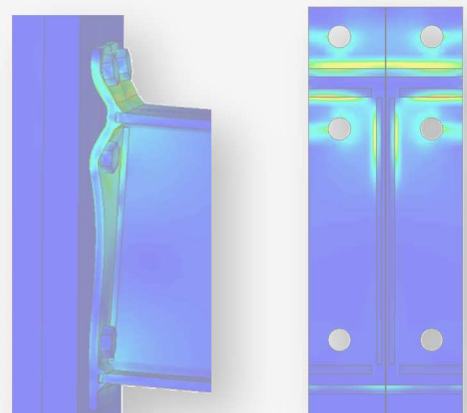
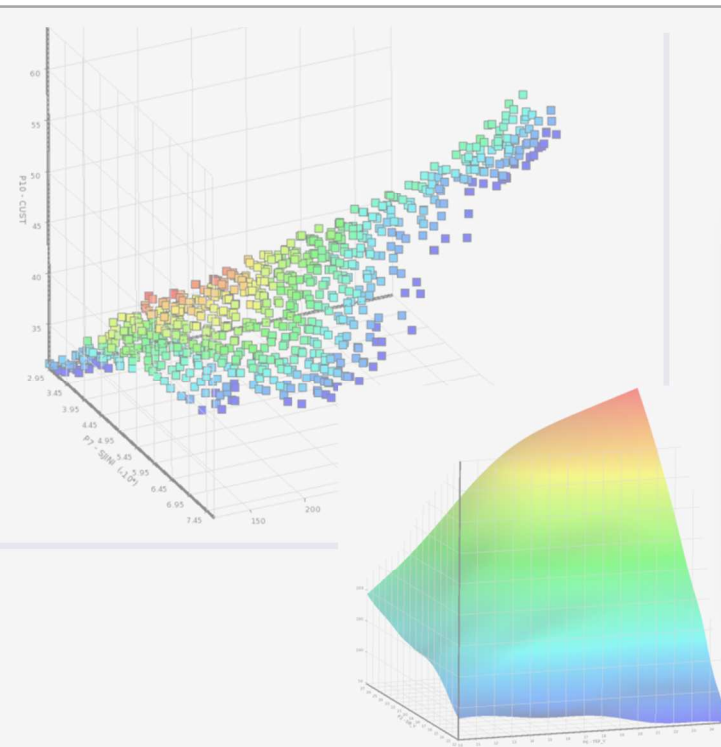
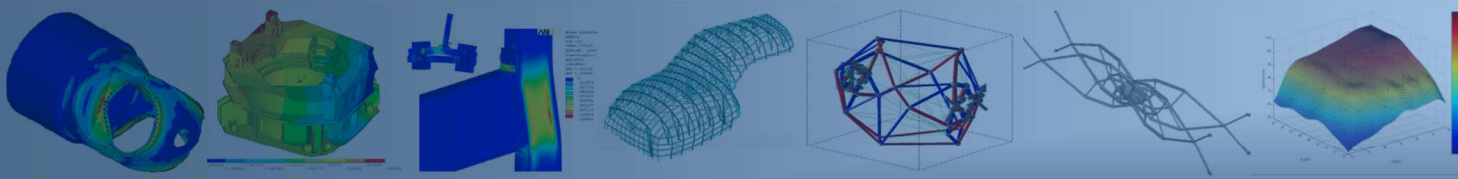


DISEÑO ÓPTIMO DE UNIONES SEMIRRÍGIDAS MEDIANTE SIMULACIÓN NUMÉRICA Y MODELOS KRIGING



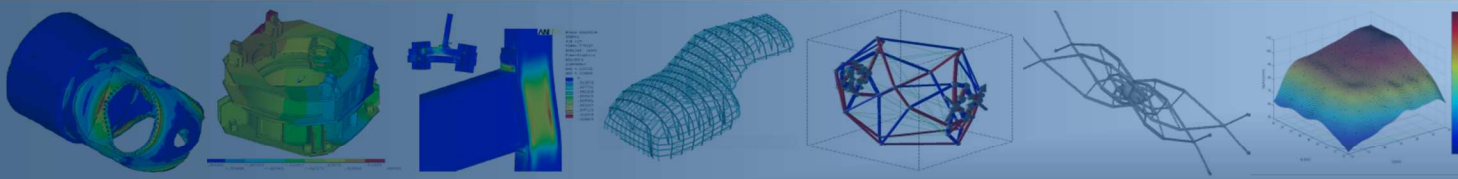
Dr. Pascual Martí Montrull¹
Ing. Jesús Martínez Frutos¹
Dra. Concepción Díaz Gómez¹
José Guillen Mercader²
Dra. M^a Eugenia Requena Pérez²
Dr. David Herrero Pérez¹
Dr. Mariano Victoria Nicolás¹

¹ Univ. Politécnica de Cartagena
Departamento de Estructuras y construcción
² Centro de Supercomputación
Fundación Parque Científico Murcia

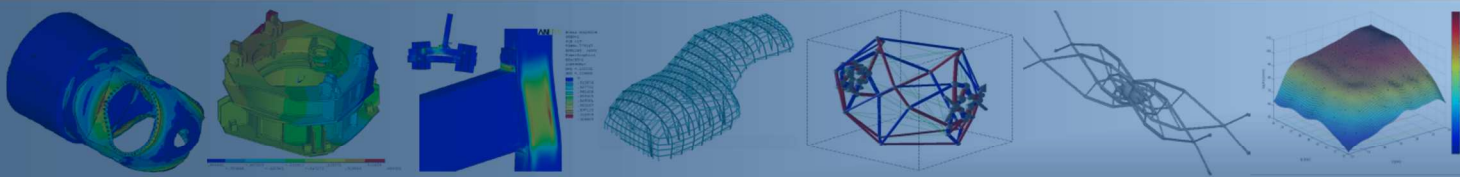


Presentación

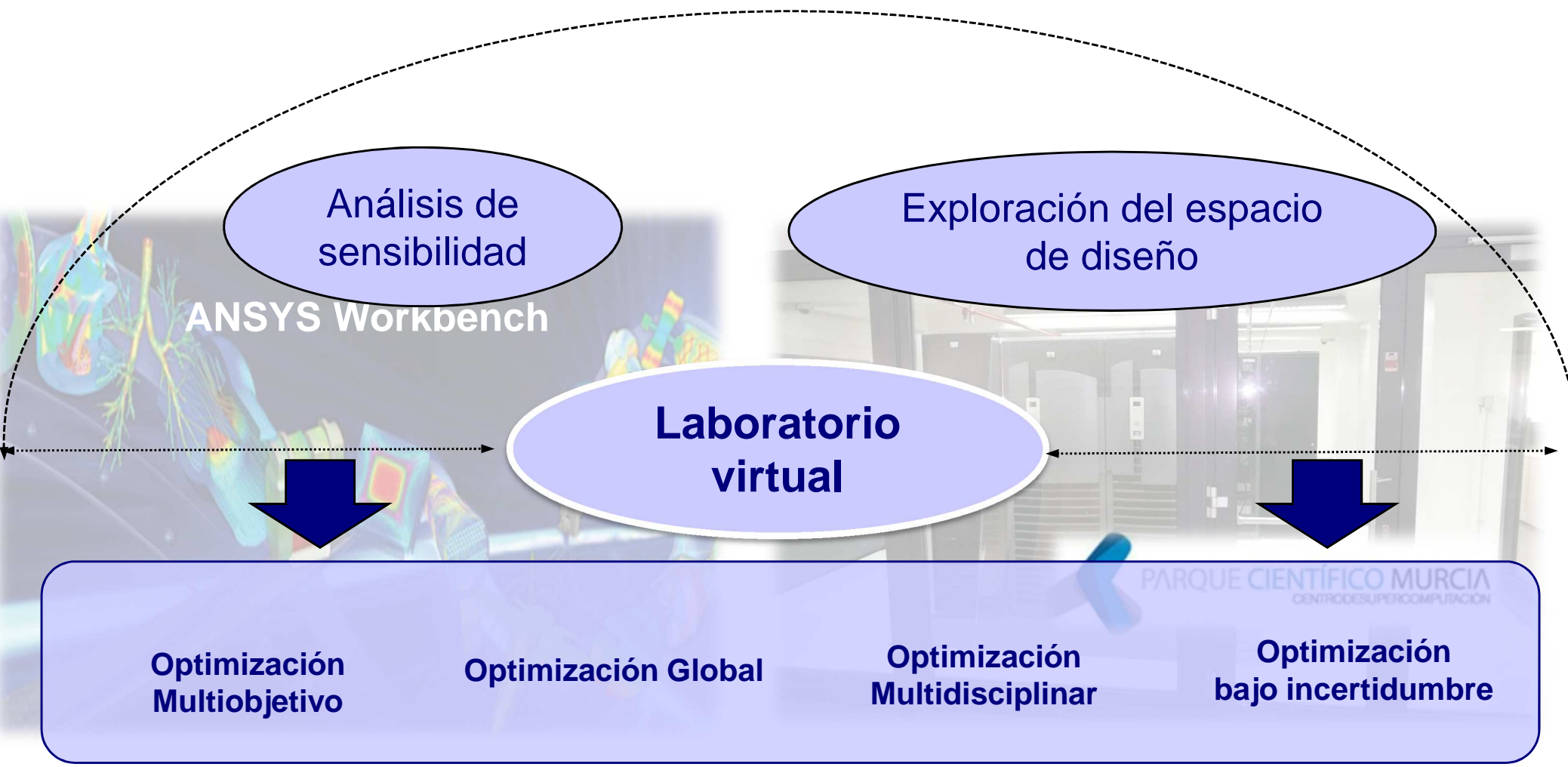
- 1 Motivación
- 2 Modelo de Elementos Finitos
- 3 Explotación de modelos de simulación de alto coste computacional
- 4 Exploración del espacio de diseño mediante el uso de Meta-modelos
- 5 Optimización Multi-objetivo de uniones semirrígidas
- 6 Conclusiones



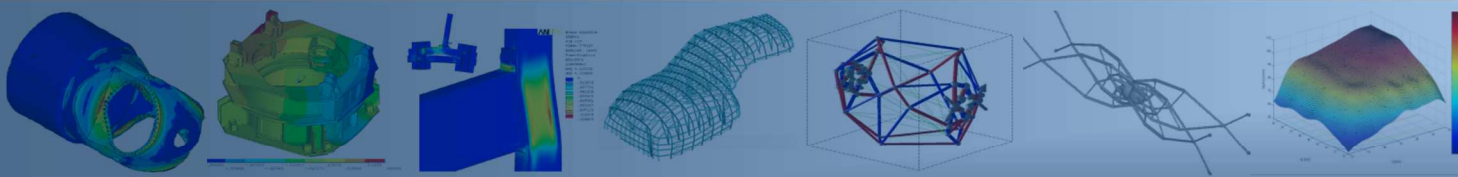
Motivación



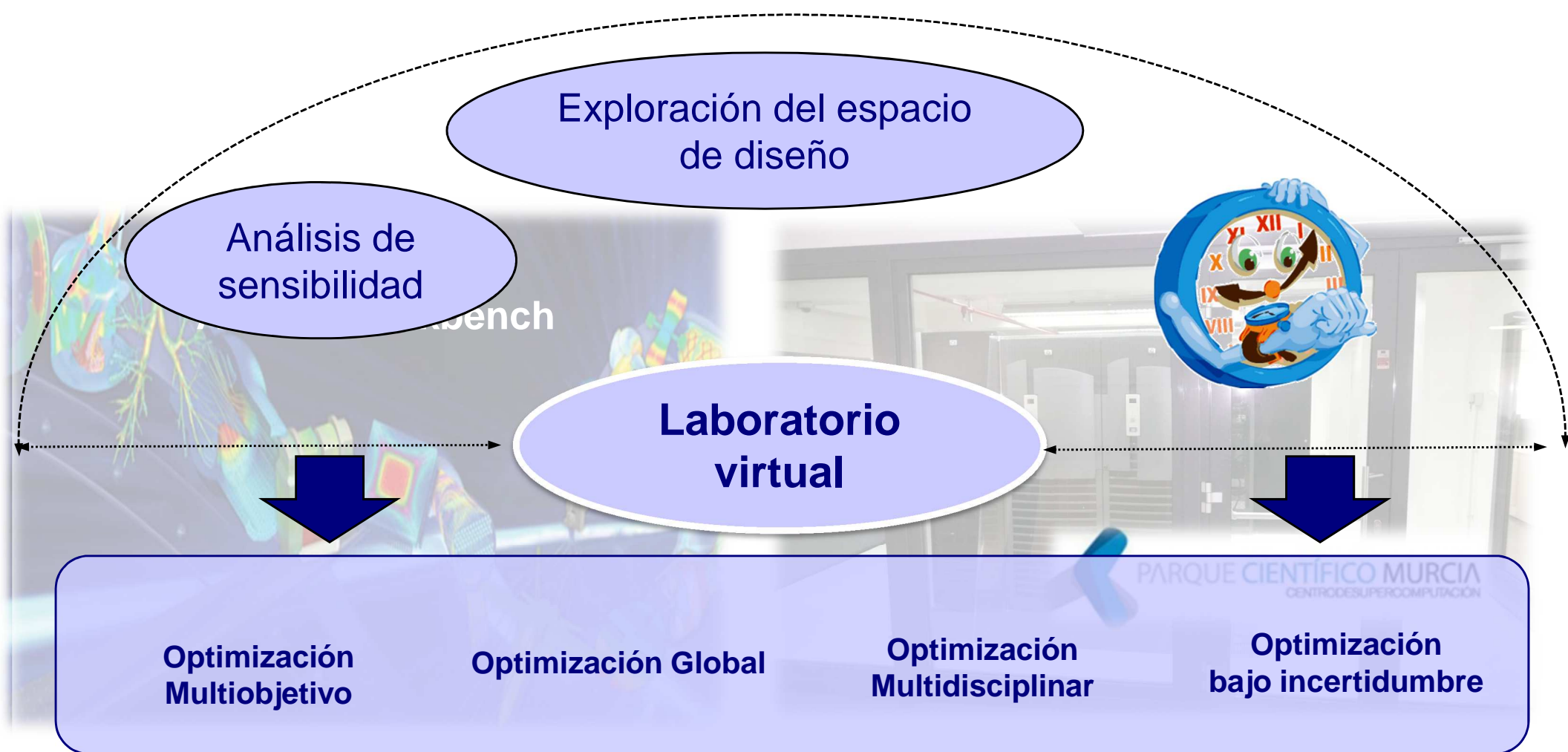
Motivación



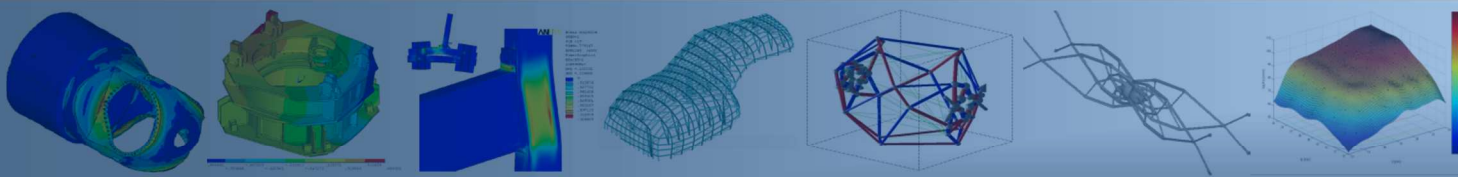
Mejores Diseños & Menores Costes



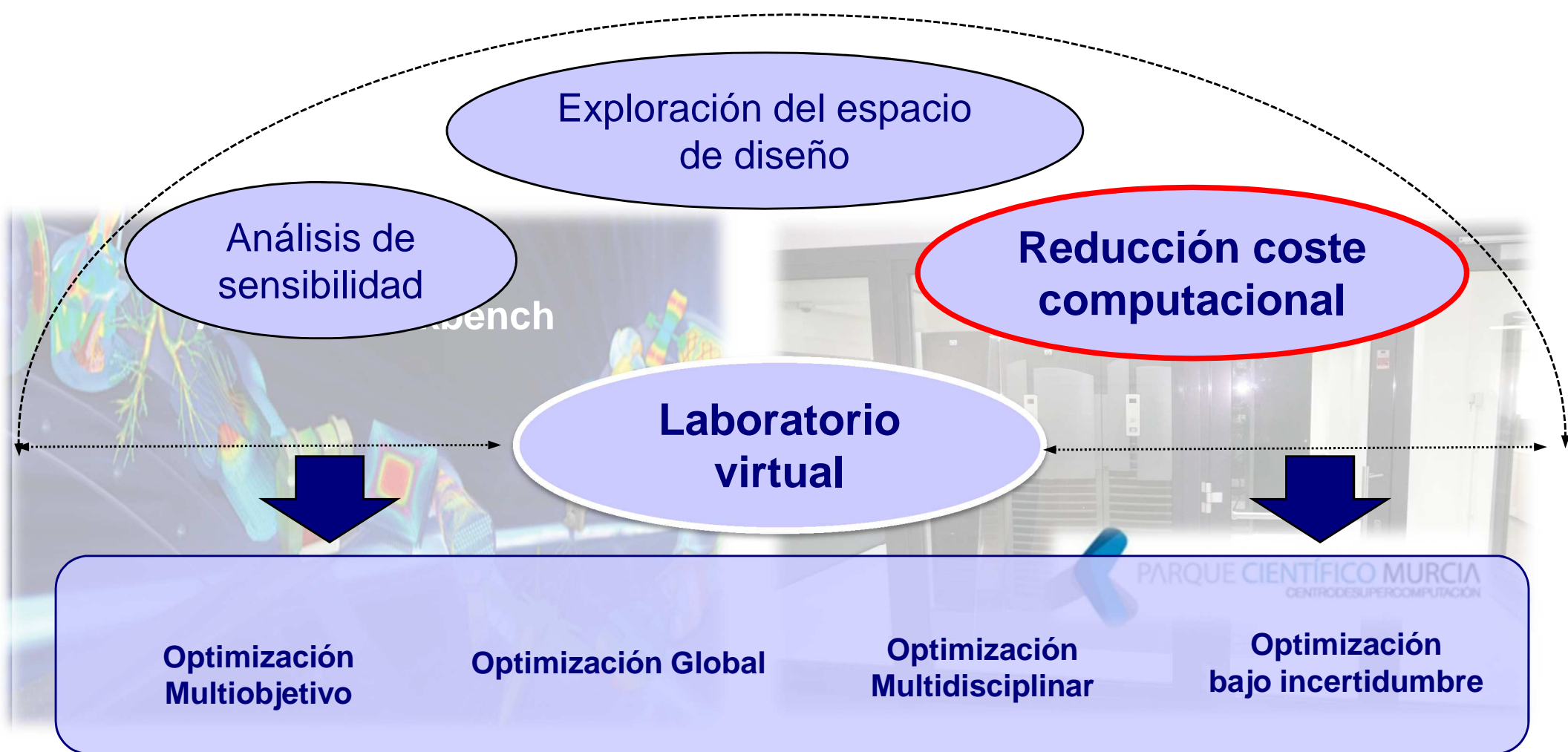
Motivación



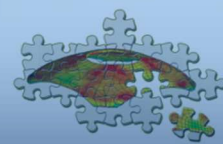
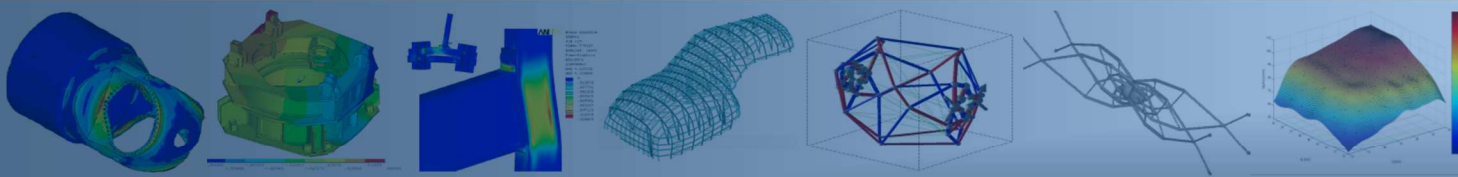
Mejores Diseños & Menores Costes



