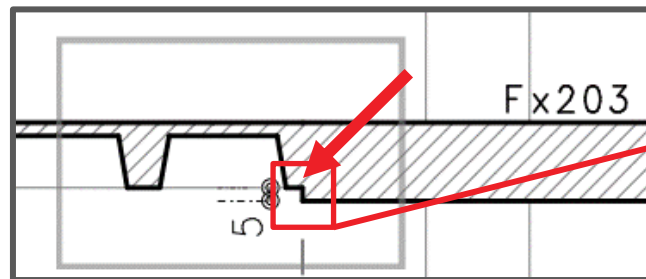
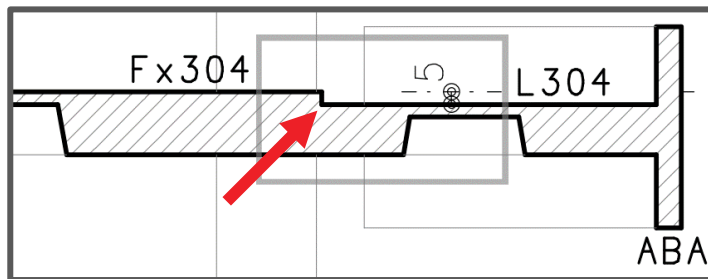
# Let's enhance productivity!?

## ❖ Structural Concept/Formwork Systems:

- **Take modulation seriously!**

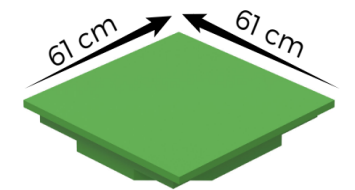
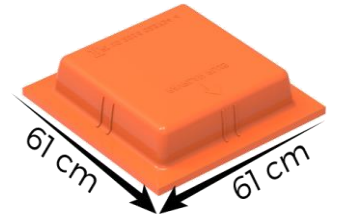
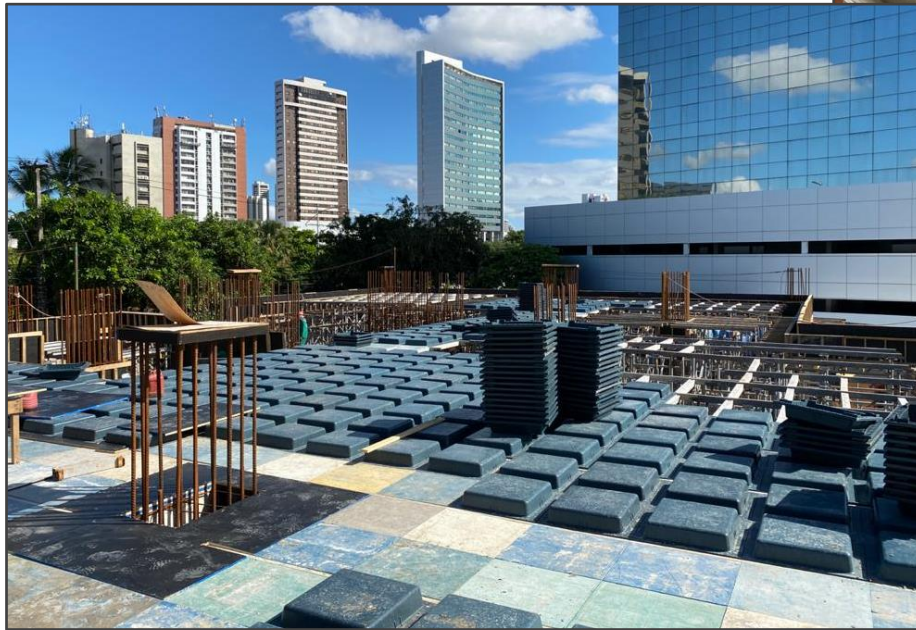


- Limit the amount of different cross sections
- Modular variation of the slab thickness



# Let's enhance productivity!?

- ❖ Structural Concept/Formwork Systems:
  - Mix **waffle** and **flat** slabs systems with **modular shoring/reshoring**

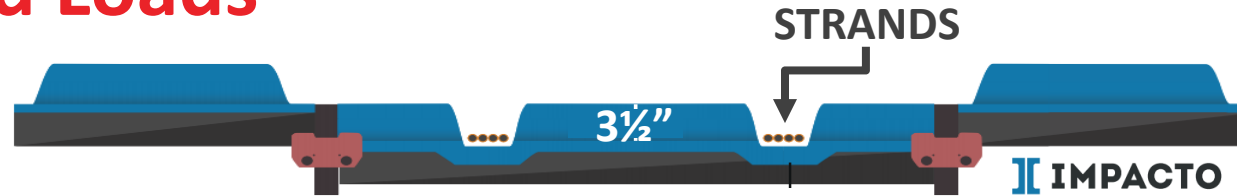


# Let's enhance productivity!?

## ❖ Structural Concept/Formwork Systems:

- Use of special plastic 'grooves' to optimize the PT

**Balanced Loads**



$$W = \frac{8 * P * f}{L^2}$$



# Let's enhance productivity!?

## ❖ Concrete options and definitions:

- HPC in columns can reduce rebar congestion without a significant cost increase, **but, preferentially, it does not have to be more than 30% higher than the rest of the structure.**
- Designing transitions and special elements with (a bit) lower  $f'_c$  than specified in the project drawings can reduce the risk of structural reinforcements due to concrete nonconformities



# Let's enhance productivity!?

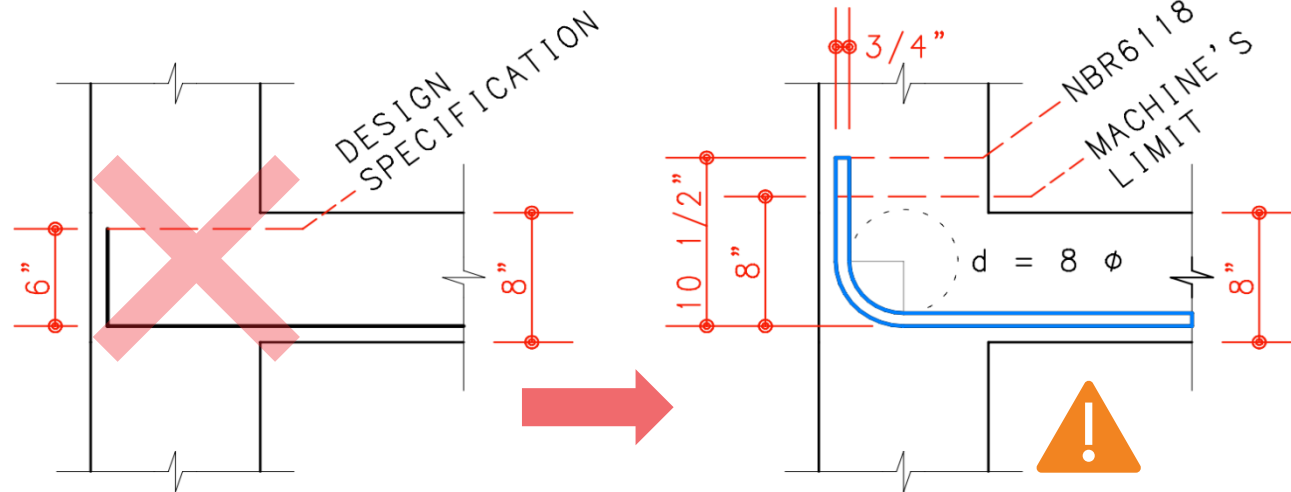
## ❖ Rebar detailing:

- **Productivity grows fast with the rebar diameter!**

ELEMENT	DIAMETER							
	3/16"	1/4"	5/16"	3/8"	1/2"	5/8"	3/4"	1"
C/W/B	18.4	24.5	31.5	44.1	55.1	73.5	110.3	220.5
S	24.5	36.8	44.1	73.5	110.3	110.3	220.5	10.0

Units: lbs/MH.

- **Take care with hooks and bends!**



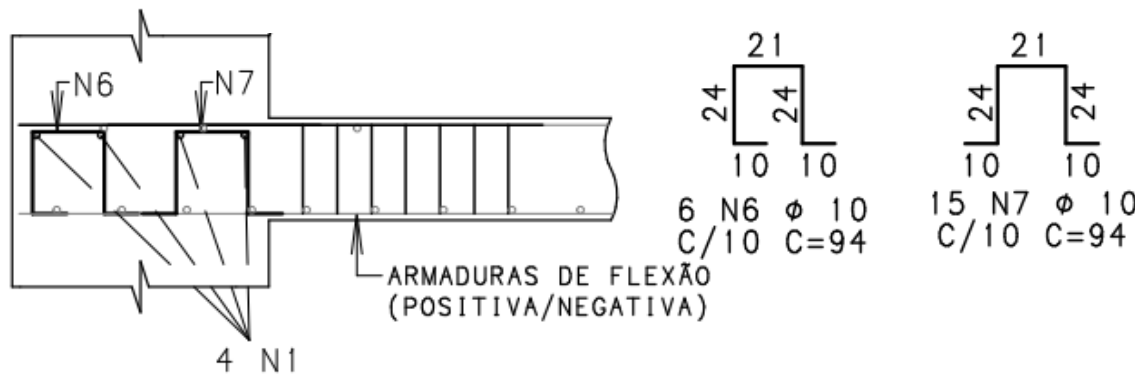
FIXED PIN

MOVEBLE PIN

# Let's enhance productivity!?

## ❖ Rebar detailing:

- **Stirrups** can be cost-effective, efficient as **constructable** well!



- Columns with a high rate of rebars ( $\geq 2\%$ ) never have to be grouped with others with less rates.



# Let's enhance productivity!?

## ❖ Rebar detailing:

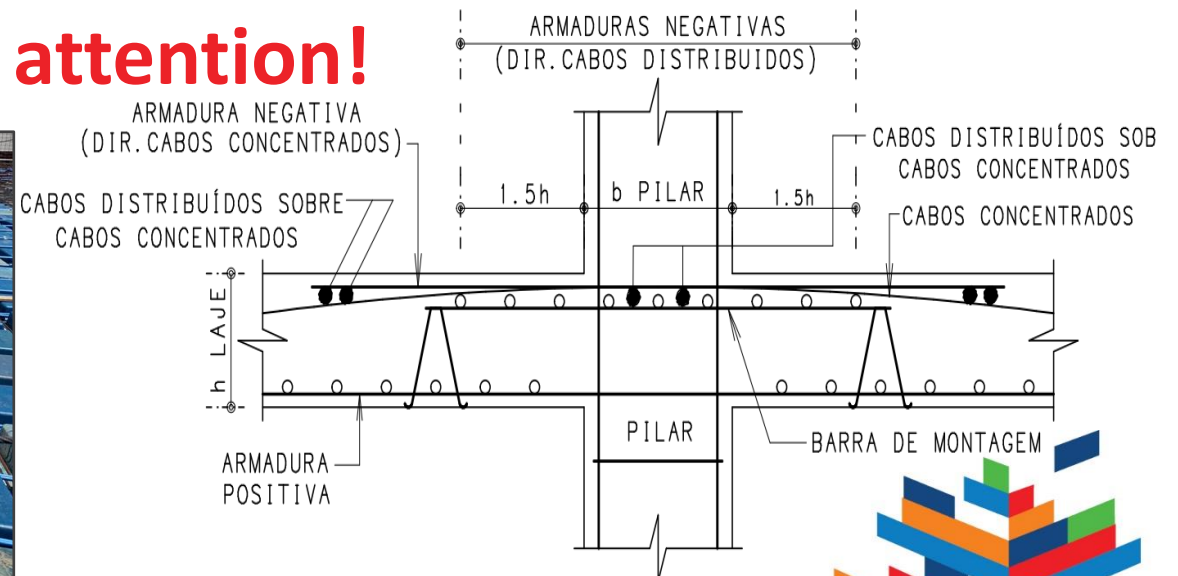
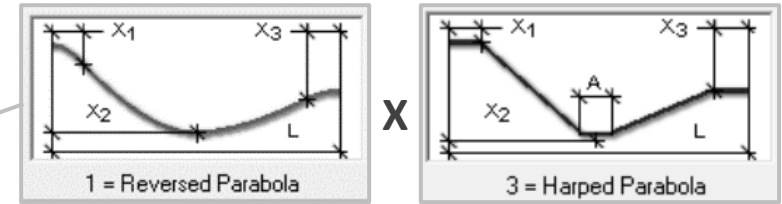
- **Mesh and prefabricating reinforcements** can be a good idea but take care w/ transportation!
- If  $P/A \geq 1.0$  Mpa (145 psi): **NRR in the top surface of the waffle slabs (shrinkage, temp. and flexure)?!**



# Let's enhance productivity!?

## ❖ Post-tensioning (PT):

- **Banded x Distributed (RP x HP?) is the best cable layout!**
- **The position of the bars and cable above the columns is critical and require special attention!**

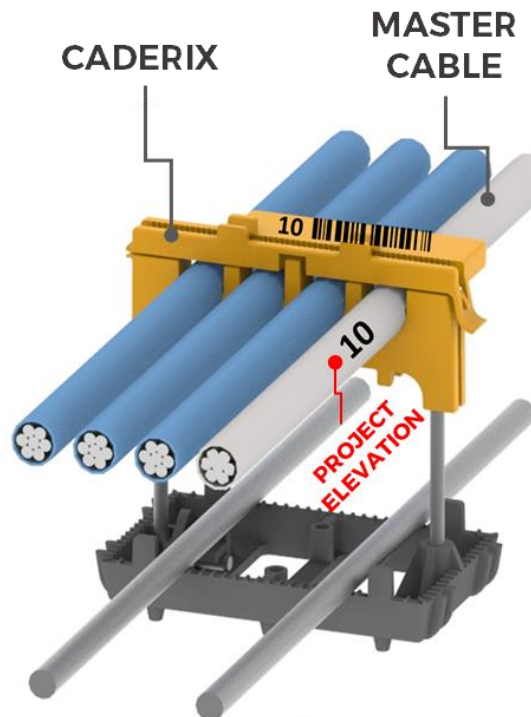




# Let's enhance productivity!?

## ❖ Post-tensioning (PT):

- Innovative solutions must be considered!



**PavScan**  
INFORMARTIZED CONFERENCE

### MOBILE APP FOR INSTALLATION & CONFERENCE



**TERMITE**  
ENGENHARIA INOVATIVA



### PT PLUG



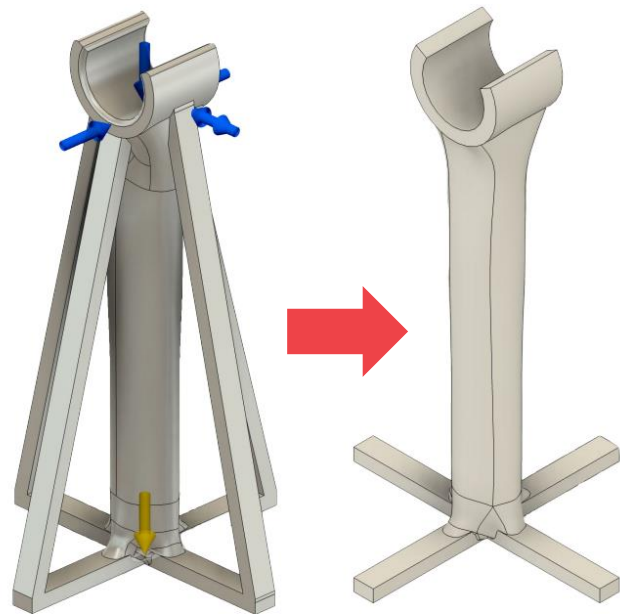
**EVEHX**



# Let's enhance productivity!?

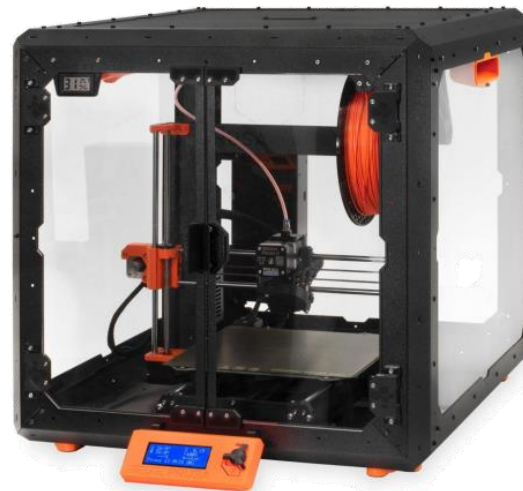
## ❖ Innovation:

- Customization and prototyping with 3D printing can easily help improve and implement **(great)** ideas!