Motivación



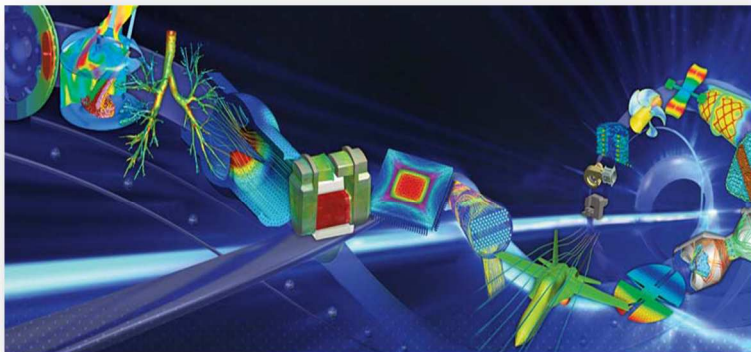
Mejores Diseños & Menores Costes

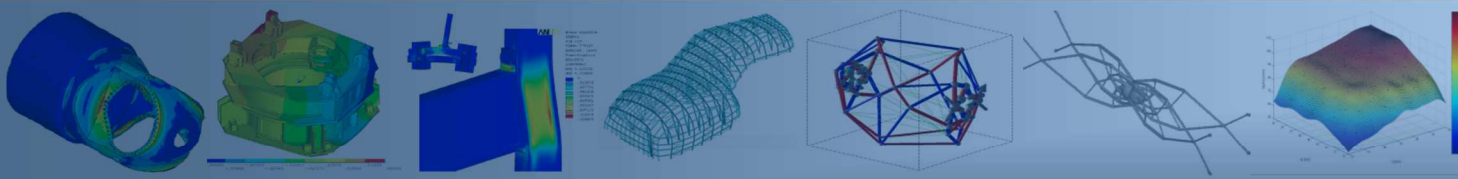


Motivación

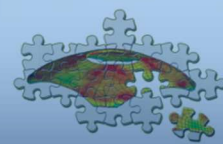
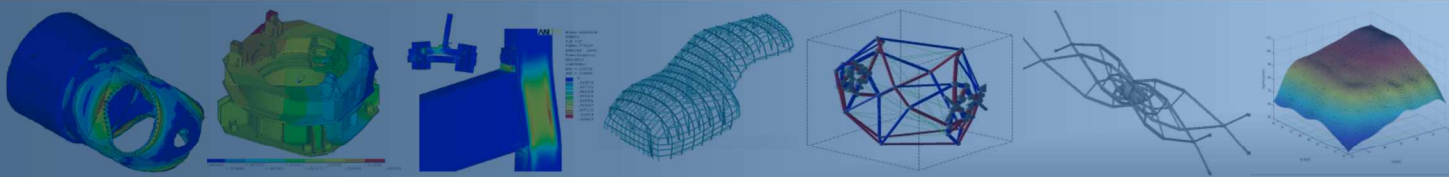
META-MODELOS + CÁLCULO DISTRIBUIDO

- Exploración y optimización de modelos de elementos finitos de alto coste computacional mediante la utilización de **Meta-modelos** y explotación del **cálculo distribuido** (Centro de Supercomputación Ben Arabí) en el entorno **ANSYS Workbench**.





Modelo de Elementos Finitos

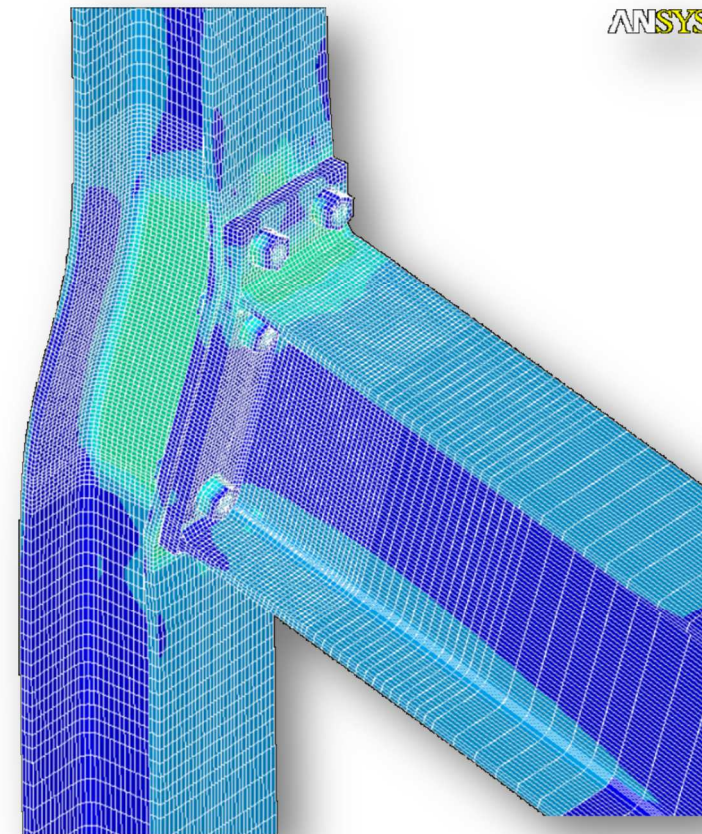


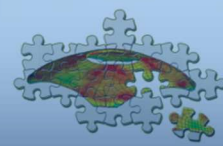
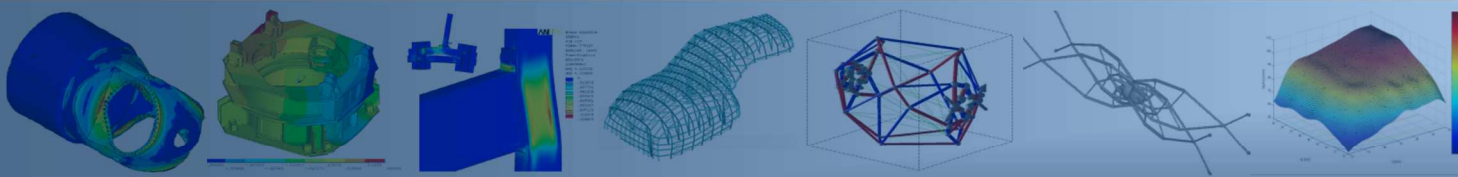
Modelización de uniones semirrígidas mediante Elementos Finitos

En la actualidad, el método de los elementos finitos está ampliamente aceptado como la técnica más eficaz para obtener soluciones numéricas de problemas estructurales.

Ventajas

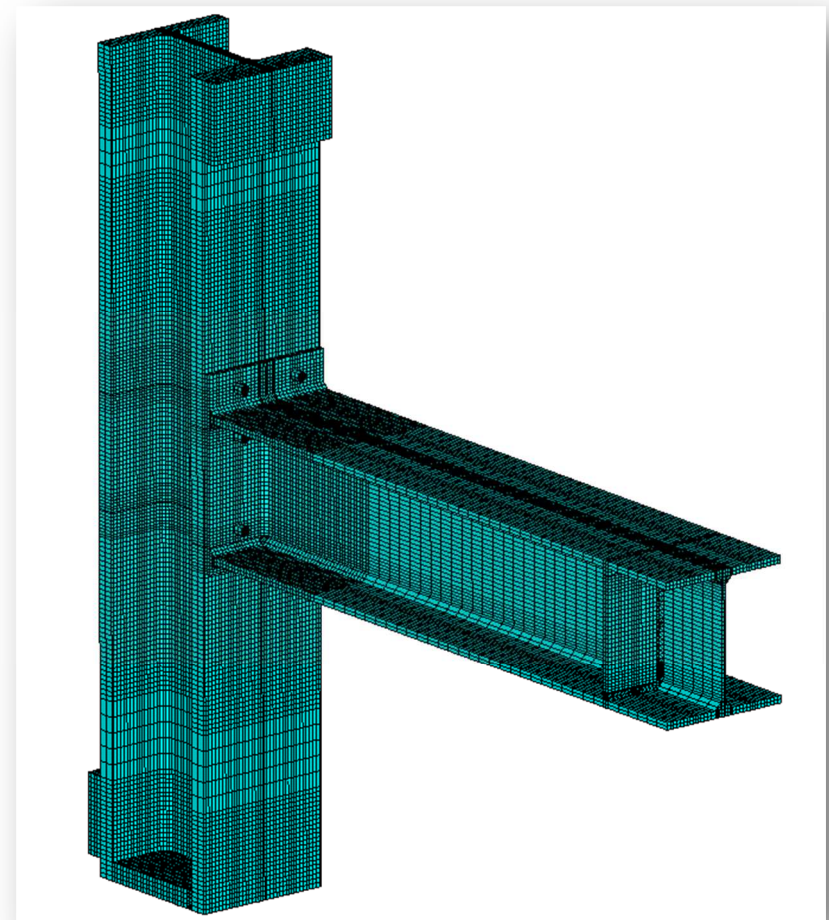
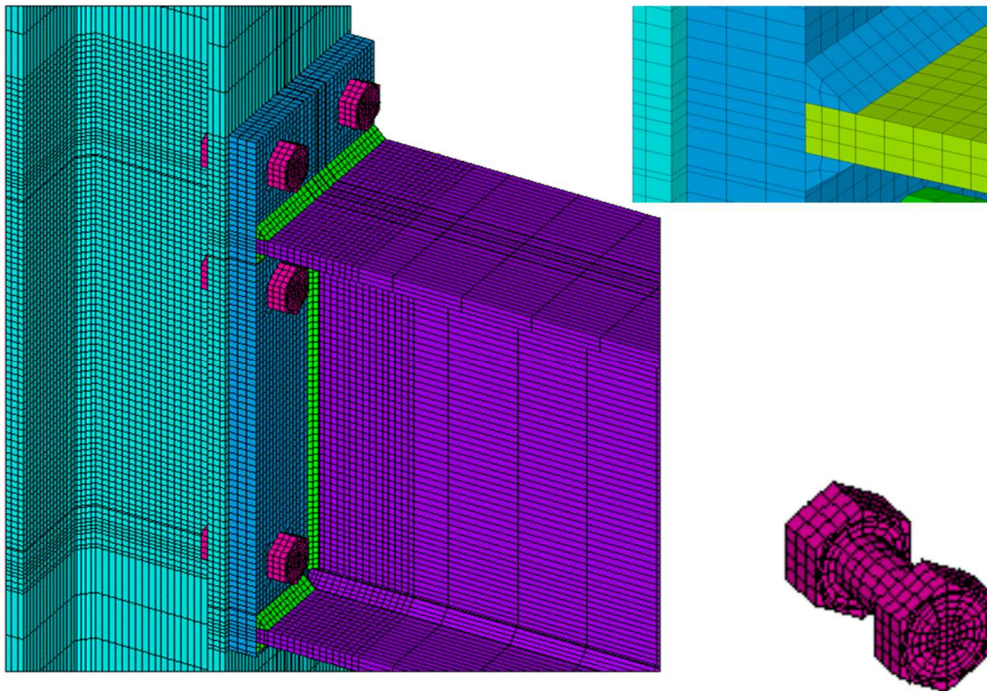
- Determinar el comportamiento rotacional de la unión.
- Evitar la necesidad de ensayos experimentales.
- Generar estudios paramétricos.
- Posibilitar el estudio de efectos locales difícil de determinar experimentalmente con suficiente precisión.

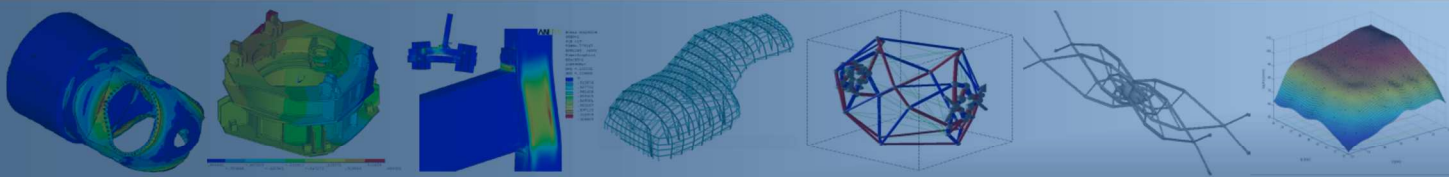




Modelo de elementos finitos. Características del MEF

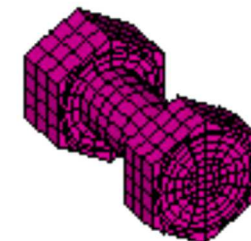
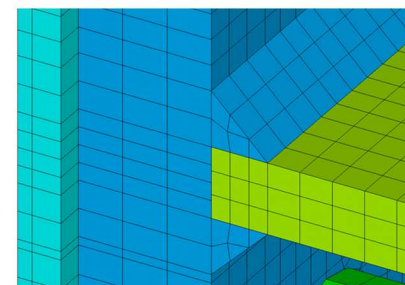
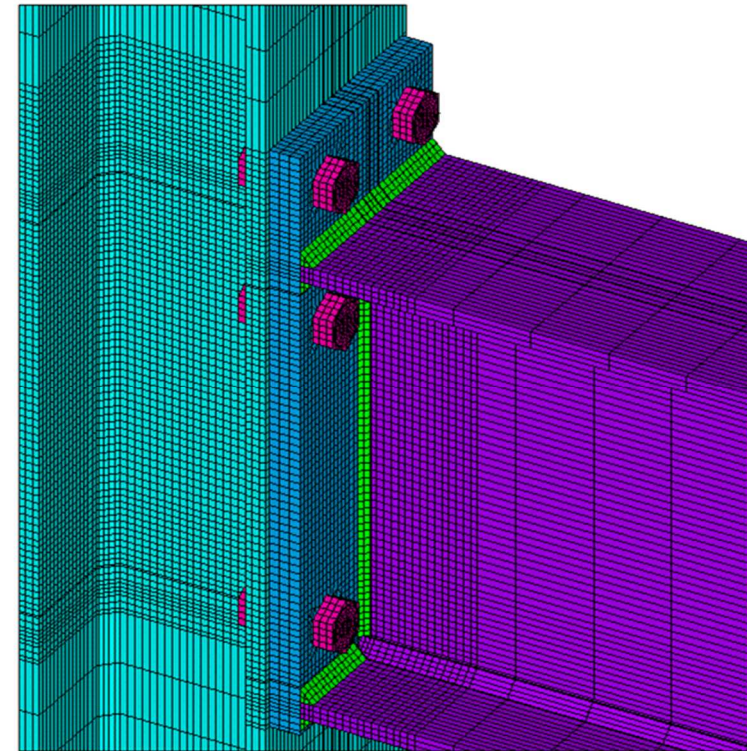
- En el presente trabajo se ha utilizado un modelo de elementos finitos desarrollado en **código APDL** de una unión semirrígida con chapa de testa extendida.

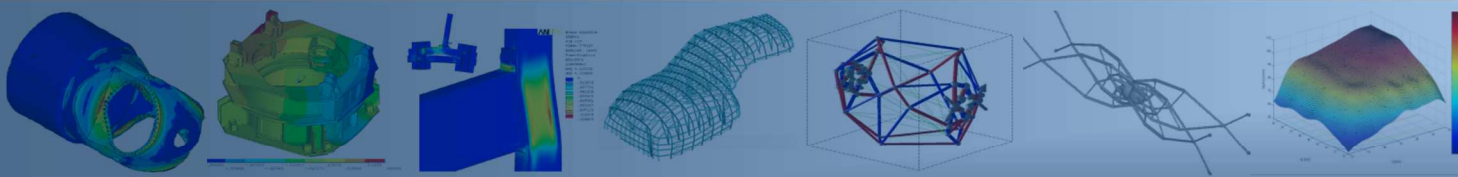




Modelo de elementos finitos. Características del MEF

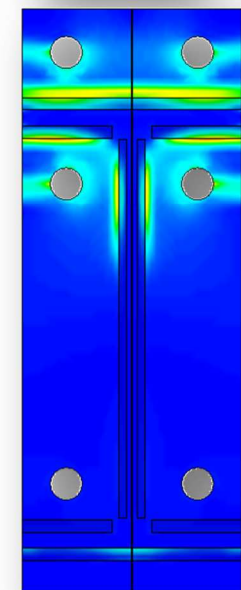
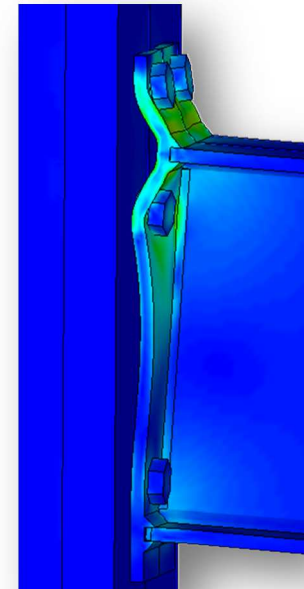
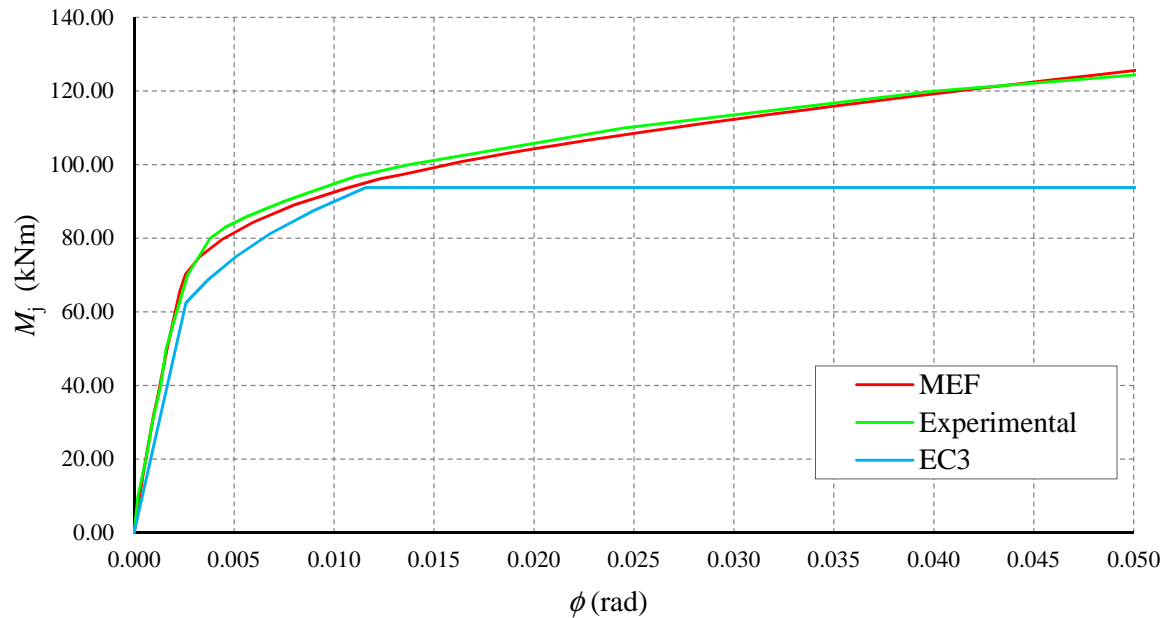
Componente	Elemento
Viga Columna Chapa de testa Soldadura Tornillos	SOLID45 Hexaédrico de 8 nodos, 3 gdl por nodo, integración completa, funciones de forma auxiliares incompatibles, grandes deformaciones y desplazamientos, y contacto
Contacto Superficie-superficie	CONTAC173 Elemento 3D de 4 nodos
	TARGET170 Superficie principal asociada al elemento de contacto
Pretensado de los tornillos	PRETS179 1 gdl en la dirección del pretensado
Estadística	
Elementos	53903
Nodos	71076
gdl	193279



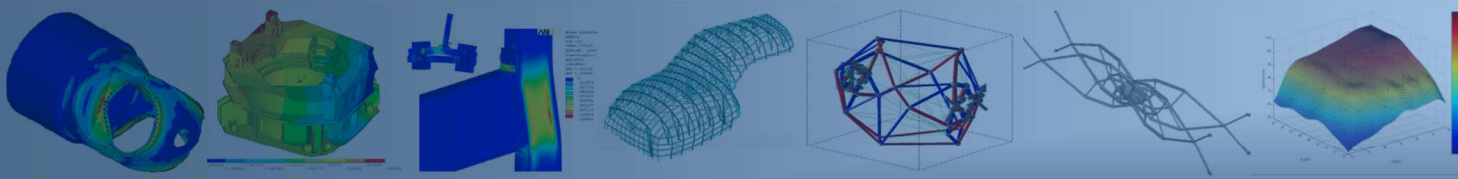


Modelo de elementos finitos. Calibración y validación

Ensayo T101.010 (Janss et al., 1987)

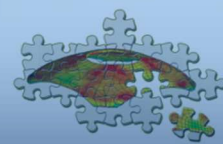
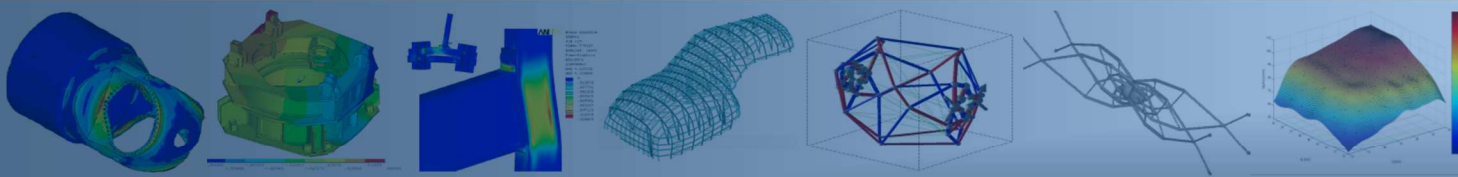


	Experimental (Janss et al., 1987)	MEF	EC3	$\frac{\text{MEF} - \text{Exp}}{\text{Exp}}$	$\frac{\text{EC3} - \text{Exp}}{\text{Exp}}$
$S_{j,ini}$ (kNm/rad)	25316	26264.95	24181.36	3.75%	-4.48%
$M_{j,Rd}$ (kNm)	96.36	93.70	93.78	-2.76%	-2.68%

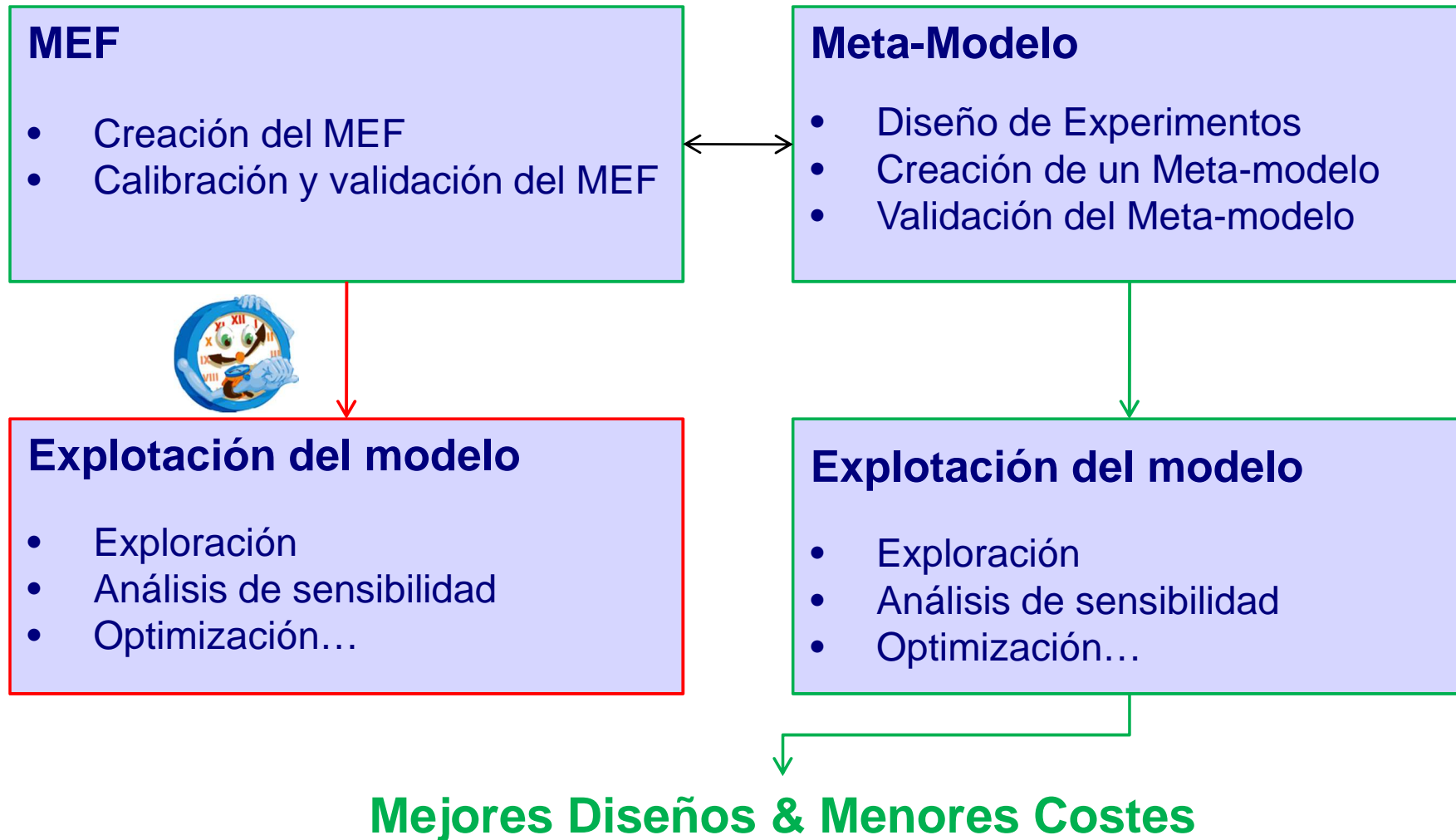


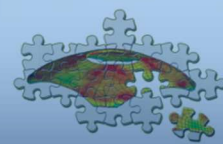
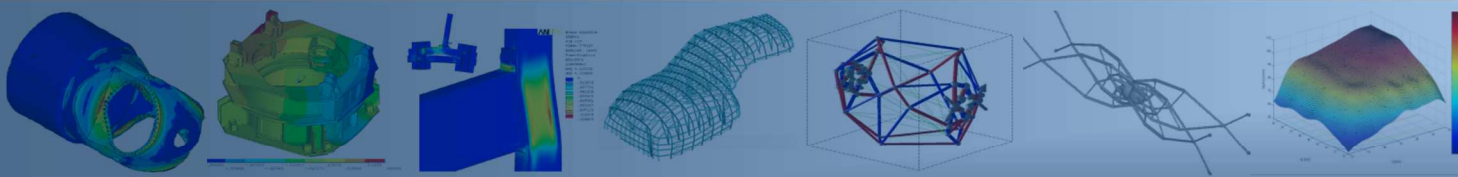
Laboratorio Virtual

Explotación de modelos de simulación de alto coste computacional

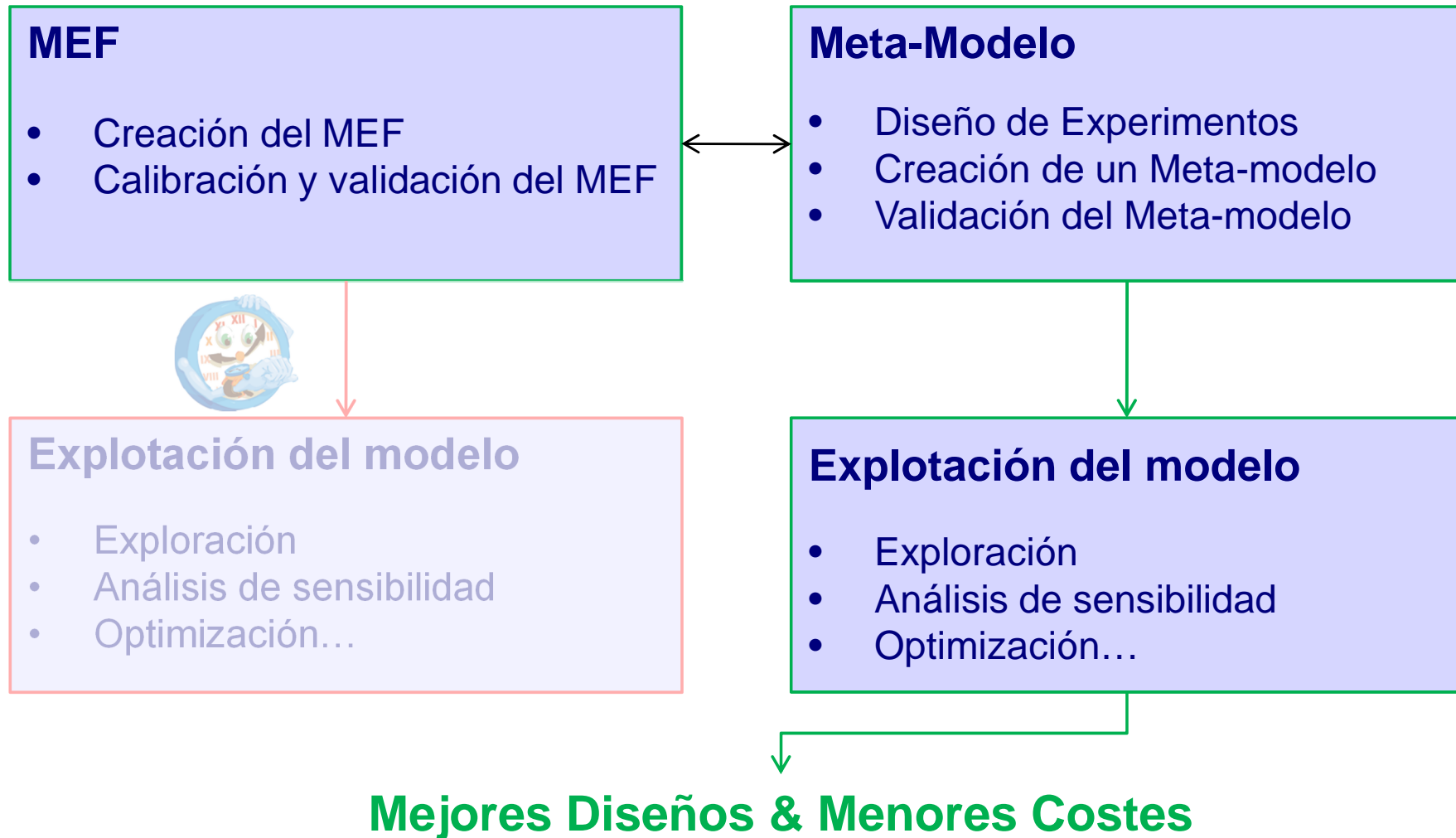


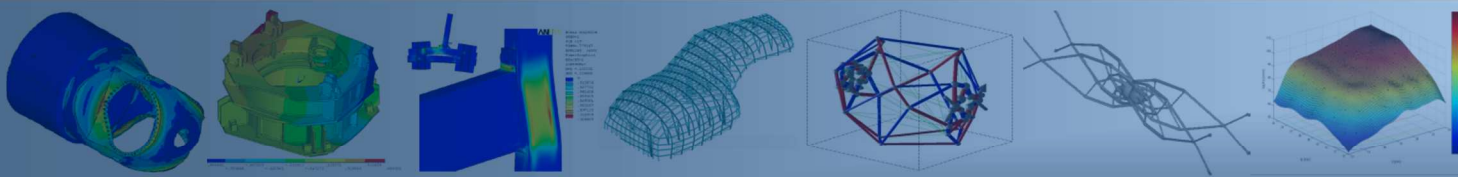
Explotación de modelos de simulación de alto coste computacional. *Metodología*





Explotación de modelos de simulación de alto coste computacional. *Metodología*





Explotación de modelos de simulación... *Goal Driven Optimization*

MEF

- Creación del MEF
- Calibración y validación del MEF



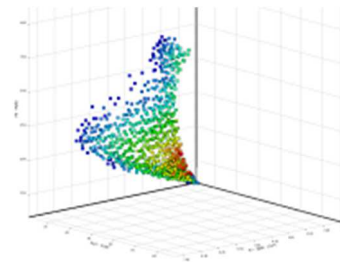
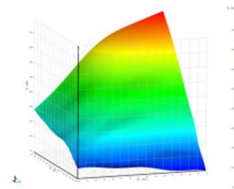
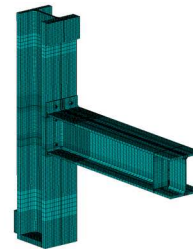
Meta-Modelo

- Diseño de Experimentos
- Creación de un Meta-modelo
- Validación del Meta-modelo

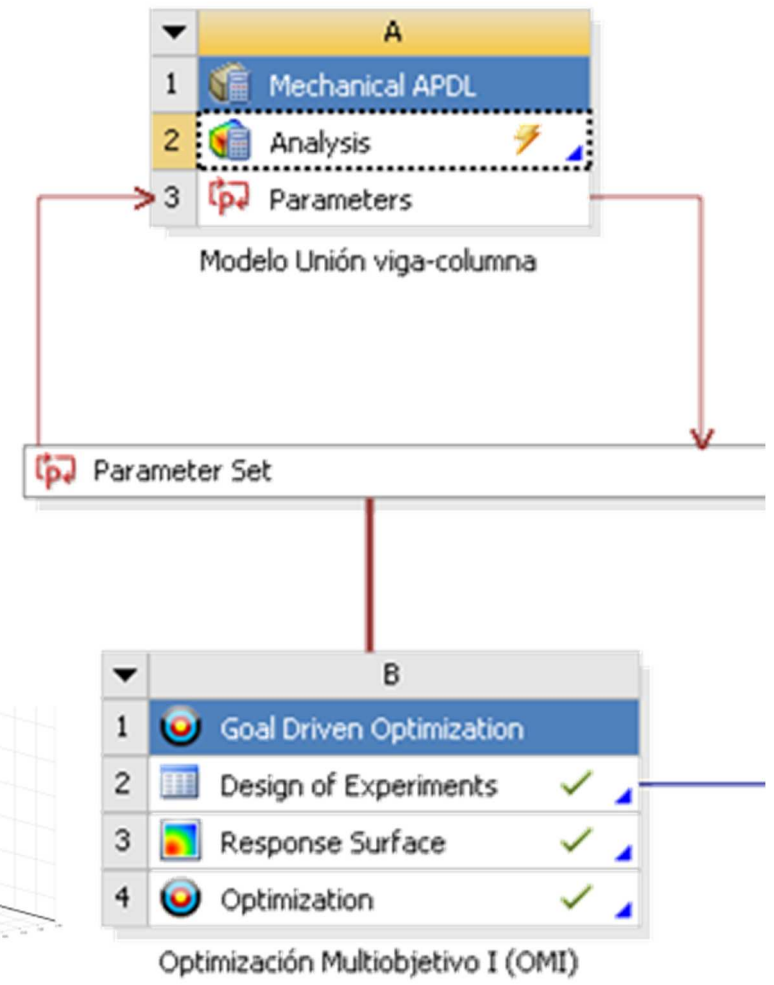


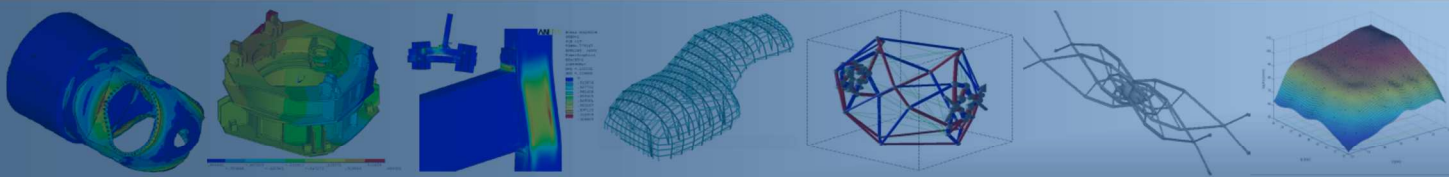
Explotación del modelo

- Exploración
- Análisis de sensibilidad
- Optimización...