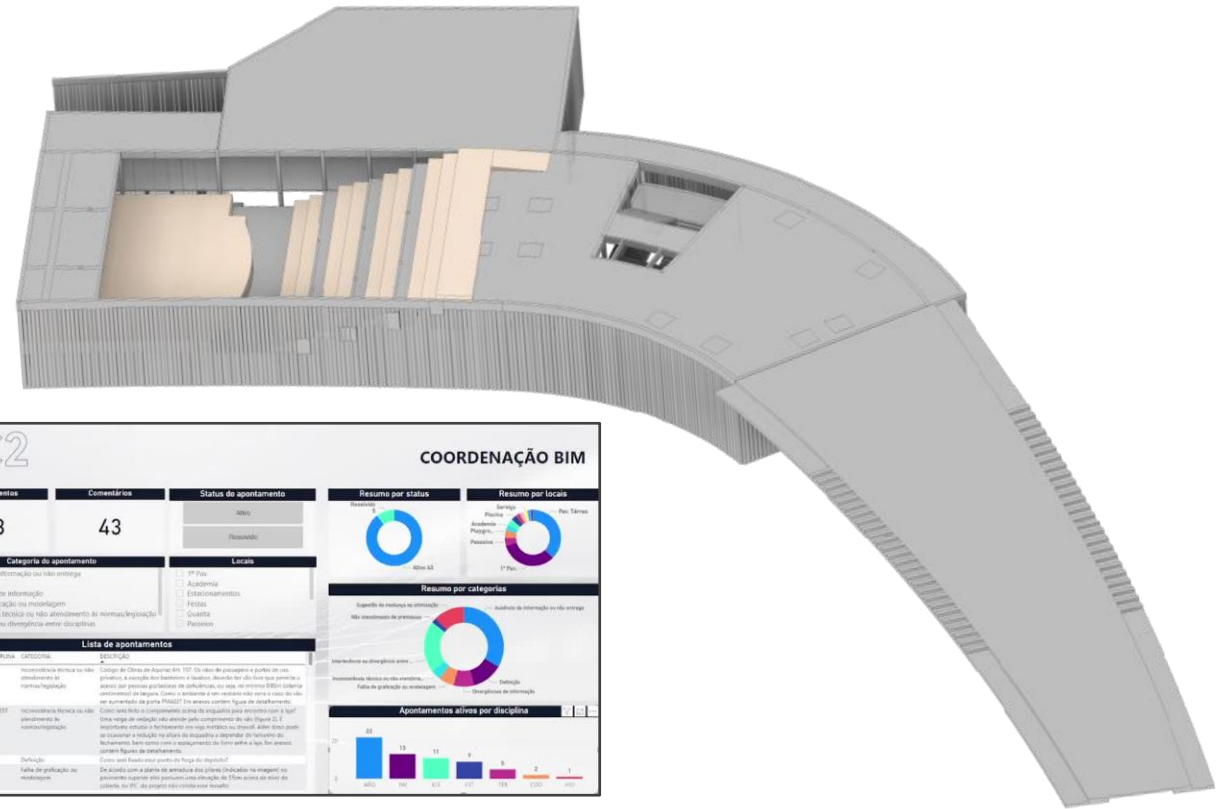
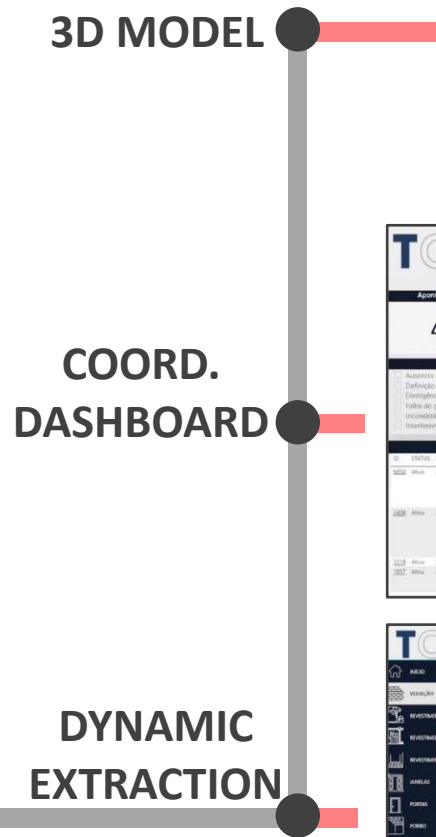
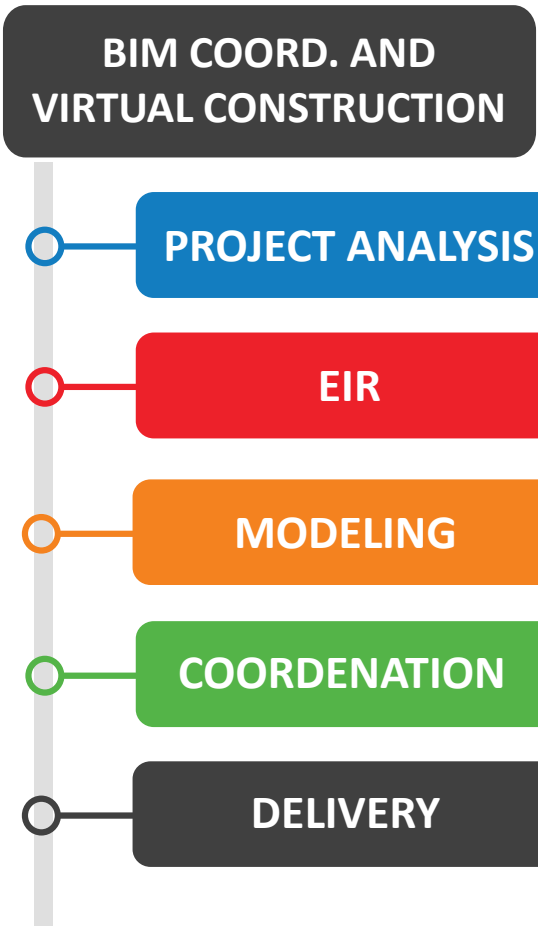
Human Intuitive Solution  
+ AI Generative Design

AI Generative Design  
Optimization



# Let's enhance productivity!?

## ❖ BIM:

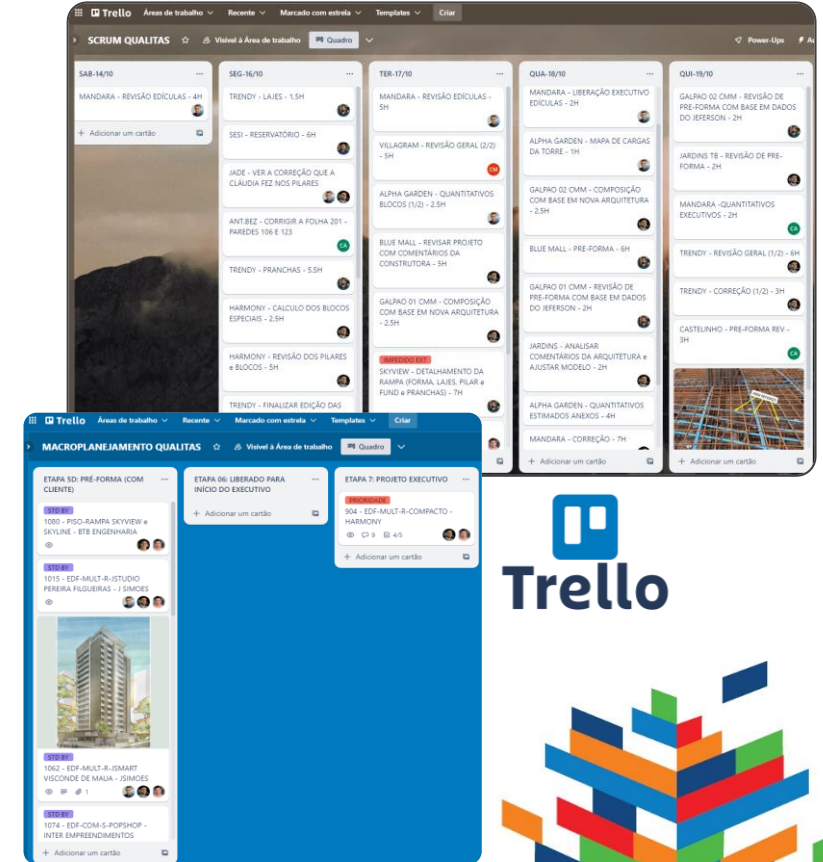
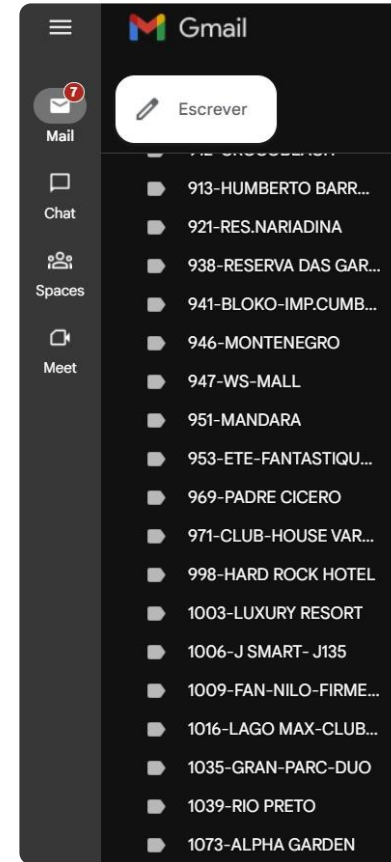