Project Schematic





Explotación de modelos de simulación... Selección de Variables de diseño

Project Schematic

A

- 1 Mechanical APDL
- 2 Analysis
- 3 Parameters

Modelo Unión viga-columna

Parameter Set

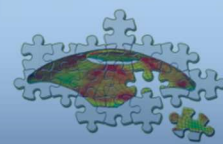
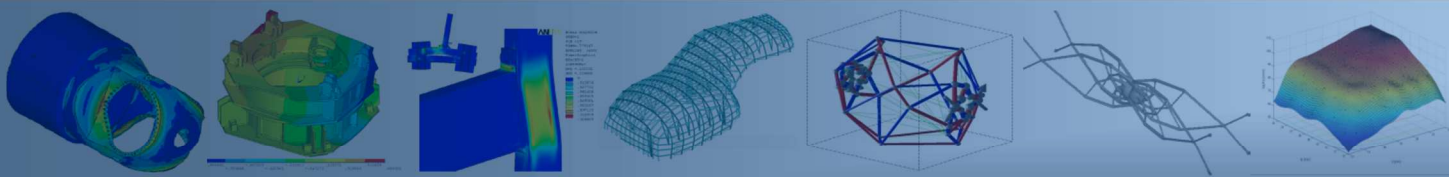
ID	Parameter Name	Value	Unit
Input Parameters			
Modelo Unión viga-columna (A1)			
P2	DB_V	15.111	
P4	PX_V	99.219	
P6	TEP_V	19.815	
* New input parameter			
Output Parameters			
Modelo Unión viga-columna (A1)			
P7	SJINI		
P8	MJRD		
P9	DUCT		
P10	CUST		
* New output parameter			
Charts			

Properties: No data

	A	B	C	D
1	APDL Parameter	Initial Value	Input	Output
26	CUST		<input type="checkbox"/>	<input checked="" type="checkbox"/>
27	D0	0	<input type="checkbox"/>	<input type="checkbox"/>
28	D1	0	<input type="checkbox"/>	<input type="checkbox"/>
29	D2	0	<input type="checkbox"/>	<input type="checkbox"/>
30	D3	0	<input type="checkbox"/>	<input type="checkbox"/>
31	D4	0	<input type="checkbox"/>	<input type="checkbox"/>
32	D5	0	<input type="checkbox"/>	<input type="checkbox"/>
33	DB	0	<input type="checkbox"/>	<input type="checkbox"/>
34	DB_V	15.111	<input checked="" type="checkbox"/>	<input type="checkbox"/>
35	DEF_H	0	<input type="checkbox"/>	<input type="checkbox"/>
36	DEF_M	0	<input type="checkbox"/>	<input type="checkbox"/>
37	DENSIDAD	0	<input type="checkbox"/>	<input type="checkbox"/>
38	DFUY	0	<input type="checkbox"/>	<input type="checkbox"/>
39	DHB	41	<input type="checkbox"/>	<input type="checkbox"/>
40	DNB	41	<input type="checkbox"/>	<input type="checkbox"/>
41	DRB	0	<input type="checkbox"/>	<input type="checkbox"/>
42	DUCT		<input type="checkbox"/>	<input checked="" type="checkbox"/>
43	DY	0	<input type="checkbox"/>	<input type="checkbox"/>
44	E	75	<input type="checkbox"/>	<input type="checkbox"/>
45	E_H	0	<input type="checkbox"/>	<input type="checkbox"/>
46	E1	0	<input type="checkbox"/>	<input type="checkbox"/>
47	E2	0	<input type="checkbox"/>	<input type="checkbox"/>
48	E3	0	<input type="checkbox"/>	<input type="checkbox"/>
49	ECT	0	<input type="checkbox"/>	<input type="checkbox"/>

Importación del código APDL

Selección de variables y respuestas del problema



Explotación de modelos de simulación... Selección de Variables de diseño

Configuración inicial:

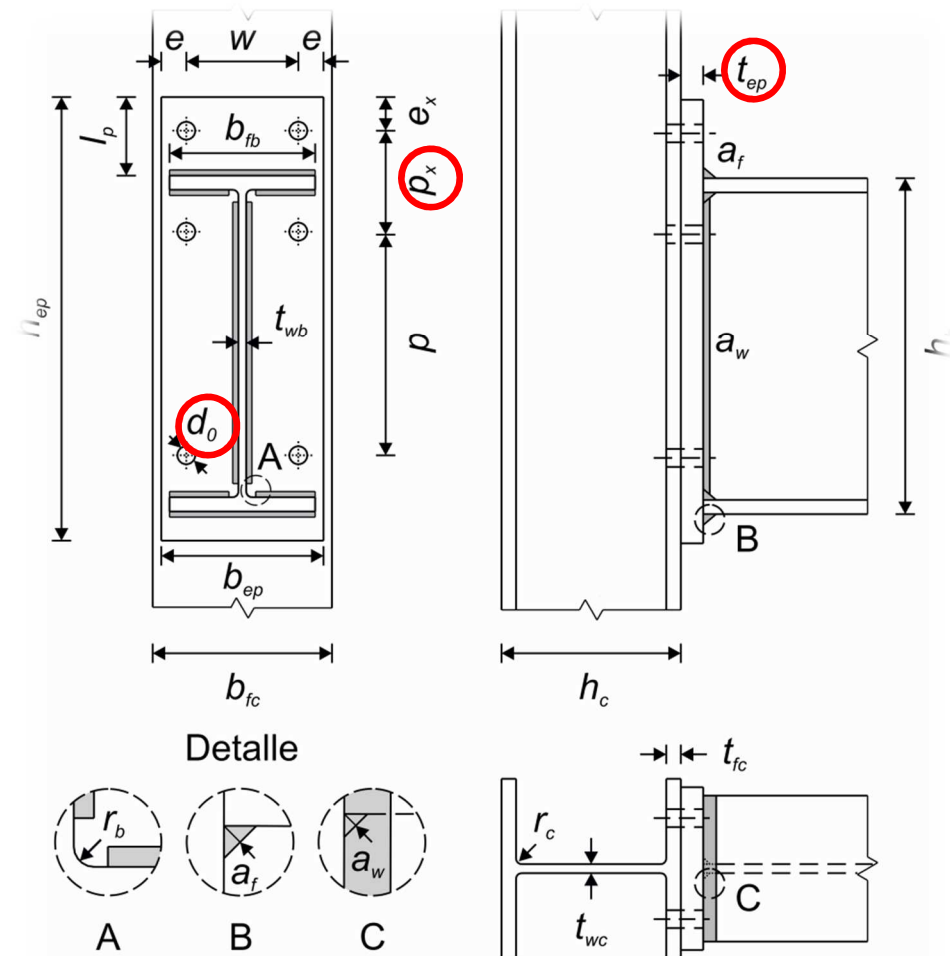
- Viga: IPE300
- Columna: HE160B
- Acero S 275:
Módulo de elasticidad: $E = 210000$ MPa.
Coeficiente de Poisson: $\nu = 0.3$.
- Tornillos:
Calidad 10.9
Fuerza de pretensado $F_p = 0.7f_u A_s$

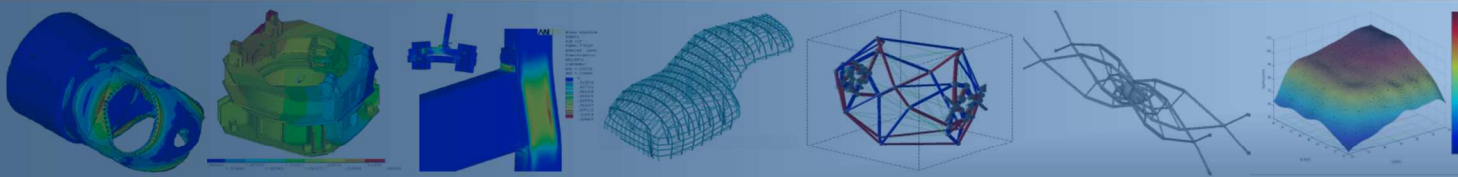
Variables de diseño:

$$12 \text{ mm} \leq d_b \leq 27 \text{ mm}$$

$$10 \text{ mm} \leq t_{ep} \leq 25 \text{ mm}$$

$$85 \text{ mm} \leq p_x \leq 150 \text{ mm}$$



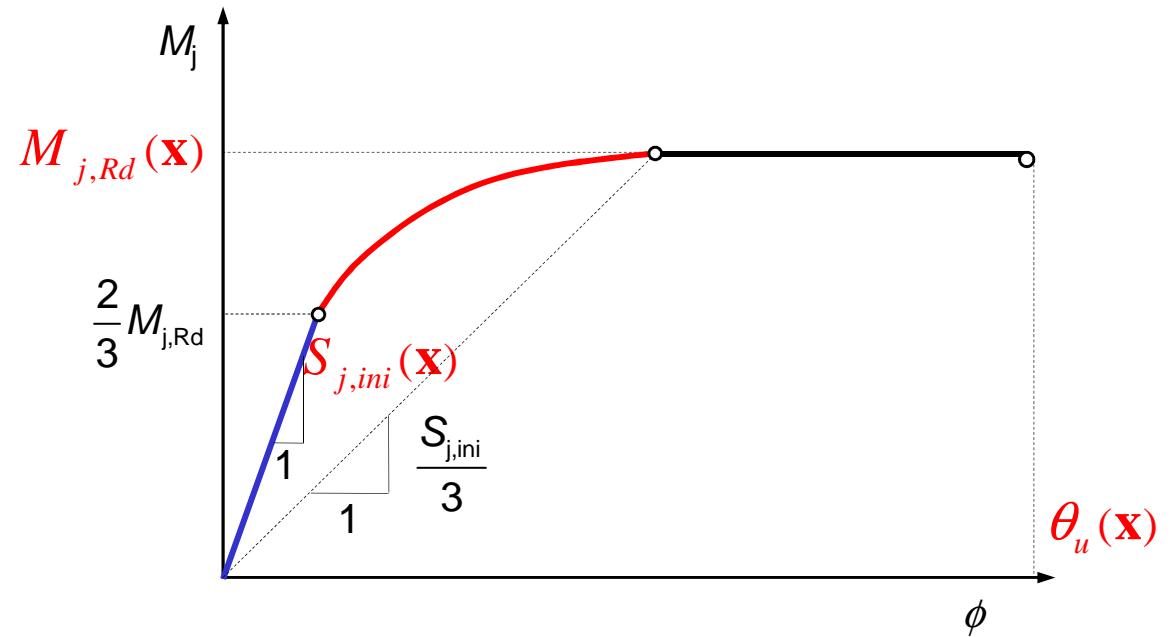


Explotación de modelos de simulación... Selección de respuestas

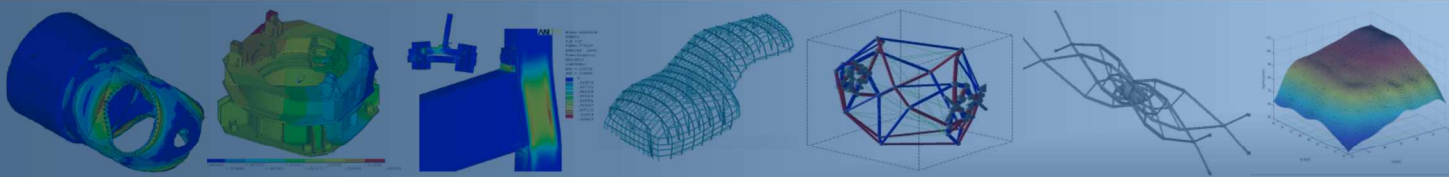
Respuestas:

1. Momento resistente.
2. Rigidez inicial.
3. Rotación máxima.
4. Coste.

$$C_u = C_p + C_t + C_s + C_m$$



- C_p coste de la chapa de testa cortada, taladrada, tratada y puesta en obra.
- C_t coste de los tornillos puesto en obra.
- C_s coste de la soldadura acabada.
- C_m coste del montaje de la chapa de testa en la viga.

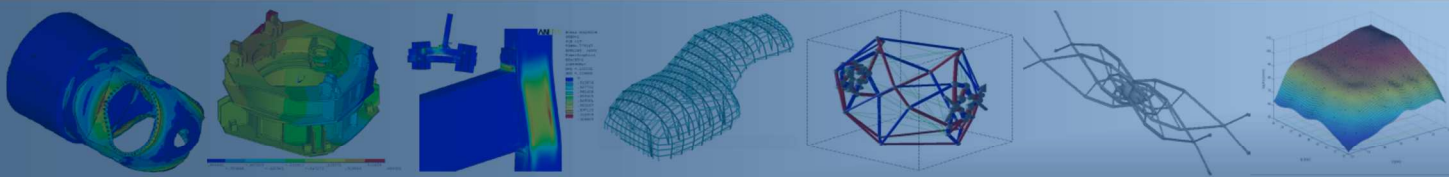


Explotación de modelos de simulación... Diseño de Experimentos

Table of Schematic B2: Design of Experiments								
	A	B	C	D	E	F	G	H
	Name	P2 - DB_V	P4 - PX_V	P6 - TEP_V	P7 - SJINI	P8 - MJRD	P9 - DUCT	P10 - CUST
1								
2	1	12	85	10	⚡	⚡	⚡	⚡
3	2	12	150	10	⚡	⚡	⚡	⚡
4	3	12	109.43	13.723	⚡	⚡	⚡	⚡
5	4	12	85	25	⚡	⚡	⚡	⚡
6	5	12	150	25	⚡	⚡	⚡	⚡
7	6	12.106	111.28	19.362	⚡	⚡	⚡	⚡
8	7	12.213	136.17	19.787	⚡	⚡	⚡	⚡
9	10	12.532	121.88	18.298	⚡	⚡	⚡	⚡
10	11	12.638	123.72	23.191	⚡	⚡	⚡	⚡
11	13	12.851	103.9	11.809	⚡	⚡	⚡	⚡
12	14	12.957	105.28	16.809	⚡	⚡	⚡	⚡
13	15	13.064	107.13	22.34	⚡	⚡	⚡	⚡
14	16	13.17	129.72	12.128	⚡	⚡	⚡	⚡
15	18	13.383	132.94	22.66	⚡	⚡	⚡	⚡
16	19	13.489	92.376	14.574	⚡	⚡	⚡	⚡
17	20	13.596	93.759	20.213	⚡	⚡	⚡	⚡
18	22	13.809	115.89	14.894	⚡	⚡	⚡	⚡
19	23	13.915	117.27	20.532	⚡	⚡	⚡	⚡
20	24	14.021	119.11	24.574	⚡	⚡	⚡	⚡
21	25	14.128	139.4	15.213	⚡	⚡	⚡	⚡
22	26	14.234	140.78	20.851	⚡	⚡	⚡	⚡
23	27	14.34	99.291	10.851	⚡	⚡	⚡	⚡
24	28	14.447	100.67	15.638	⚡	⚡	⚡	⚡
25	29	14.553	102.06	21.277	⚡	⚡	⚡	⚡
26	30	14.66	125.11	11.17	⚡	⚡	⚡	⚡
27	31	14.766	126.49	15.957	⚡	⚡	⚡	⚡
28	32	14.872	127.87	21.596	⚡	⚡	⚡	⚡
29	33	14.979	145.39	11.489	⚡	⚡	⚡	⚡
30	34	15.085	146.31	16.277	⚡	⚡	⚡	⚡
31	35	15.191	147.7	21.915	⚡	⚡	⚡	⚡
32	36	15.298	88.227	13.404	⚡	⚡	⚡	⚡
33	37	15.404	89.61	19.043	⚡	⚡	⚡	⚡
34	38	15.511	90.993	23.723	⚡	⚡	⚡	⚡

100 MUESTRAS

Design of Experiment	
	Value
Design of Experiment	
GDO	
DX	
Custom	
Central Composite Design	
Optimal Space-Filling Design	
Box-Behnken Design	
Custom	
Custom + Sampling	
Sparse Grid Initialization	

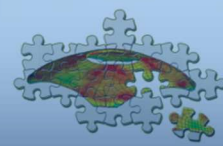
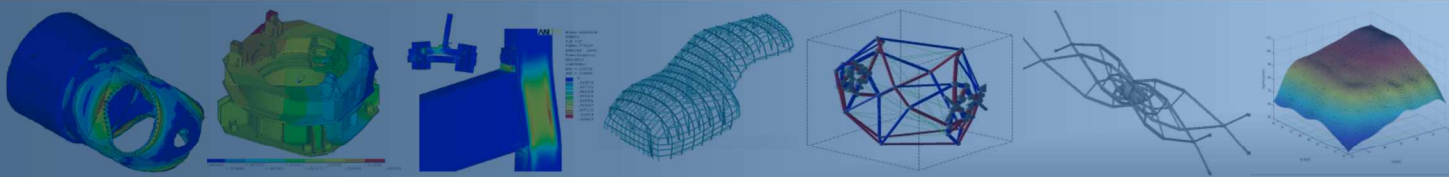


Explotación de modelos de simulación... Diseño de Experimentos

Table of Schematic B2: Design of Experiments								
	A	B	C	D	E	F	G	H
	Name	P2 - DB_V	P4 - PX_V	P6 - TEP_V	P7 - SJINI	P8 - MJRD	P9 - DUCT	P10 - CUST
1								
2	1	12	85	10	⚡	⚡	⚡	⚡
3	2	12	150	10	⚡	⚡	⚡	⚡
4	3	12	109.43	13.723	⚡	⚡	⚡	⚡
5	4	12	85	25	⚡	⚡	⚡	⚡
6	5	12	150	25	⚡	⚡	⚡	⚡
7	6	12.106	111.28	19.362	⚡	⚡	⚡	⚡
8	7	12.213	136.17	19.787	⚡	⚡	⚡	⚡
9	10	12.532	121.88	18.298	⚡	⚡	⚡	⚡
10	11	12.638	123.72	23.191	⚡	⚡	⚡	⚡
11	13	12.851	103.9	11.809	⚡	⚡	⚡	⚡
12	14	12.957	105.28	16.809	⚡	⚡	⚡	⚡
13	15	13.064	107.13	22.34	⚡	⚡	⚡	⚡
14	16	13.17	129.72	12.128	⚡	⚡	⚡	⚡
15	18	13.383	132.94	22.66	⚡	⚡	⚡	⚡
16	19	13.489	92.376	14.574	⚡	⚡	⚡	⚡
17	20	13.596	93.759	20.213	⚡	⚡	⚡	⚡
18	22	13.809	115.89	14.894	⚡	⚡	⚡	⚡
19	23	13.915	117.27	20.532	⚡	⚡	⚡	⚡
20	24	14.021	119.11	24.574	⚡	⚡	⚡	⚡
21	25	14.128	139.4	15.213	⚡	⚡	⚡	⚡
22	26	14.234	140.78	20.851	⚡	⚡	⚡	⚡
23	27	14.34	99.291	10.851	⚡	⚡	⚡	⚡
24	28	14.447	100.67	15.638	⚡	⚡	⚡	⚡
25	29	14.553	102.06	21.277	⚡	⚡	⚡	⚡
26	30	14.66	125.11	11.17	⚡	⚡	⚡	⚡
27	31	14.766	126.49	15.957	⚡	⚡	⚡	⚡
28	32	14.872	127.87	21.596	⚡	⚡	⚡	⚡
29	33	14.979	145.39	11.489	⚡	⚡	⚡	⚡
30	34	15.085	146.31	16.277	⚡	⚡	⚡	⚡
31	35	15.191	147.7	21.915	⚡	⚡	⚡	⚡
32	36	15.298	88.227	13.404	⚡	⚡	⚡	⚡
33	37	15.404	89.61	19.043	⚡	⚡	⚡	⚡
34	38	15.511	90.993	23.723	⚡	⚡	⚡	⚡

100 MUESTRAS

CCD + Optimal Latin Hypercube



Explotación de modelos de simulación... Evaluación del DOE

ANSYS Remote Solve Manager 14.0

File Options View Tools Help

US_v1 - Workbench

All Jobs

My Computer

- Queues
 - arabi_ansys
 - Local
- Compute Servers
 - localhost
 - RSM Arabi

Job	Status	Submitted	Owner	Prio...	Server	Queue
VIEW3/UpdateDesignPoints(1)	Running	05/08/2011 15:22:39	FPCMUR\jmartinezf	Normal	RSM Arabi	arabi_ansys
VIEW3/UpdateDesignPoints(2)	Running	05/08/2011 15:22:42	FPCMUR\jmartinezf	Normal	RSM Arabi	arabi_ansys
VIEW3/UpdateDesignPoints(3)	Running	05/08/2011 15:22:45	FPCMUR\jmartinezf	Normal	RSM Arabi	arabi_ansys
VIEW3/UpdateDesignPoints(4)	Running	05/08/2011 15:22:49	FPCMUR\jmartinezf	Normal	RSM Arabi	arabi_ansys
VIEW3/UpdateDesignPoints(5)	Running	05/08/2011 15:22:52	FPCMUR\jmartinezf	Normal	RSM Arabi	arabi_ansys
VIEW3/UpdateDesignPoints(6)	Running	05/08/2011 15:22:55	FPCMUR\jmartinezf	Normal	RSM Arabi	arabi_ansys
VIEW3/UpdateDesignPoints(7)	Running	05/08/2011 15:22:58	FPCMUR\jmartinezf	Normal	RSM Arabi	arabi_ansys
VIEW3/UpdateDesignPoints(8)	Running	05/08/2011 15:23:01	FPCMUR\jmartinezf	Normal	RSM Arabi	arabi_ansys
VIEW3/UpdateDesignPoints(9)	Running	05/08/2011 15:23:05	FPCMUR\jmartinezf	Normal	RSM Arabi	arabi_ansys
VIEW3/UpdateDesignPoints(10)	Running	05/08/2011 15:23:08	FPCMUR\jmartinezf	Normal	RSM Arabi	arabi_ansys
VIEW3/UpdateDesignPoints(11)	Queued	05/08/2011 15:23:11	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(12)	Queued	05/08/2011 15:23:14	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(13)	Queued	05/08/2011 15:23:17	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(14)	Queued	05/08/2011 15:23:21	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(15)	Queued	05/08/2011 15:23:25	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(16)	Queued	05/08/2011 15:23:28	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(17)	Queued	05/08/2011 15:23:32	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(18)	Queued	05/08/2011 15:23:35	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(19)	Queued	05/08/2011 15:23:38	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(20)	Queued	05/08/2011 15:23:41	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(21)	Queued	05/08/2011 15:23:45	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(22)	Queued	05/08/2011 15:23:48	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(23)	Queued	05/08/2011 15:23:51	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
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VIEW3/UpdateDesignPoints(25)	Queued	05/08/2011 15:23:58	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(26)	Queued	05/08/2011 15:24:01	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(27)	Queued	05/08/2011 15:24:04	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(28)	Queued	05/08/2011 15:24:07	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(29)	Queued	05/08/2011 15:24:10	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(30)	Queued	05/08/2011 15:24:13	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(31)	Queued	05/08/2011 15:24:17	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(32)	Queued	05/08/2011 15:24:20	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys
VIEW3/UpdateDesignPoints(33)	Queued	05/08/2011 15:24:23	FPCMUR\jmartinezf	Normal	Not Assigned	arabi_ansys

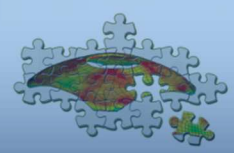
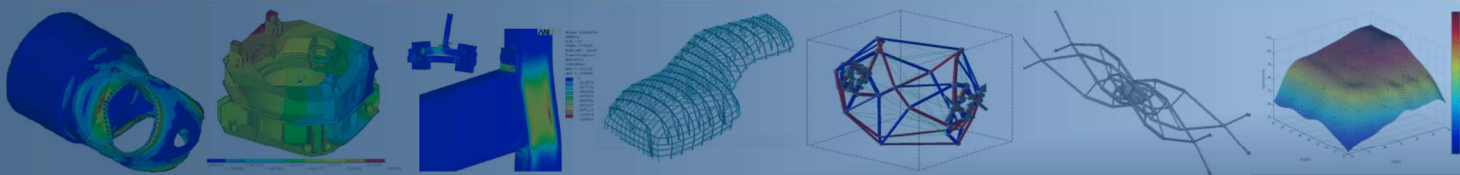
ANSYS Remote Solve Manager



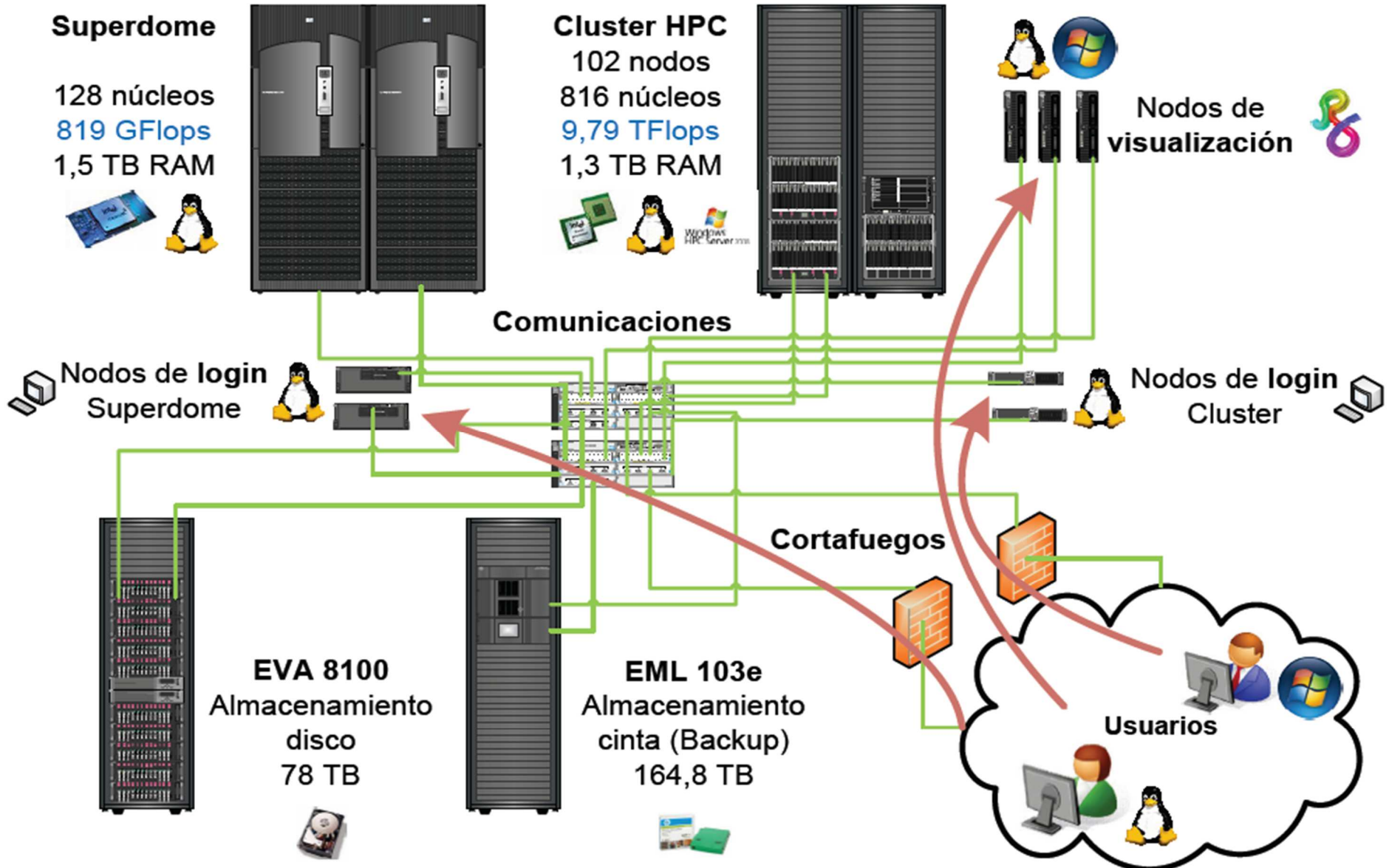
ANSYS Mechanical Solver 10 tasks
ANSYS HPC Pack 10 tasks

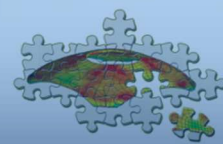
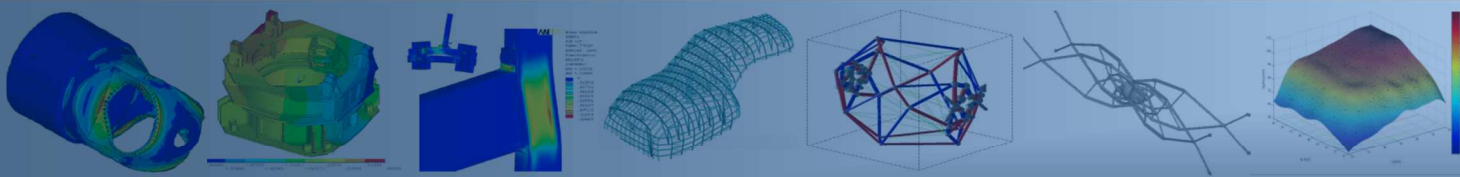
10X Speedup

8.3 días → 20 horas



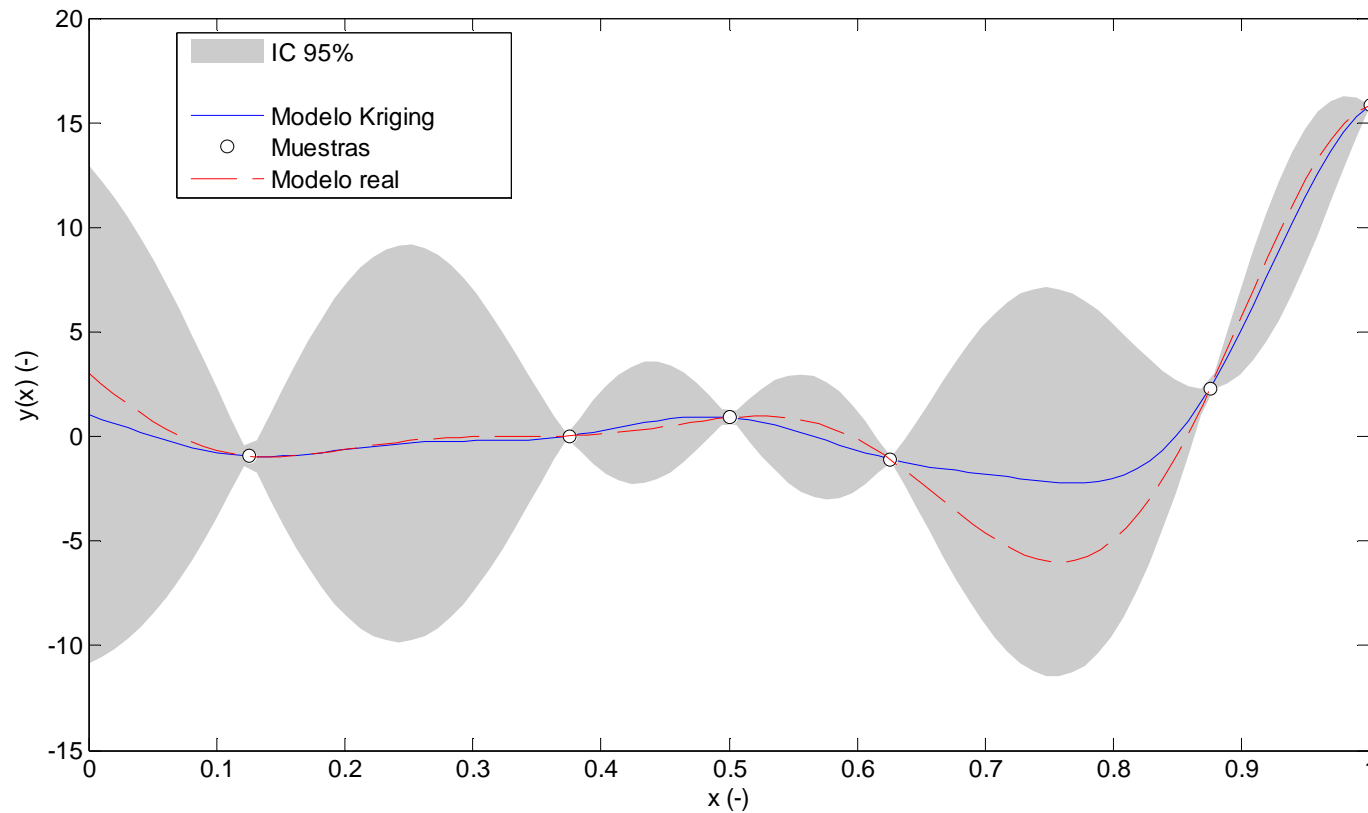
Supercomputador Ben Arabí

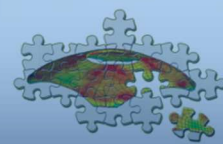
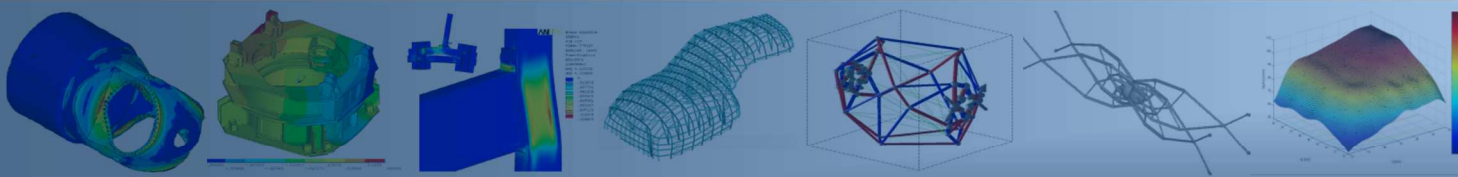




Explotación de modelos de simulación... ¿Qué es un Meta-modelo?

Aproximación global del modelo de simulación que permita evaluaciones con un bajo coste computacional.



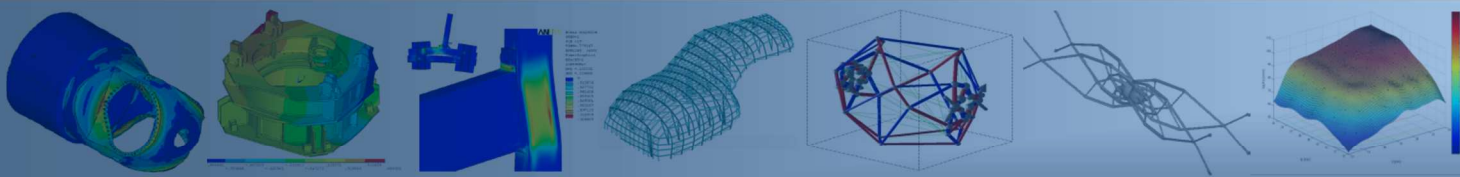


Explotación de modelos de simulación... ¿Qué es un Meta-modelo?

Aproximación global del modelo de simulación que permita evaluaciones con un bajo coste computacional.