# Let's enhance productivity!?

## ❖ Office/Construction site communication:

- All information matters!

Nome	Data de modificação	Tipo	Tamanho
230530 - ARQUITETURA	21/09/2023 10:57	Pasta de arquivos	
230607 - CONCEITUAL	21/09/2023 10:57	Pasta de arquivos	
230706 - ARQUITETURA COMENTADA	21/09/2023 10:57	Pasta de arquivos	
230712 - ARQUITETURA COMENTADA	21/09/2023 10:57	Pasta de arquivos	
230717 - IMAGEM	21/09/2023 10:57	Pasta de arquivos	
230721 - ARQUITETURA COMENTADA	21/09/2023 10:57	Pasta de arquivos	
230724 - ARQUITETURA COMENTADA	21/09/2023 10:57	Pasta de arquivos	
230808 - TOPOGRAFIA	21/09/2023 10:57	Pasta de arquivos	
230809 - COMENTARIO SOBRE INSTALACO...	21/09/2023 10:57	Pasta de arquivos	
230818 - ARQUITETURA COMENTADA	21/09/2023 10:57	Pasta de arquivos	
230901 - ARQUITETURA COMENTADA	21/09/2023 10:57	Pasta de arquivos	
230906 - COMENTARIO DR JOSE SOBRE P...	21/09/2023 10:57	Pasta de arquivos	
230918 - ARQUITETURA	22/09/2023 10:47	Pasta de arquivos	
230918 - APROVACAO FORMA TIPO	21/09/2023 10:57	Pasta de arquivos	



# Ranking productivity: Data matter!

“You can't manage what you don't measure.”  
(William Edwards Deming)



**IMPACTO** Contato Login Cadastro

**CALCULADORA DE PRODUTIVIDADE**

Área: 100, Ciclo: 10, Serventes: 1, Auxiliares: 1, Profissionais: 1, Encarregados: 1, Mestres: 1

Atualizar Entenda como funciona

SUA OBRA ESTÁ CLASSIFICADA EM: **7º LUGAR**

VOCÊ ESTÁ GASTANDO: **R\$ 85,65/m²**

**60%** A MAIS QUE O 1º LUGAR

7º	Posição	1º
100	Área (m²)	626,77
10	Ciclo de laje (dias)	7
5	Funcionários	33
R\$ 85,65	Custo (m²)	R\$ 53,68

Sugestões

Ciclo de Laje (dias): 0 2 4 6 8 10 12

Serventes, Auxiliares, Profissionais, Encarregados, Mestres

Obra (light blue bar), Sugestão (Média) (green dot)

\* Sugestões baseadas na média dos 5 primeiros lugares.

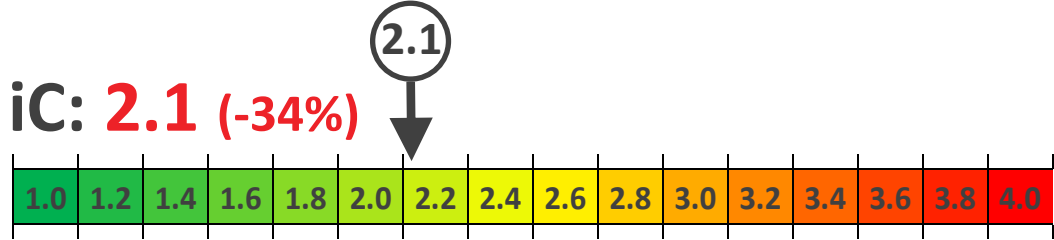
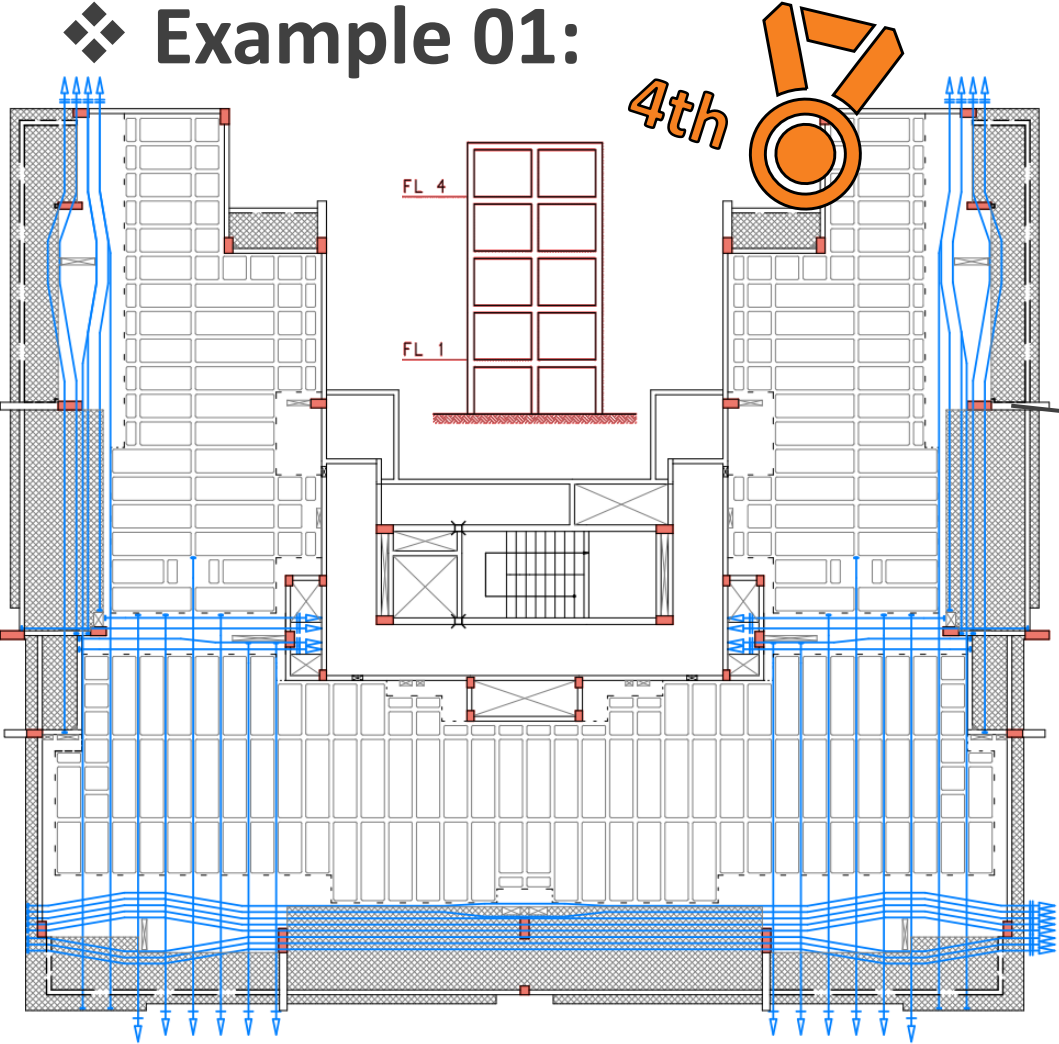


More than 2000 cycles cataloged!!!