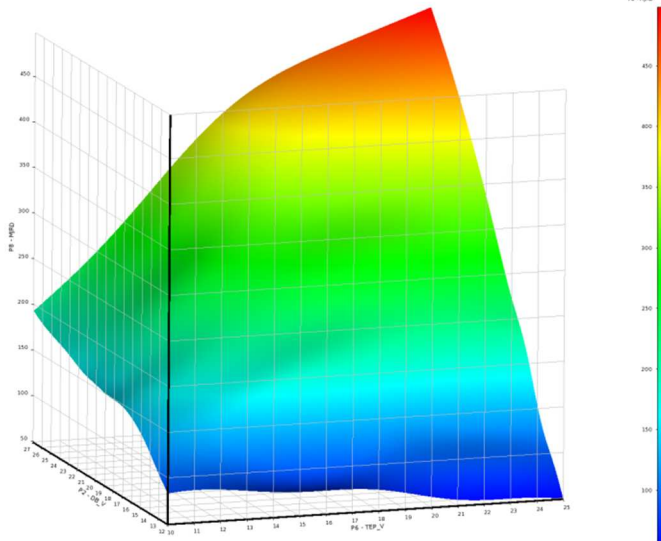


- Superficie de respuesta polinómica
- Redes neuronales
- **Kriging**
- Funciones de base radial
- Sparse grid

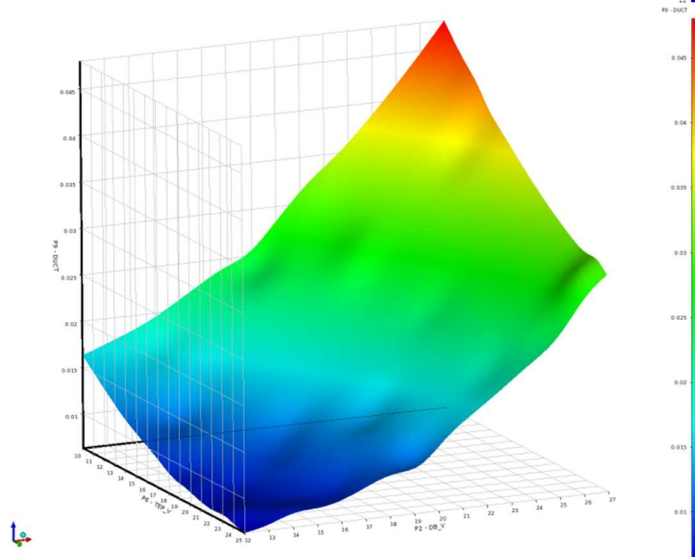


Explotación de modelos de simulación... Modelos Kriging

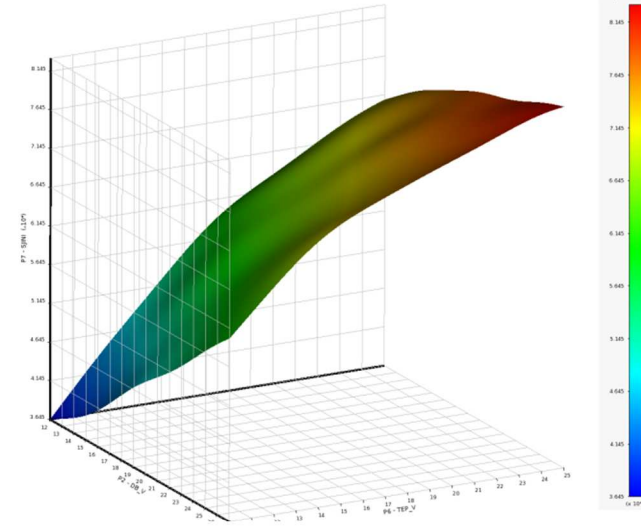
$$\tilde{M}_{j,Rd}(d_b, t_{ep})$$



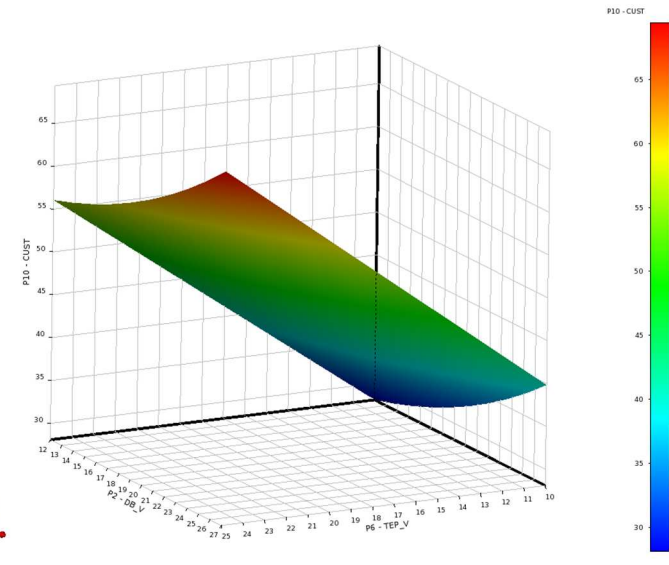
$$\tilde{\theta}_u(d_b, t_{ep})$$

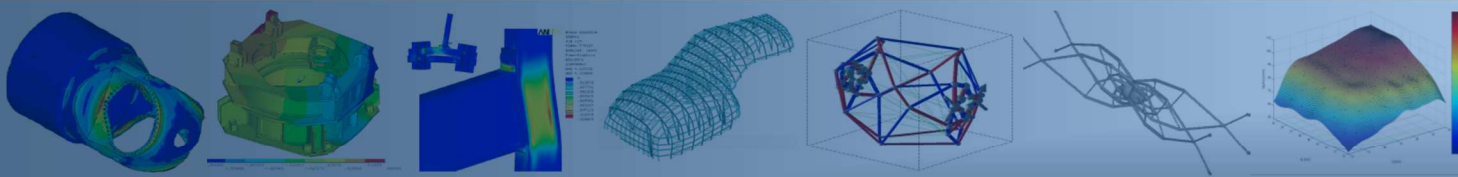


$$\tilde{S}_{j,ini}(d_b, t_{ep})$$

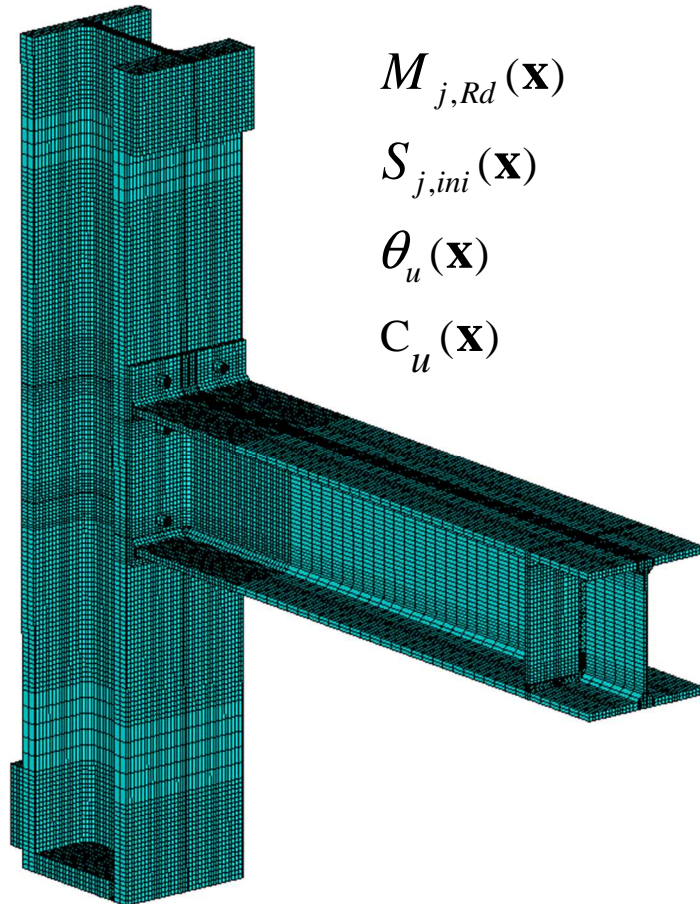


$$\tilde{c}_u(d_b, t_{ep})$$





Explotación de modelos de simulación... Meta-modelos



$$M_{j,Rd}(\mathbf{x})$$

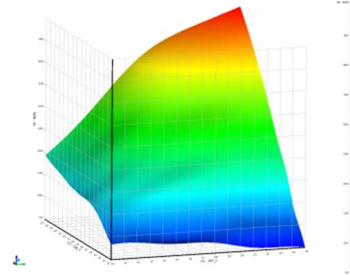
$$S_{j,ini}(\mathbf{x})$$

$$\theta_u(\mathbf{x})$$

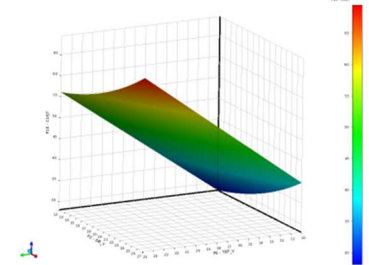
$$C_u(\mathbf{x})$$

Aproximación
Global

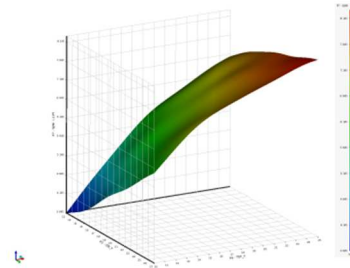
$$\tilde{M}_{j,Rd}(\mathbf{x})$$



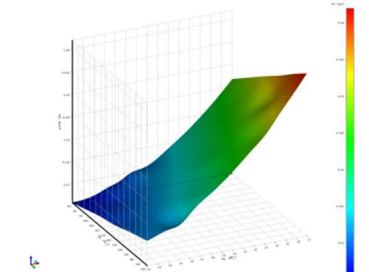
$$\tilde{C}_u(\mathbf{x})$$



$$\tilde{S}_{j,ini}(\mathbf{x})$$

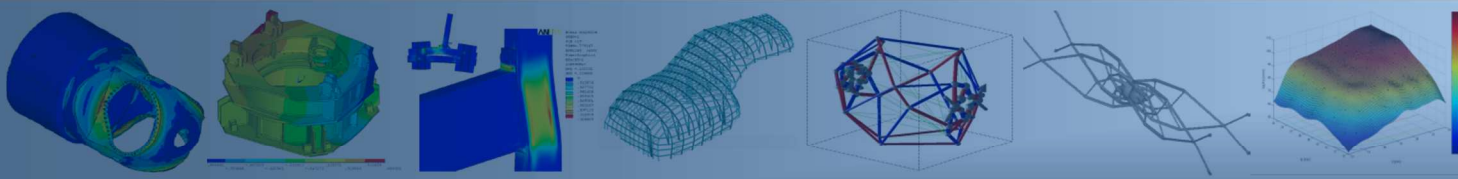


$$\tilde{\theta}_u(\mathbf{x})$$



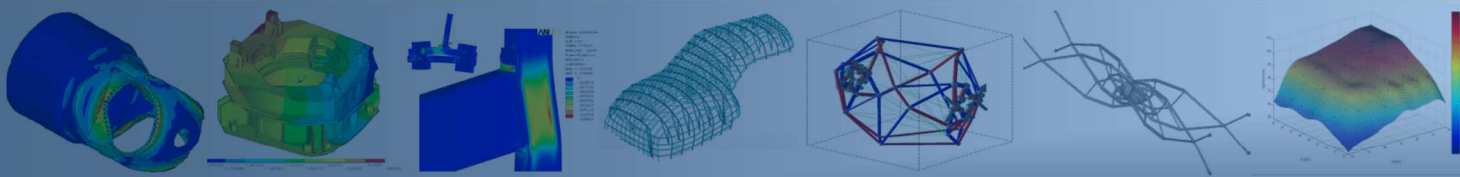
1 evaluación ~ 5760seg

1 evaluación ~ 1 mseg



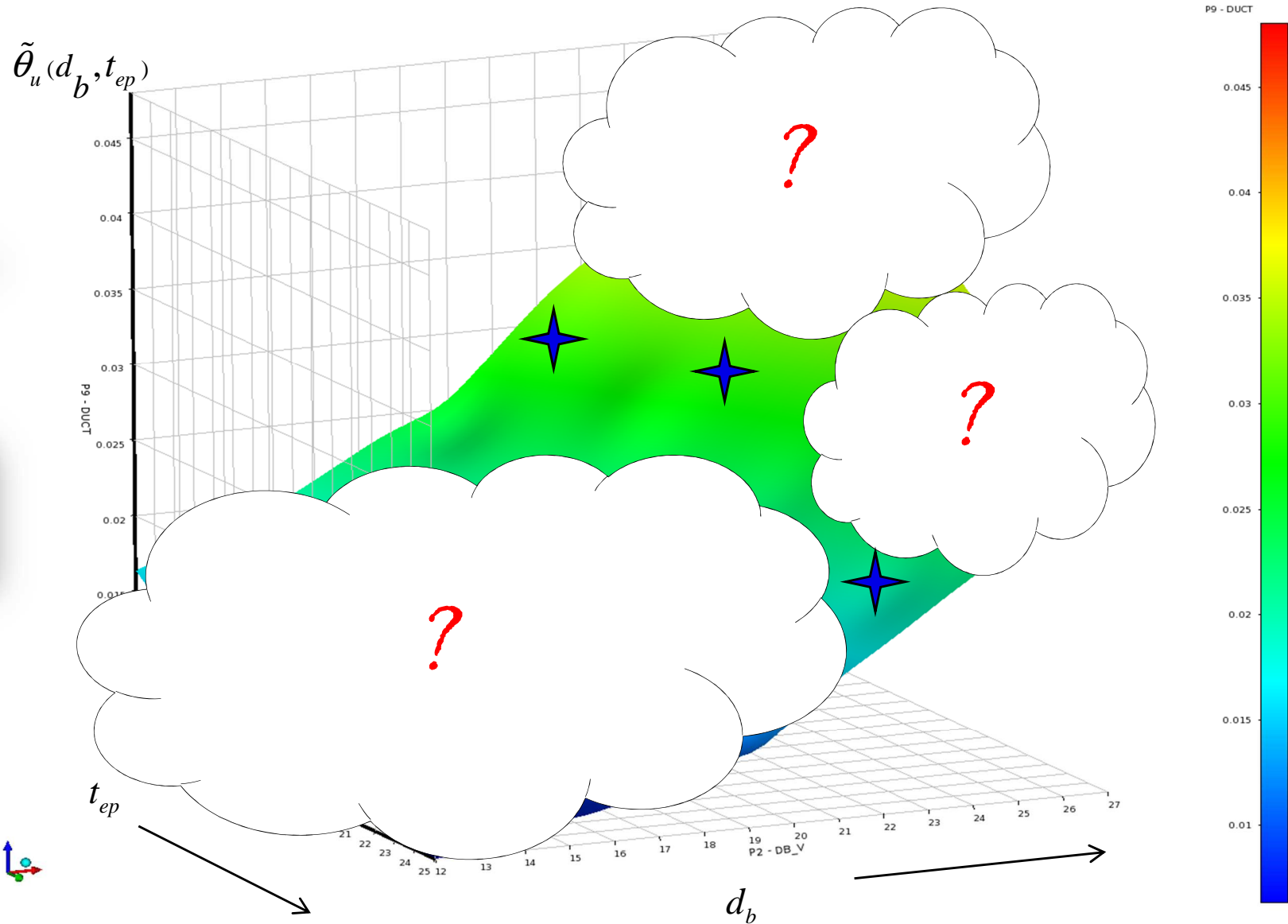
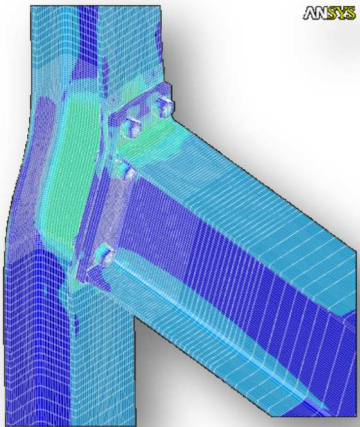
Laboratorio Virtual

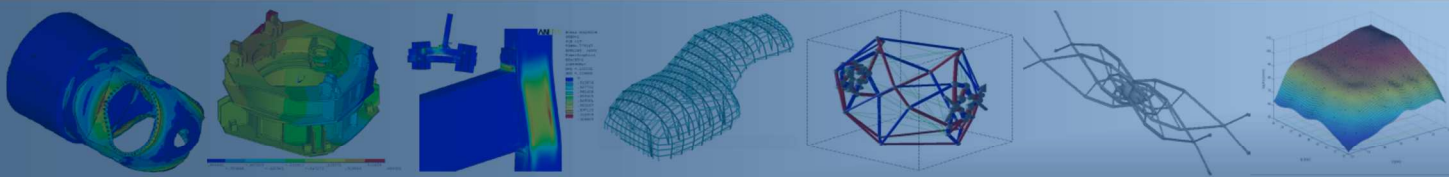
Exploración del espacio de diseño mediante Meta-modelos



Exploración del espacio de diseño. Espacio de diseño

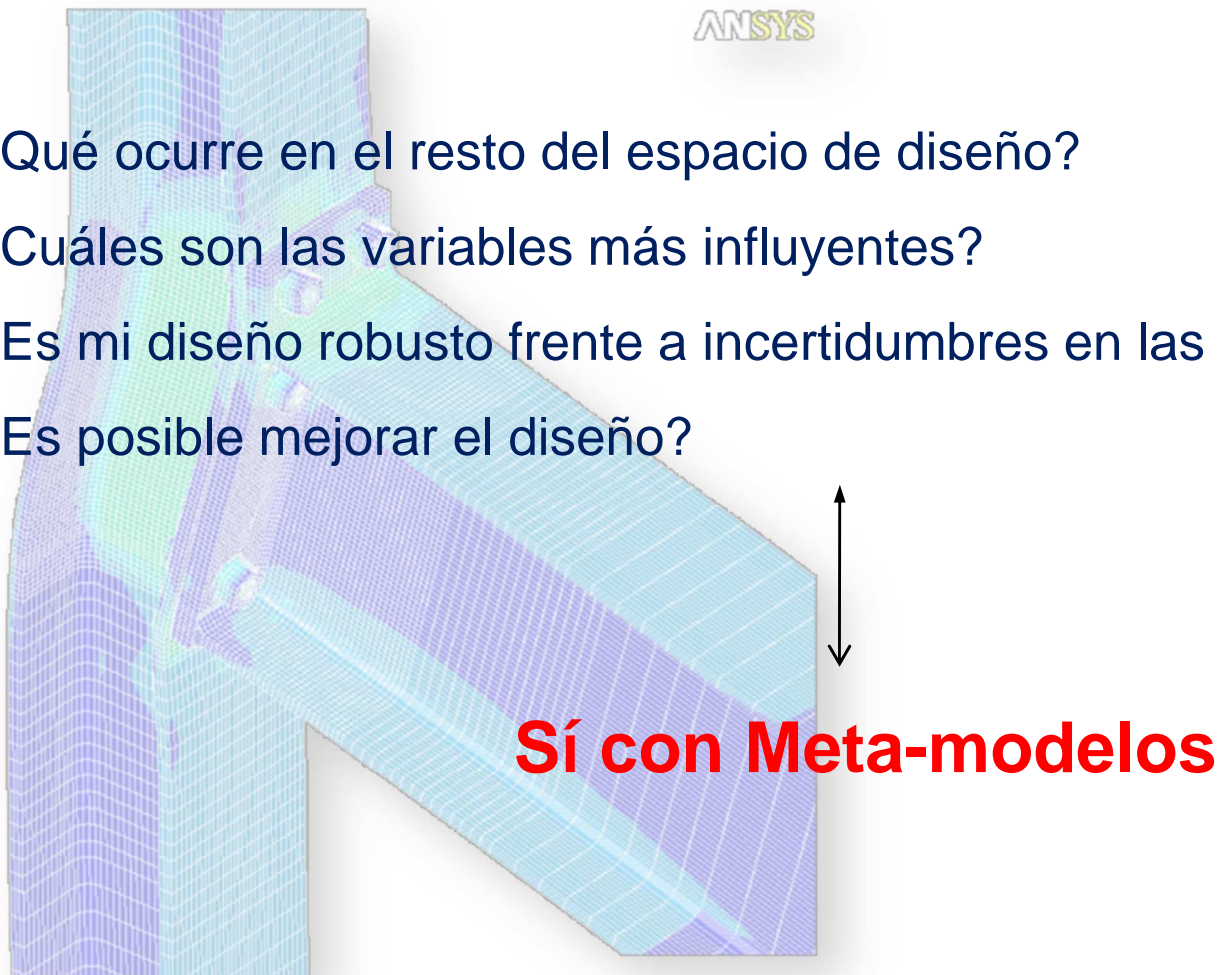
★ evaluación

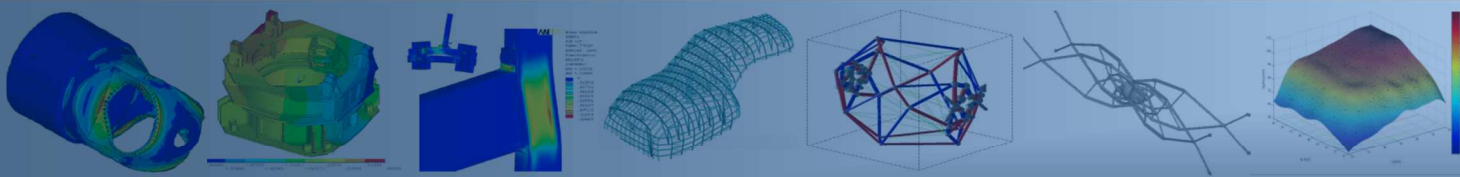




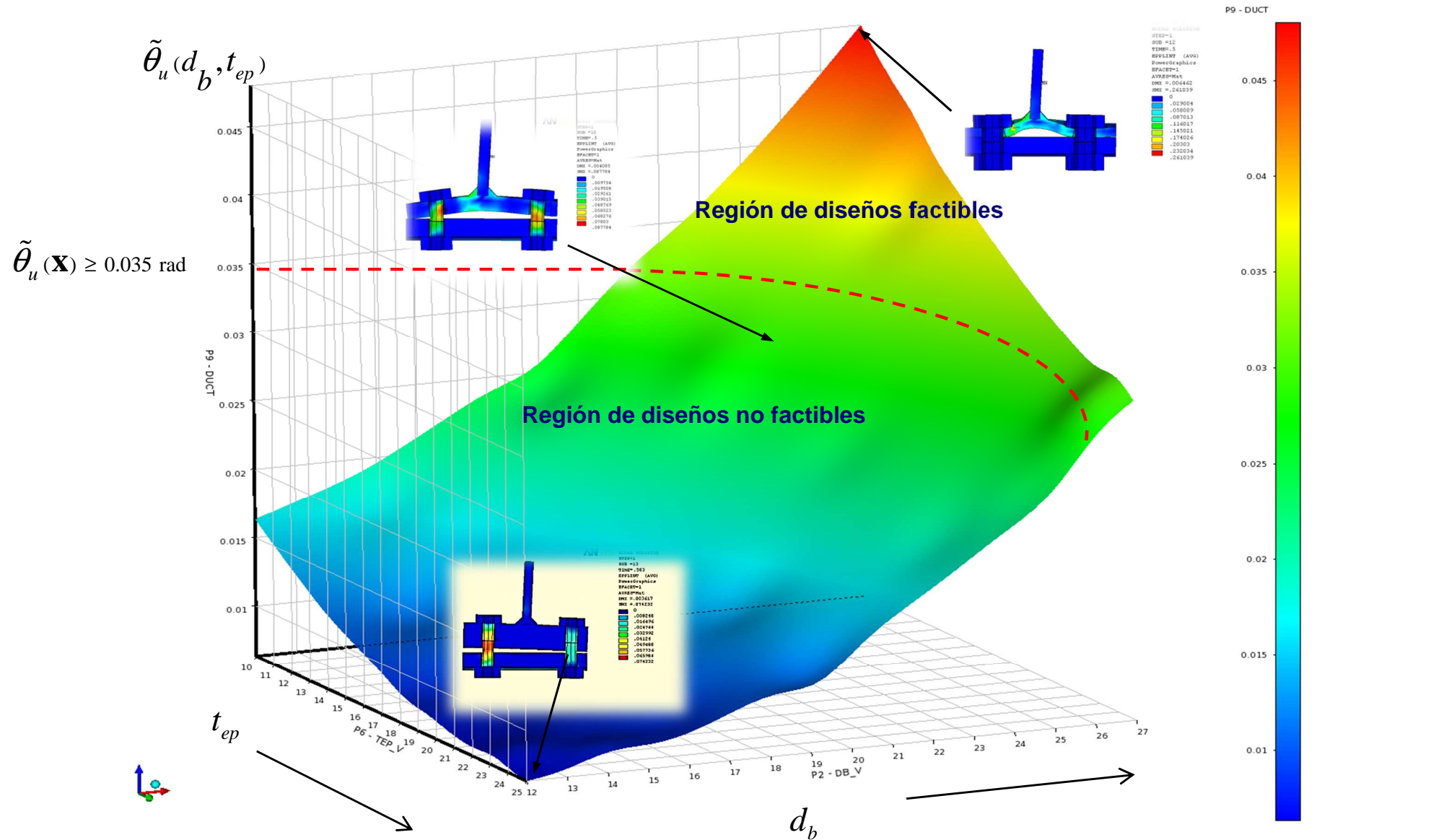
Exploración del espacio de diseño. Espacio de diseño

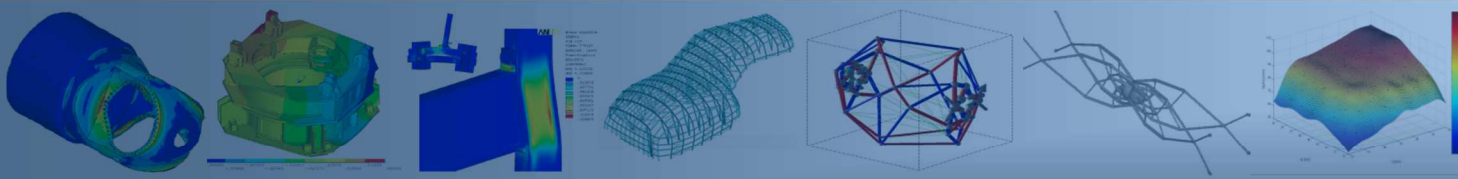
- ¿Qué ocurre en el resto del espacio de diseño?
- ¿Cuáles son las variables más influyentes?
- ¿Es mi diseño robusto frente a incertidumbres en las variables y/o parámetros?
- ¿Es posible mejorar el diseño?



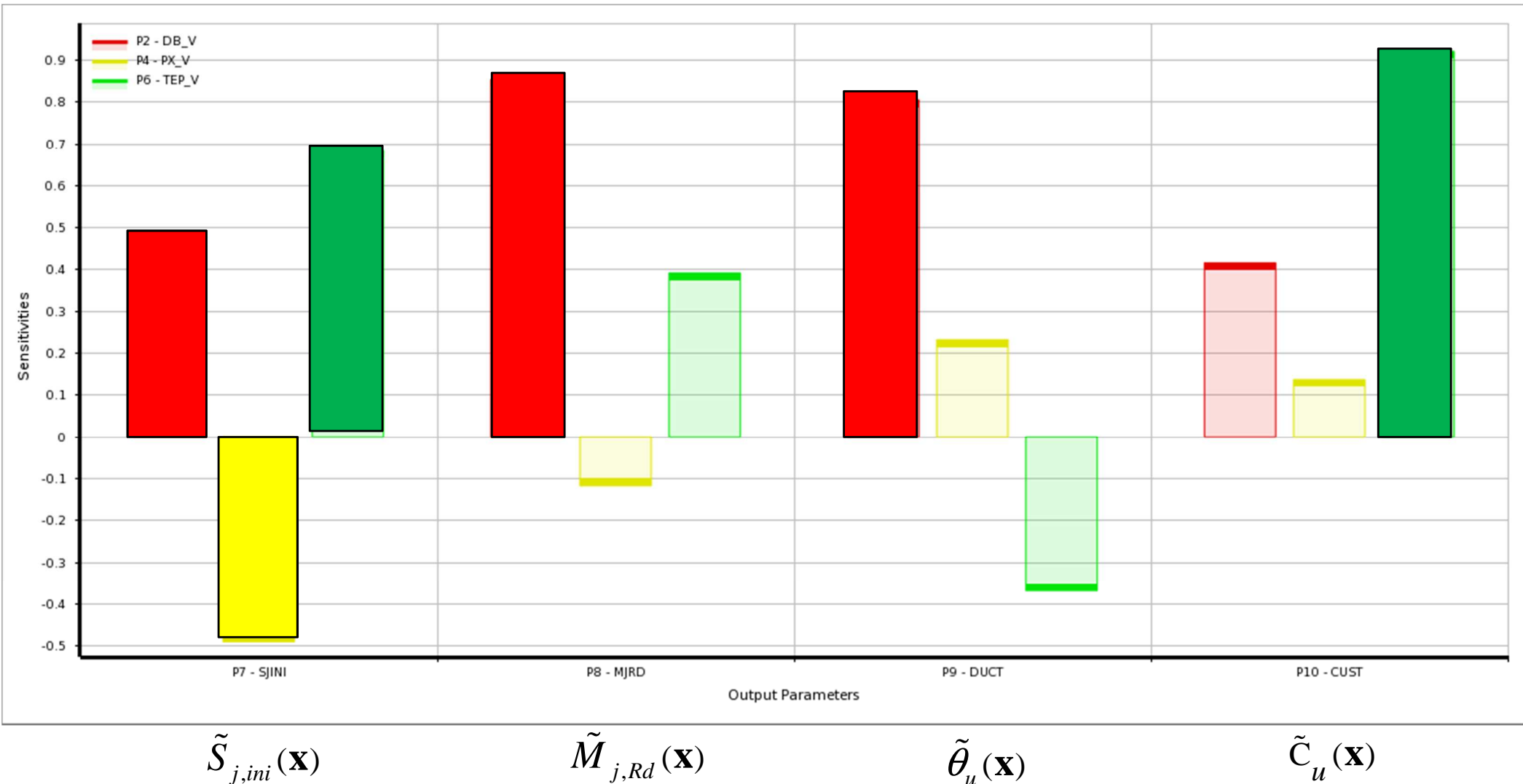


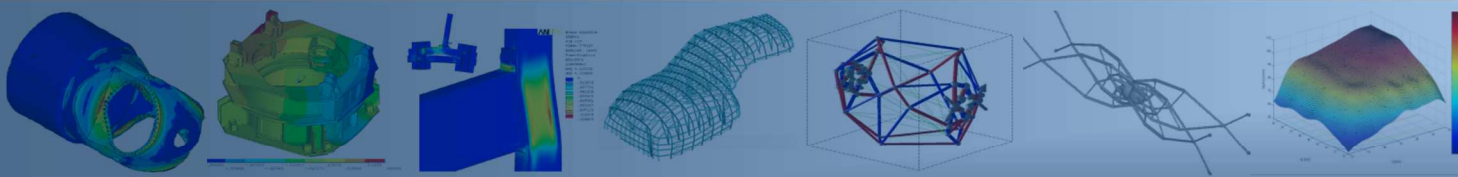
Exploración del espacio de diseño. Ductilidad





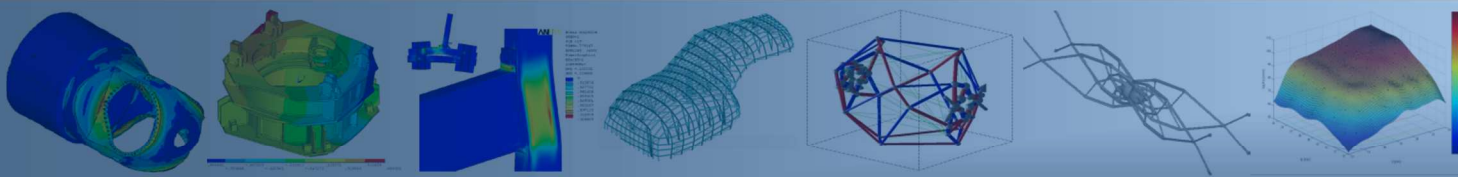
Exploración del espacio de diseño. Análisis de sensibilidad global





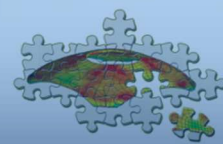
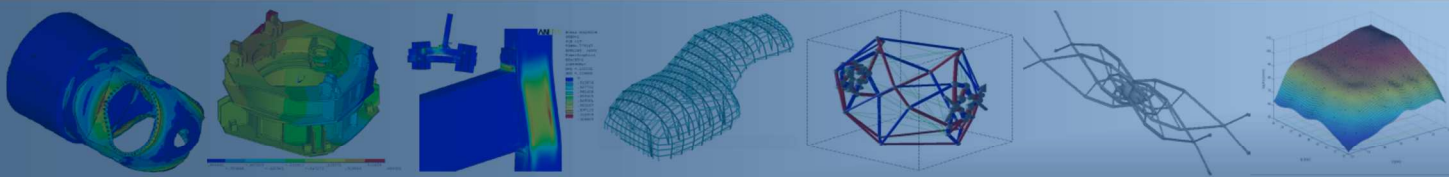
Exploración del espacio de diseño. Algunas conclusiones

- Del conjunto de variables de diseño estudiadas el espesor de la chapa de testa resulta la más influyente en el coste de la unión.
- El momento resistente de la unión se ve principalmente influenciado por el diámetro de los tornillos y en menor medida por el espesor de la chapa de testa.
- Para uniones de elevada resistencia (grandes diámetros de tornillos) un incremento del espesor de la chapa de testa genera una disminución de la ductilidad, pudiendo dar lugar a modos de fallo frágiles.
- La rigidez inicial de la unión es directamente proporcional al diámetro de tornillos y al espesor de la chapa, e inversamente proporcional a la separación de las dos filas superiores de tornillos.



Laboratorio Virtual

Optimización Multi-objetivo de uniones semirrígidas



Optimización Multi-objetivo de uniones semirrígidas

$$\min_{\mathbf{x}} \{ \tilde{c}_u(\mathbf{x}), -\tilde{M}_{j,Rd}(\mathbf{x}), -\tilde{S}_{j,ini}(\mathbf{x}) \}$$

sujeto a : $\tilde{\theta}_u(\mathbf{x}) \geq 0.035 \text{ rad}$

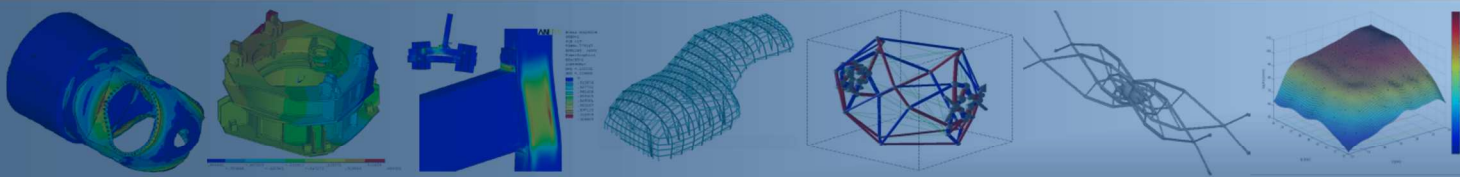
$$d_b = \{10, 12, 16, 20, 24, 27\} \text{ mm}$$

$$t_{ep} = \{10, 12, 14, 15, 16, 18, 20, 25\} \text{ mm}$$

$$85 \text{ mm} \leq p_x \leq 150 \text{ mm}$$

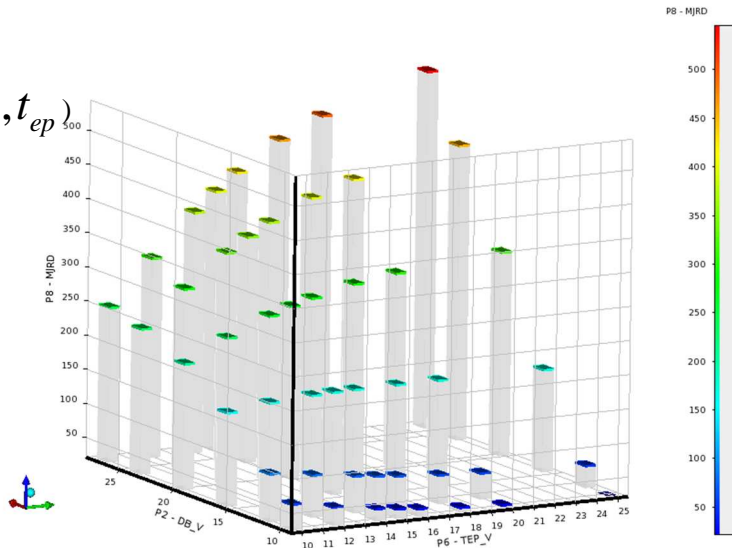
	A	B
1	Property	Value
2	[-] Design Points	
3	Preserve Design Points After DX Run	<input type="checkbox"/>
4	[-] Optimization	
5	Optimization Method	Screening
6	Number of Samples	10000
7	Constraint Handling (GDO)	As Hard Constraints
8	Size of Generated Sample Set	10000
9	Verify Candidate Points	<input type="checkbox"/>

	A	B	C	D	E	F	G	H
1		P2 - DB_V	P4 - PX_V	P6 - TEP_V	P7 - SJINI	P8 - MJRD	P9 - DUCT	P10 - CUST
2	[-] Optimization Study							
3	Objective	No Objective	No Objective	No Objective	Maximize	Maximize	Values >= Target	Minimize
4	Target Value	10	85	10			0.035	
5	Importance	Default	Default	Default	Default	Default	Default	Default
6	[-] Candidate Points							
7	Candidate A	27	95.703	12	★★ 76973	291.3	0.035292	★ 43.239
8	Candidate B	27	101.61	12	★★ 73983	279.29	0.037503	★ 43.38
9	Candidate C	27	113.73	16	★★ 75280	★ 362.41	0.035026	51.531