# Some real examples

## ❖ Example 01:

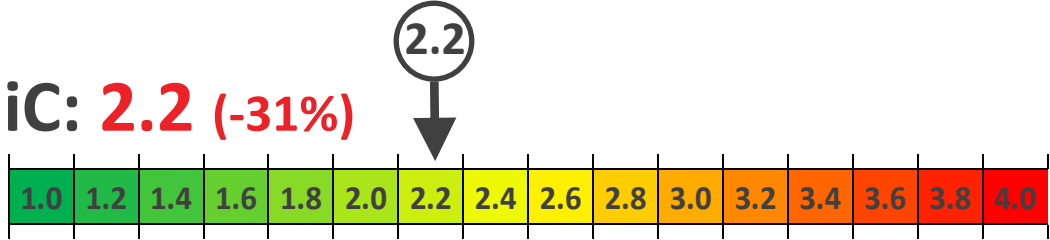
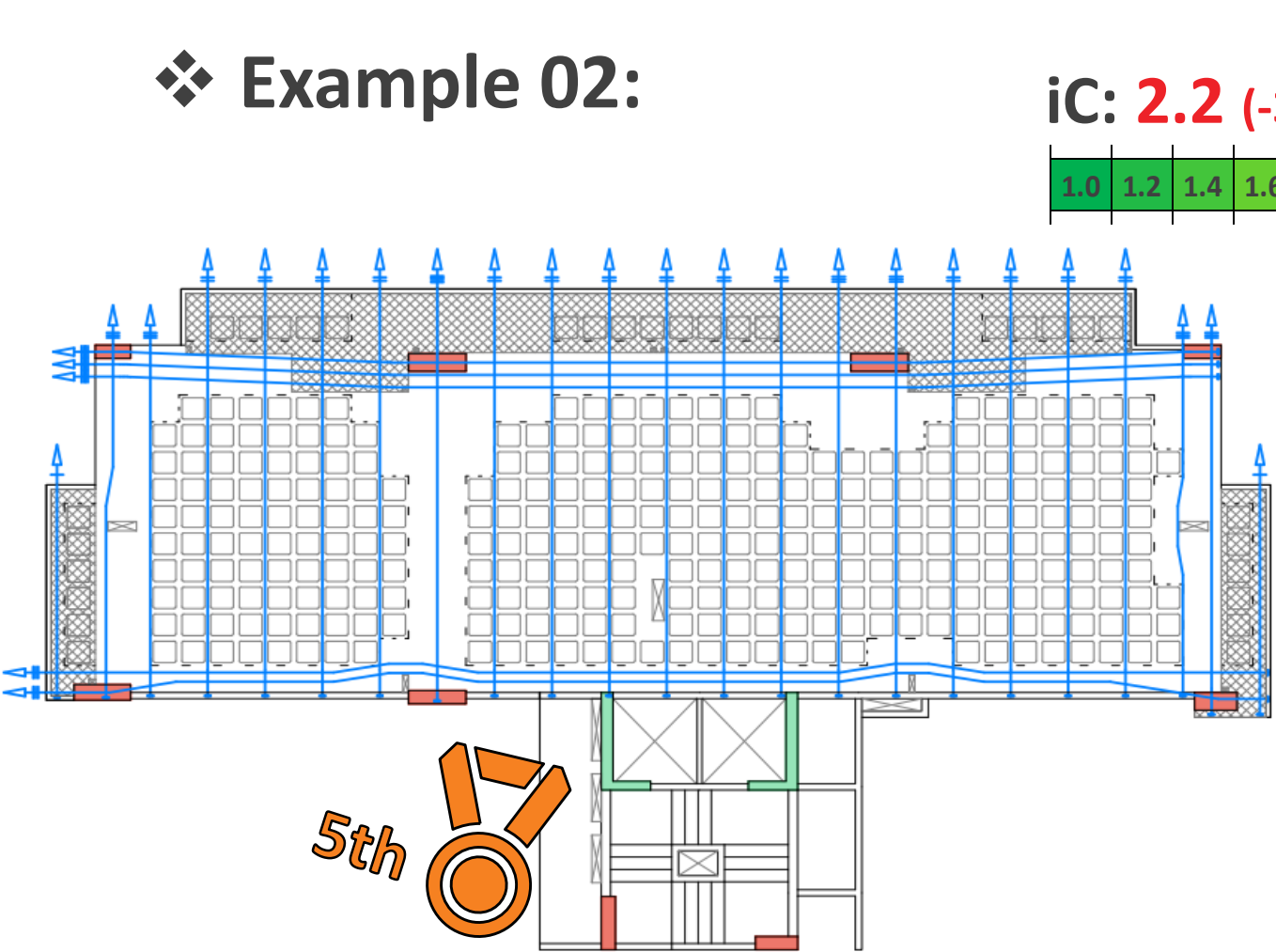


- $i1 = 0.65 \text{ ft}^3/\text{ft}^2$
- $i2 = 1.55 \text{ ft}^2/\text{ft}^2$
- $i3 = 3.21 \text{ lb}/\text{ft}^2$
- $i4 = 0.31 \text{ lb}/\text{ft}^2$
- $\lambda = 29.5$
- $\text{RUP}_{\text{cum}} = 4.75 \text{ sqft}/\text{MH} (+32\%)$
- $\$ 10.00/\text{sqft} (+11\%)$

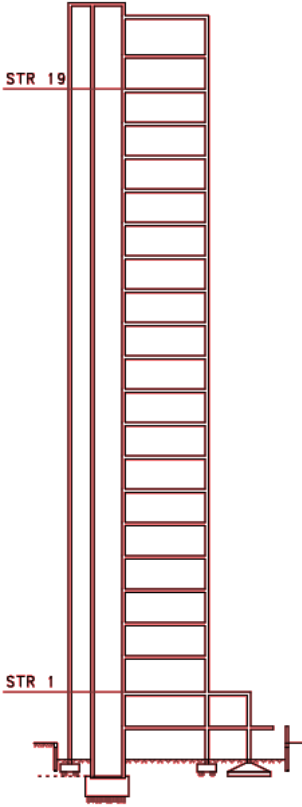


# Some real examples

## ❖ Example 02:

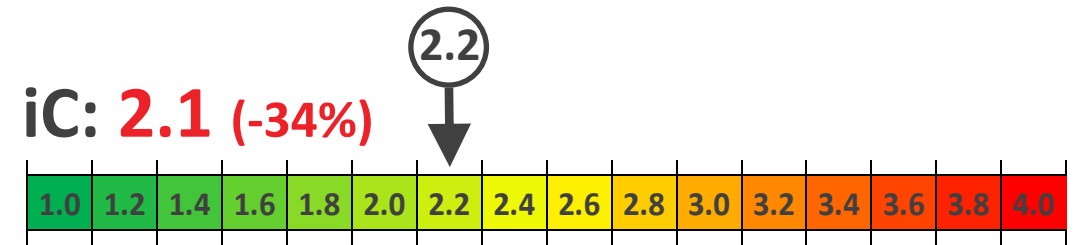
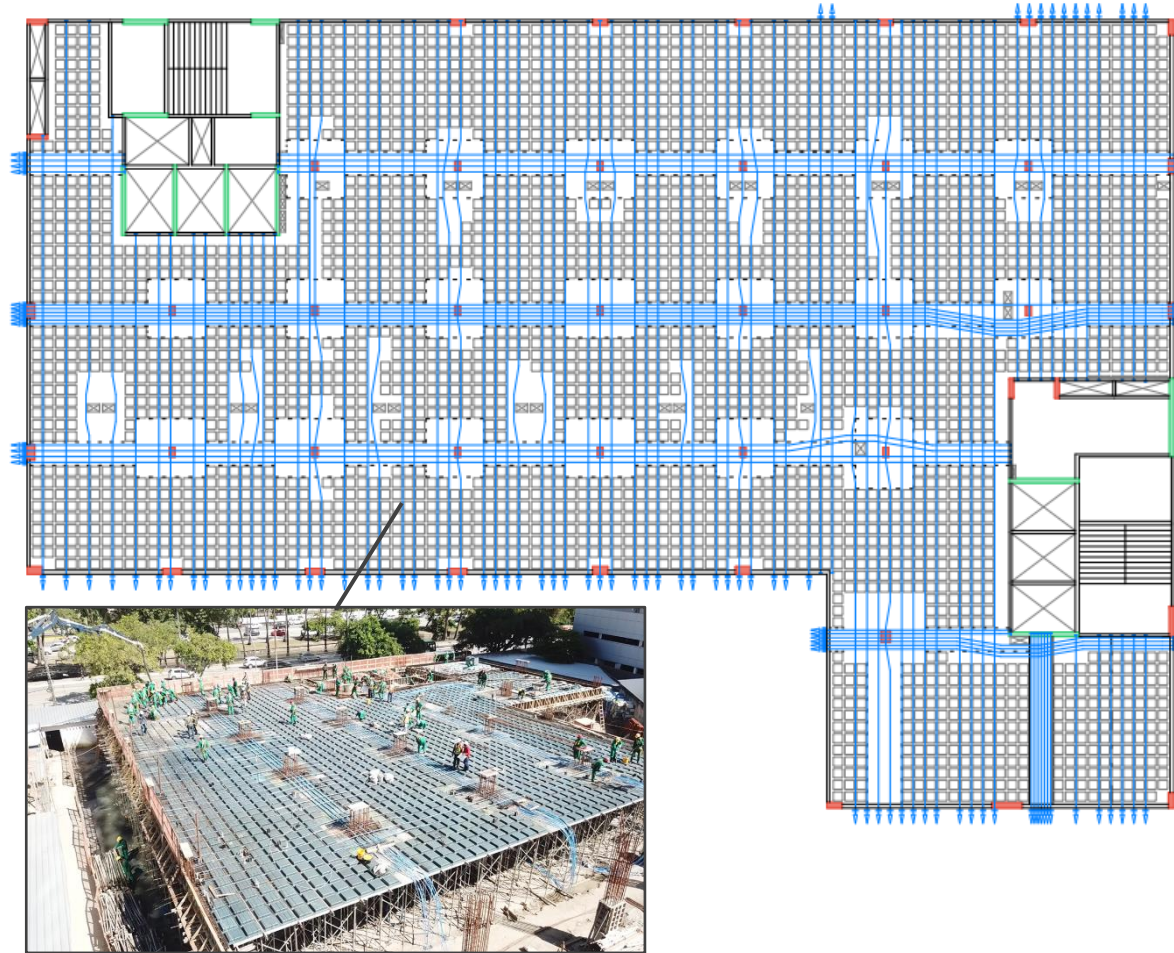


- $i1 = 0.76 \text{ ft}^3/\text{ft}^2$
- $i2 = 1.56 \text{ ft}^2/\text{ft}^2$
- $i3 = 4.06 \text{ lb}/\text{ft}^2$
- $i4 = 0.66 \text{ lb}/\text{ft}^2$
- $\lambda = 37.6$
- $\text{RUP}_{\text{cum}} = 3.94 \text{ sqft}/\text{MH} (+9\%)$
- **\$ 12.00/sqft (+33%\*\*)**

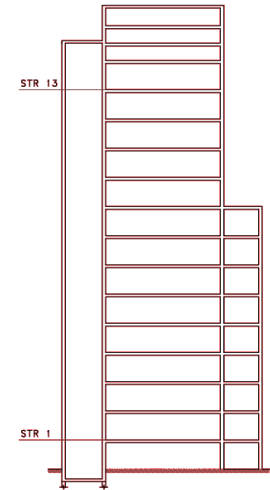


# Some real examples

## ❖ Example 03:



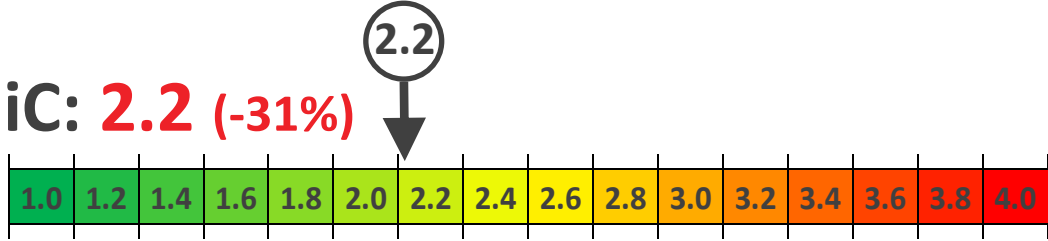
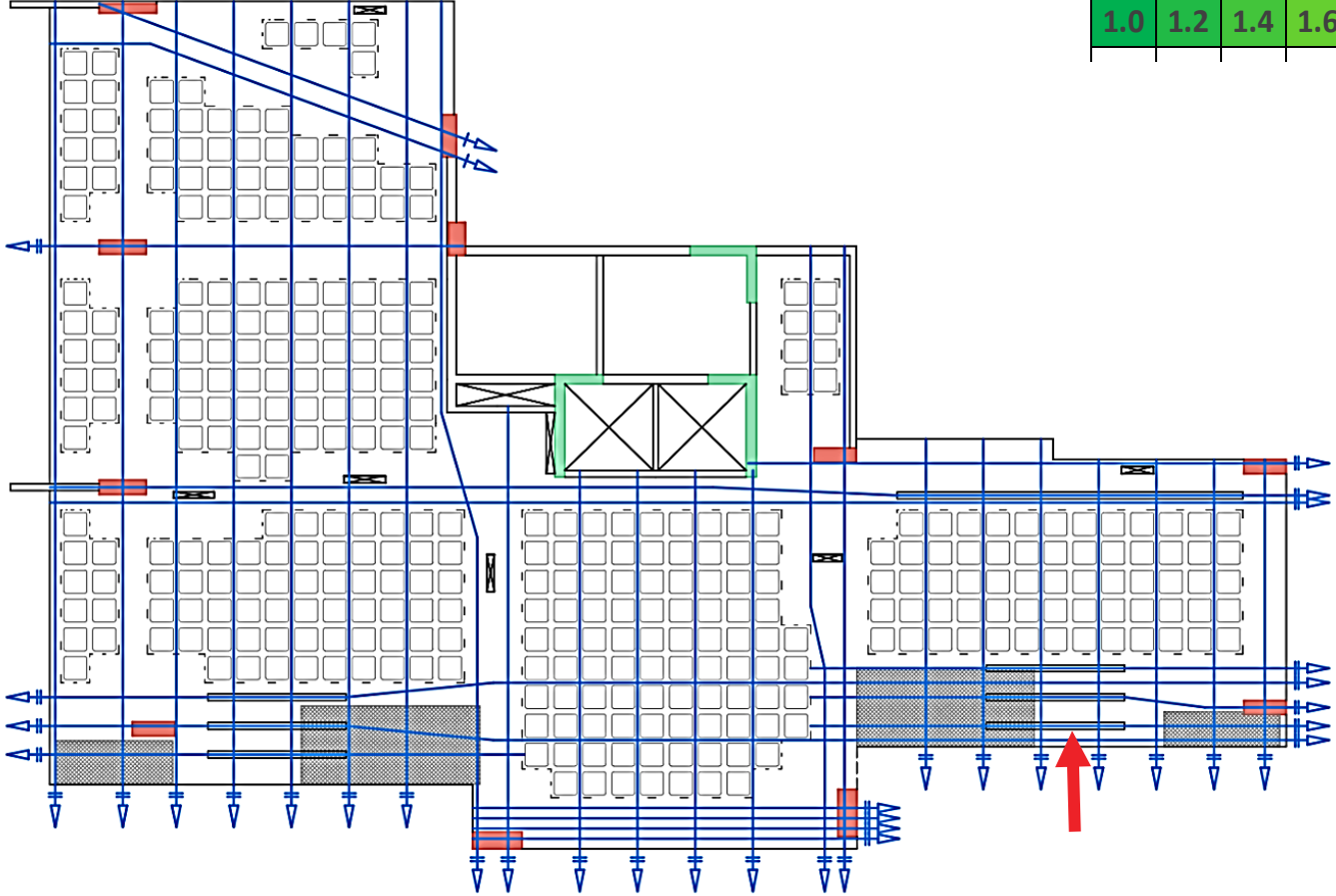
- $i1 = 0.66 \text{ ft}^3/\text{ft}^2$
- $i2 = 1.53 \text{ ft}^2/\text{ft}^2$
- $i3 = 2.87 \text{ lb}/\text{ft}^2$
- $i4 = 0.69 \text{ lb}/\text{ft}^2$
- $\lambda = 37.5$
- $\text{RUP}_{\text{cum}} = 4.57 \text{ sqft}/\text{MH} (+27\%)$
- $\$ 10.00/\text{sqft} (11\%)$



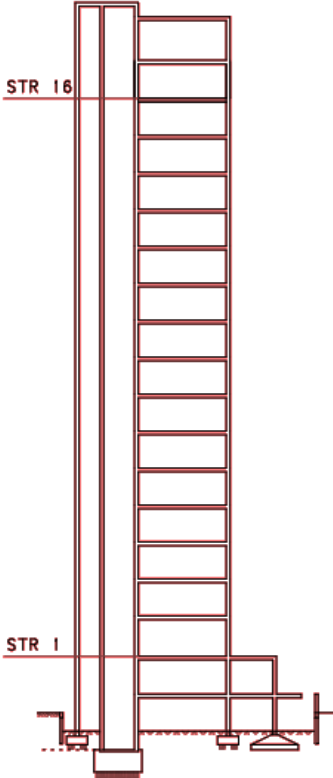


# Some real examples

## ❖ Example 04:



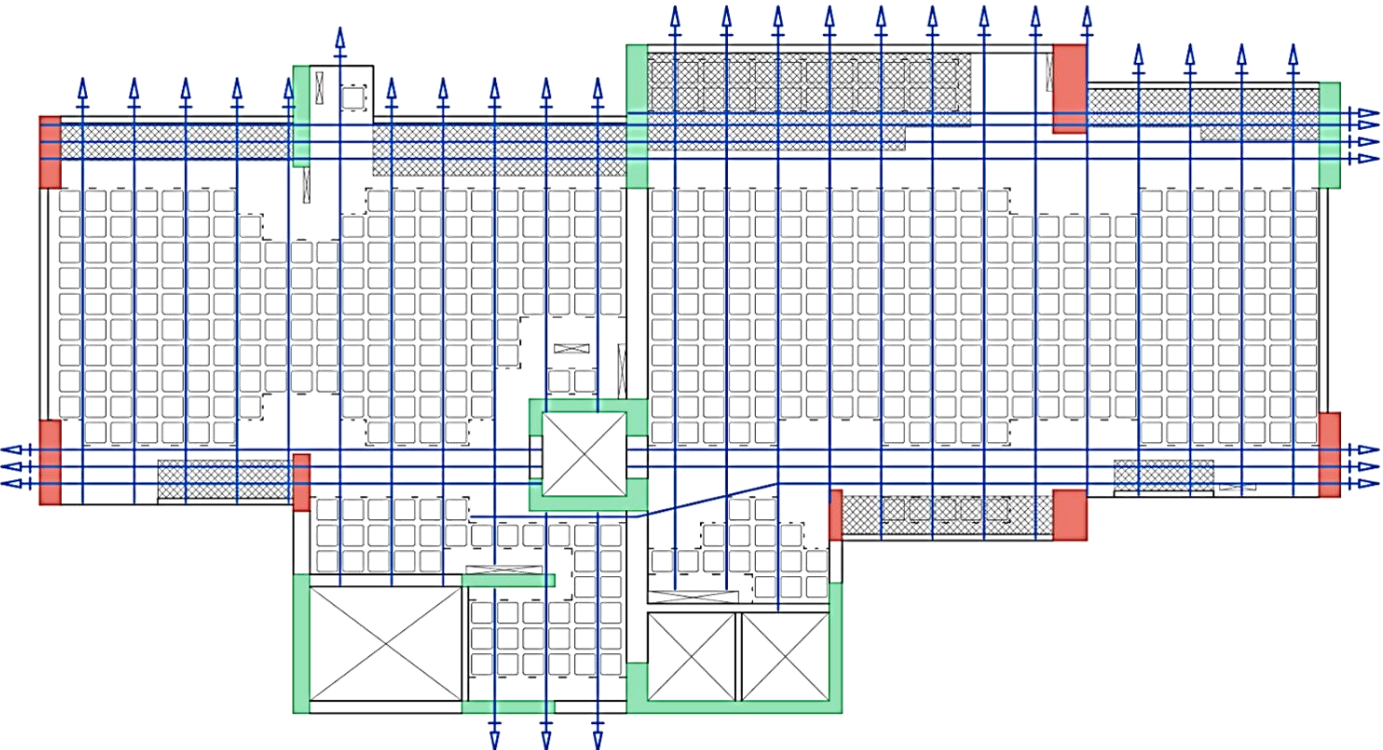
- $i1 = 0.79 \text{ ft}^3/\text{ft}^2$
- $i2 = 1.57 \text{ ft}^2/\text{ft}^2$
- $i3 = 3.52 \text{ lb}/\text{ft}^2$
- $i4 = 0.70 \text{ lb}/\text{ft}^2$
- $\lambda = 40.5^* \mid 29.9$
- $\text{RUP}_{\text{cum}} = 4.25 \text{ sqft}/\text{MH} (+18\%)$
- $\$ 12.00/\text{sqft} (+33\%)$



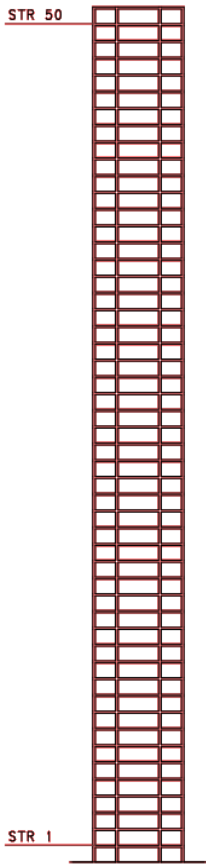
# Some real examples

## ❖ Example 05:

iC: **3.2 (0%)**



- **i1 = 1.22 ft<sup>3</sup>/ft<sup>2</sup> (+2X!)**
- **i2 = 2.06 ft<sup>2</sup>/ft<sup>2</sup>**
- **i3 = 6.99 lb/ft<sup>2</sup>**
- **i4 = 0.72 lb/ft<sup>2</sup>**
- **λ = 34.1**
- **RUPcum = 2.45 sqft/MH (-32%)**
- **\$ 19.00/sqft (+111%)**



# Getting to 'NET Zero'!

Include voids, coffers or profile sections to reduce concrete volume in thick or planar concrete sections (slabs, rafts, diaphragm walls, profiled retaining wave walls)	4	2022
Increase utilisation factors and assess design optimisation	4	2022



## A zero-carbon future

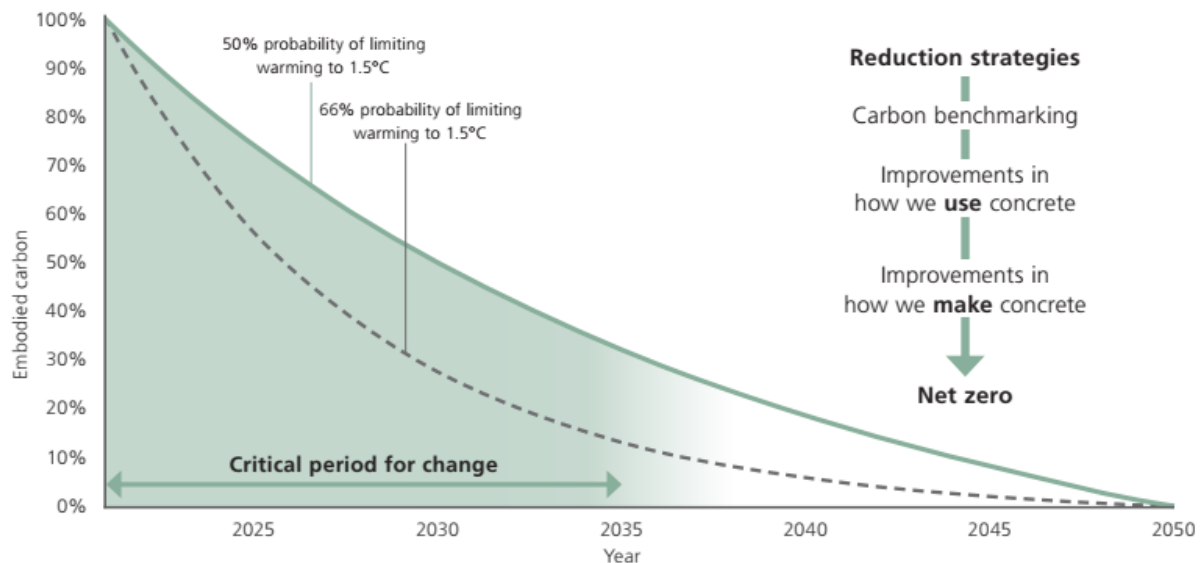


Fig 1: Idealised reduction rate for embodied carbon in concrete

Engineers Design and specification	D1	Include voids, coffers or profile sections to reduce concrete volume in thick or planar concrete sections (slabs, rafts, diaphragm walls, profiled retaining wave walls)	4	2022
	D2	Increase utilisation factors and assess design optimisation	4	2022
	D3	Make use of EN 1992 provisions to reduce material partial factors based on quality control and reduced deviations	1	2022
	D4	Take account in design of the real strength of concrete arising from the cement content that is required for workability and early strength gain	1	2022
		Specify reinforcement that will not corrode and define the real lifetime of RC elements	1	2022
		Specify an upper bound on kg CO <sub>2</sub> e/m <sup>3</sup> . Consider contractual incentives if a lower carbon content is achieved. Allow the concrete supplier the maximum possible flexibility to meet or beat the specified upper-bound kg CO <sub>2</sub> e/m <sup>3</sup>	3	2022

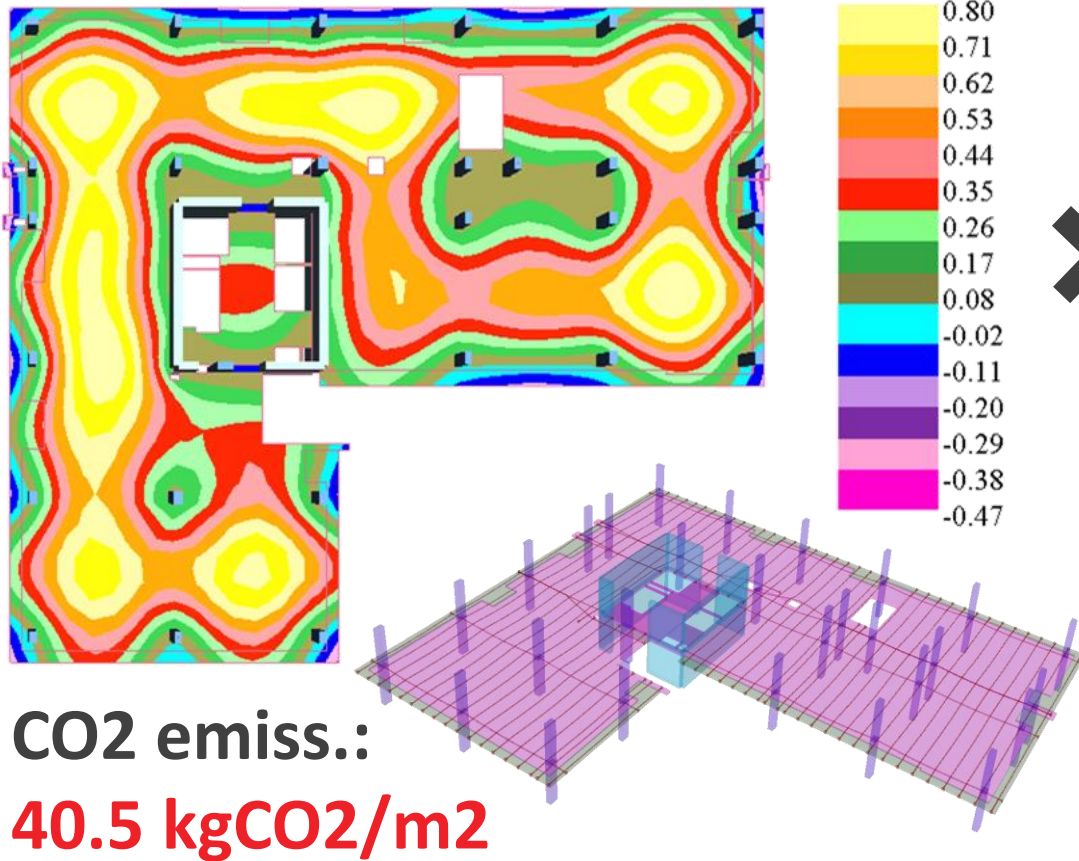


THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

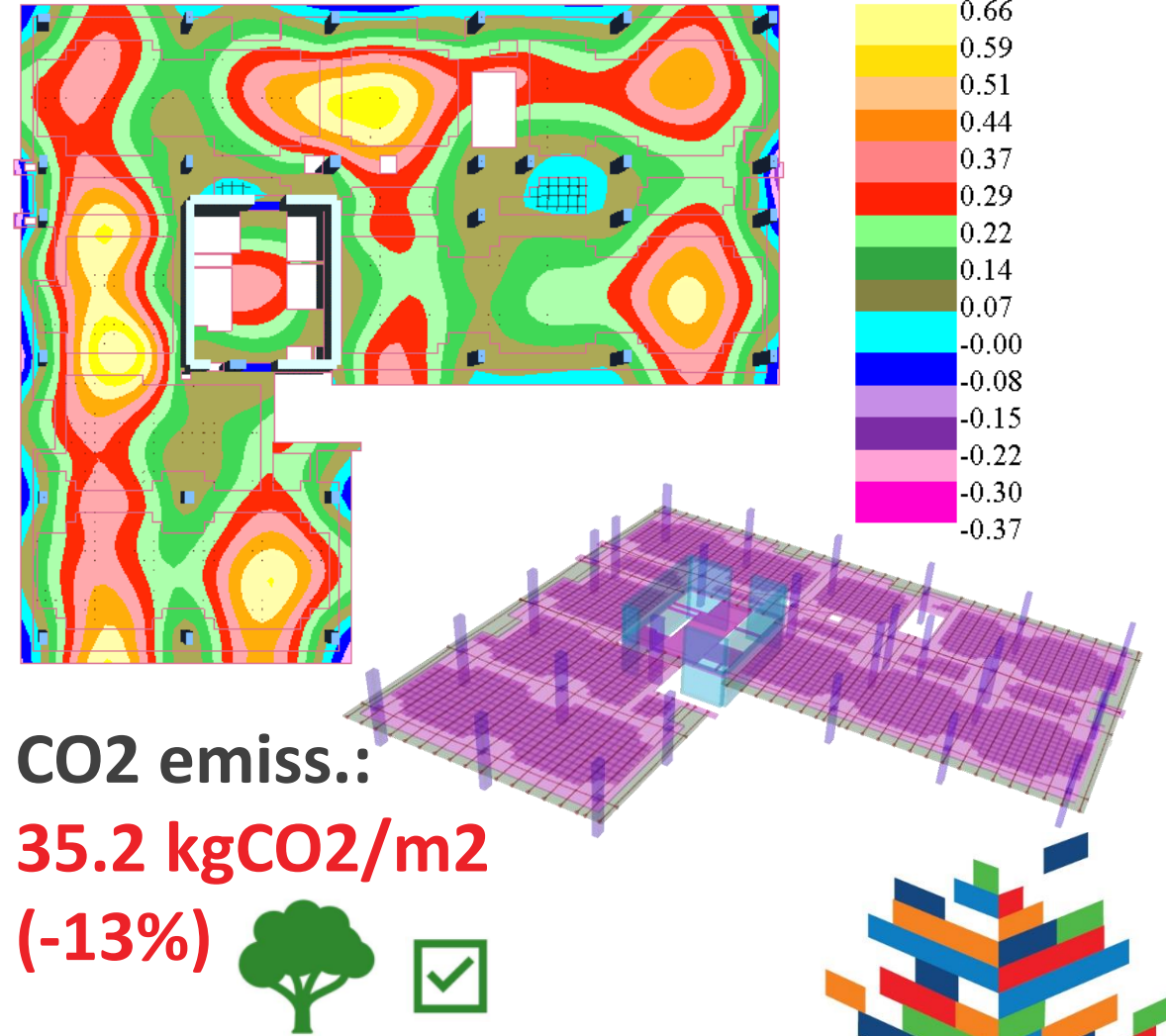
**aci** CONCRETE CONVENTION

# Getting to 'NET Zero'!

## ❖ Comparative (Only slabs):



×



**Thank you!**  
**Any questions?**



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