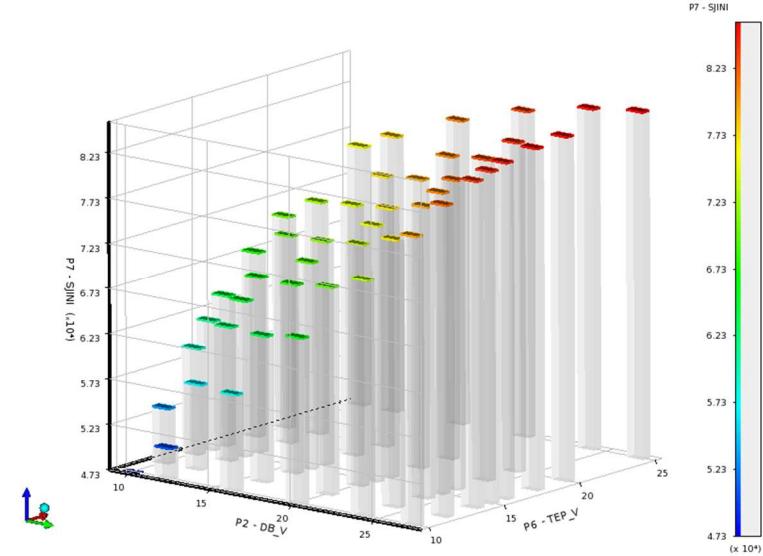


Optimización Multi-objetivo de uniones semirrígidas. Meta-modelos

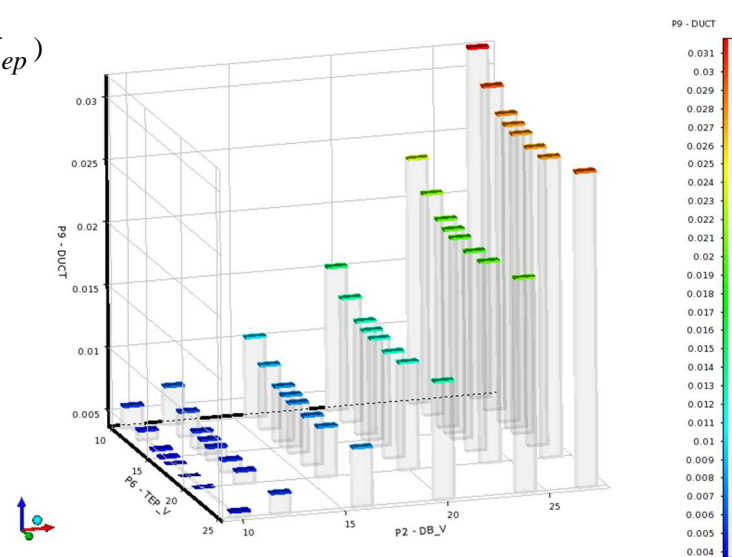
$$\tilde{M}_{j,Rd}(d_b, t_{ep})$$



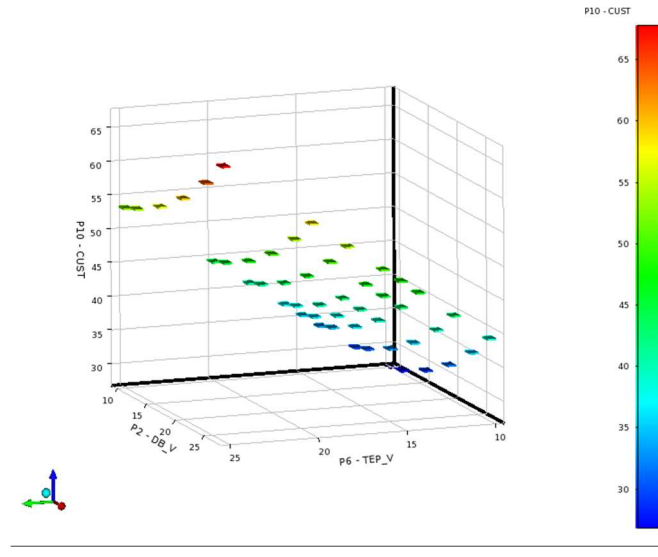
$$\tilde{S}_{j,ini}(d_b, t_{ep})$$

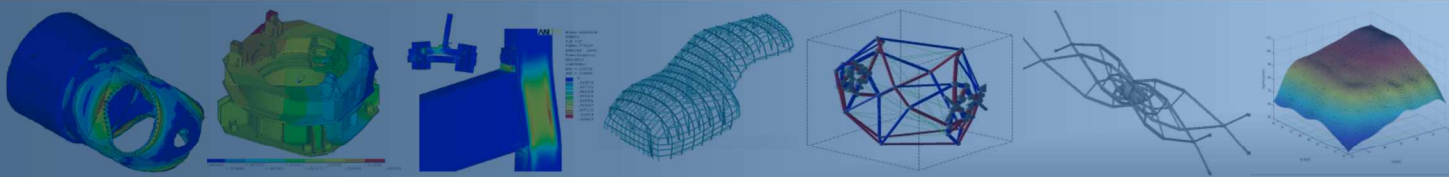


$$\tilde{\theta}_u(d_b, t_{ep})$$

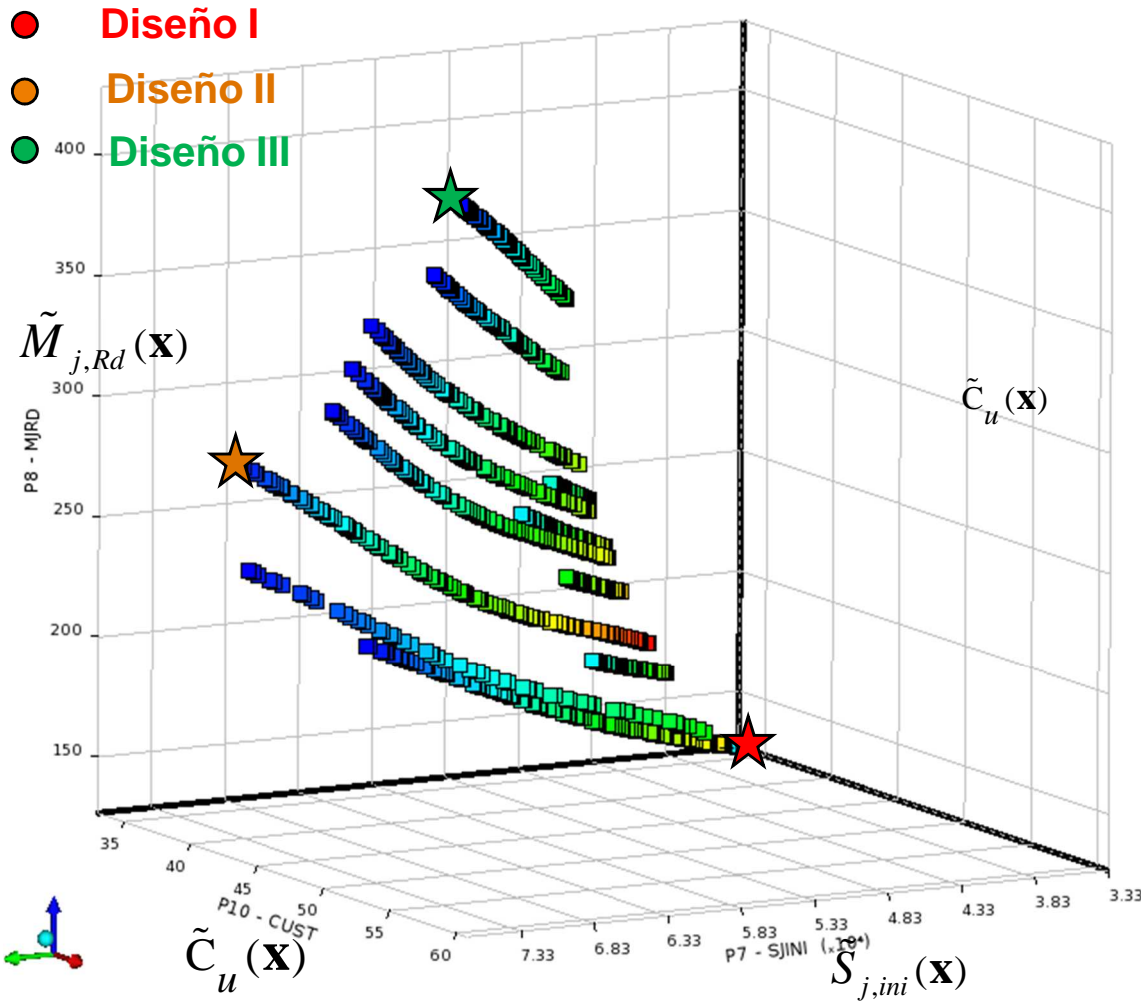


$$\tilde{c}_u(d_b, t_{ep})$$





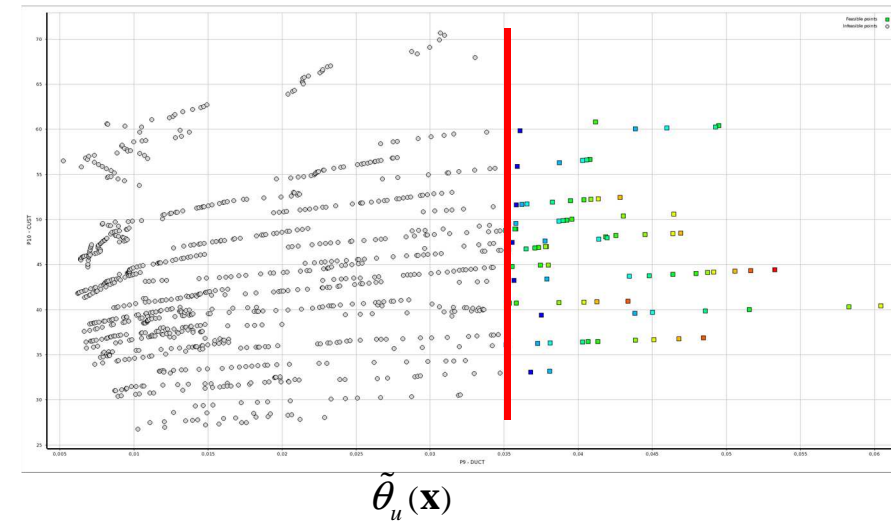
Optimización Multi-objetivo de uniones semirrígidas

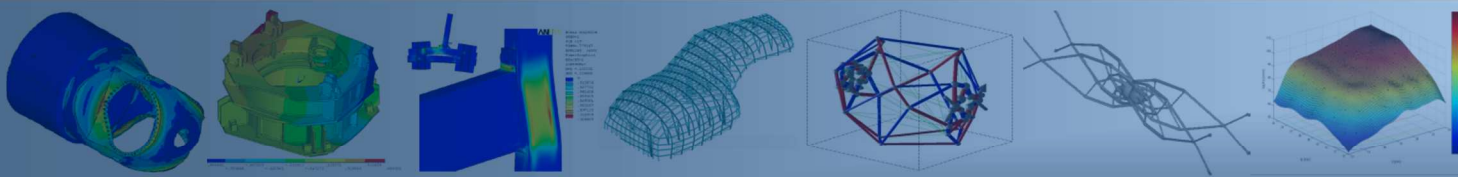


Región no factible

$$\tilde{\theta}_u(\mathbf{x}) < 35mrad$$

$$\tilde{\theta}_u(\mathbf{x}) \geq 35mrad$$

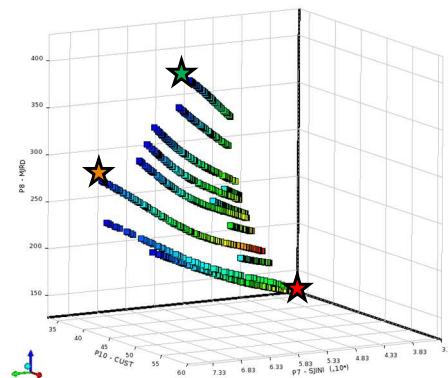


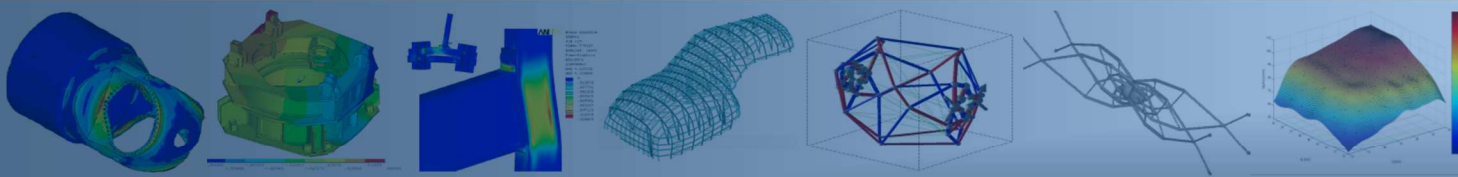


Optimización Multi-objetivo de uniones semirrígidas

		Diseño I			Diseño II			Diseño III		
		d_b	t_{ep}	p_x	d_b	t_{ep}	p_x	d_b	t_{ep}	p_x
		20	10	149.773	27	12	95.703	27	20	124.045
$\tilde{M}_{j,Rd}(\mathbf{x})$	(kNm)	126.841			291.298			428.362		
$\tilde{C}_u(\mathbf{x})$	(uc)	33.290			43.239			59.804		
$\tilde{S}_{j,ini}(\mathbf{x})$	(kNm/rad)	33288.774			76973.304			76720.723		
$\tilde{\theta}_u(\mathbf{x})$	(rad)	0.039			0.035			0.035		

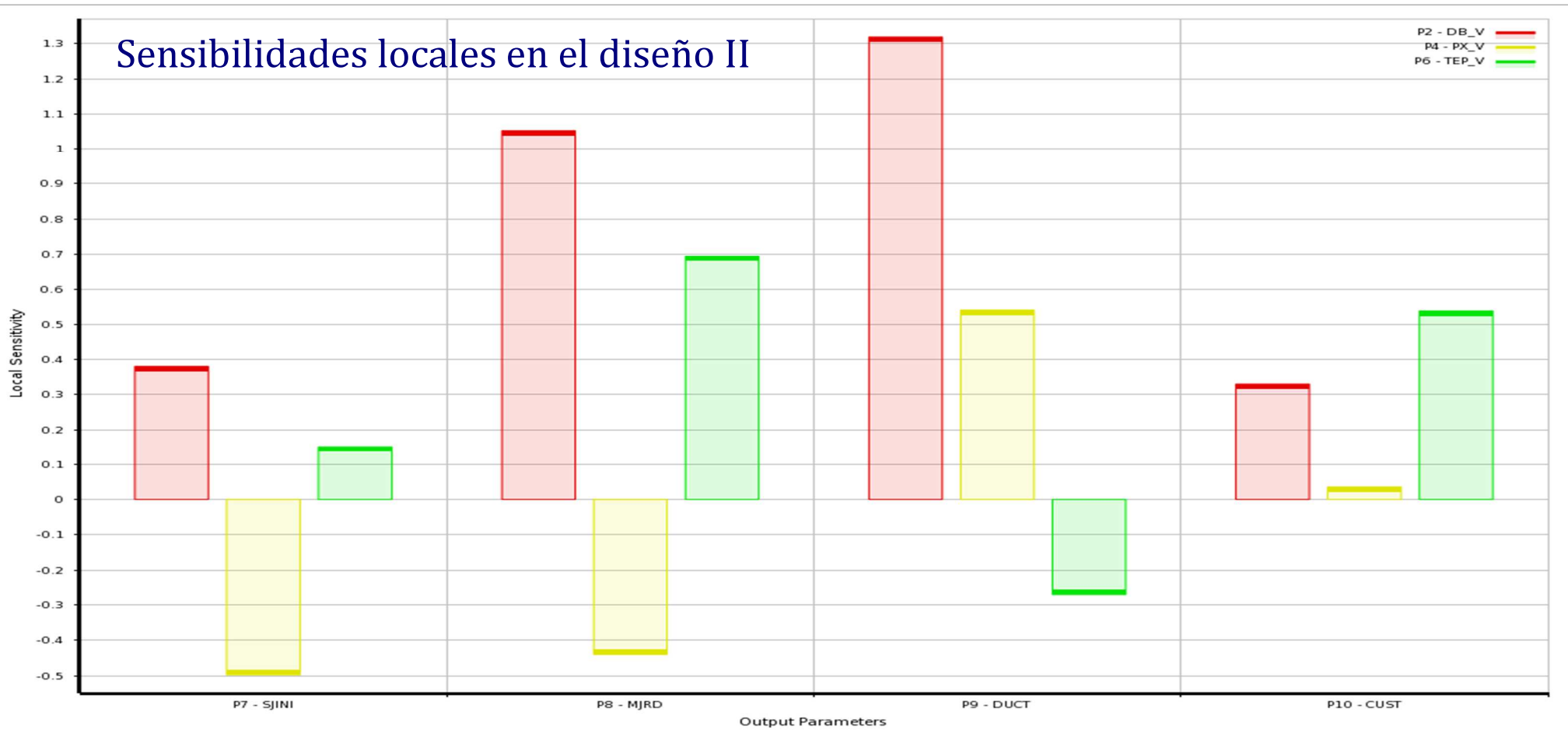
Dimensiones en mm.





Optimización Multi-objetivo de uniones semirrígidas

Sensibilidades locales en el diseño II

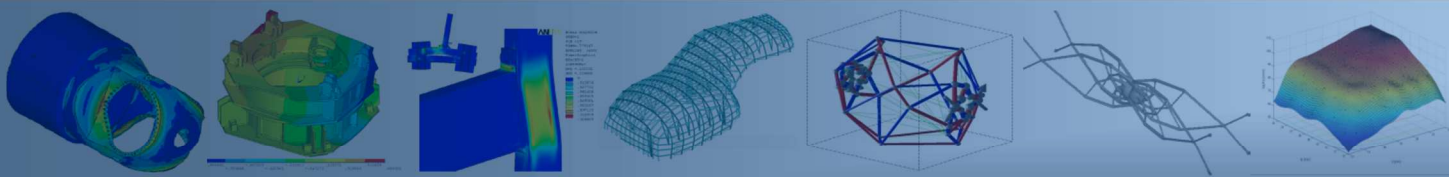


$$\tilde{S}_{j,ini}(\mathbf{x})$$

$$\tilde{M}_{j,Rd}(\mathbf{x})$$

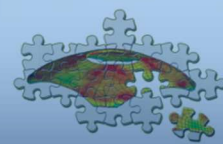
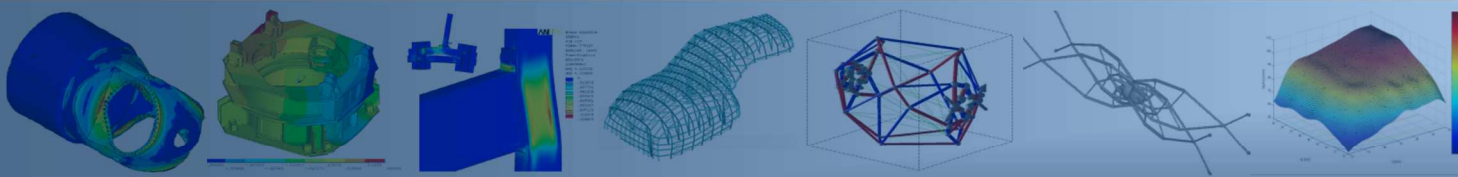
$$\tilde{\theta}_u(\mathbf{x})$$

$$\tilde{C}_u(\mathbf{x})$$



Optimización Multi-objetivo de uniones semirrígidas. Errores de la aproximación

	Diseño I			Diseño II			Diseño III		
	Kriging	MEF	Dif. (%)	Kriging	MEF	Dif. (%)	Kriging	MEF	Dif. (%)
$\tilde{M}_{j,Rd}(\mathbf{x}, \mathbf{z})$	126.841	128.139	-1.013	291.298	294.839	-1.201	428.362	438.540	-2.322
$\tilde{C}_u(\mathbf{x})$	33.290	33.352	-0.187	43.239	43.284	-0.103	59.804	59.779	0.042
$\tilde{S}_{j,ini}(\mathbf{x}, \mathbf{z})$	33288.774	34514.737	-3.552	76973.304	79533.487	-3.219	76720.723	74818.099	2.543
$\tilde{\theta}_u(\mathbf{x}, \mathbf{z})$	0.039	0.037	5.101	0.035	0.033	5.271	0.035	0.033	5.004



Optimización Multi-objetivo de uniones semirrígidas

CPUtime = $ngen \times npop \times time_mef = 100 \times 50 \times 2$ horas = 10000 horas = **1.14 años**

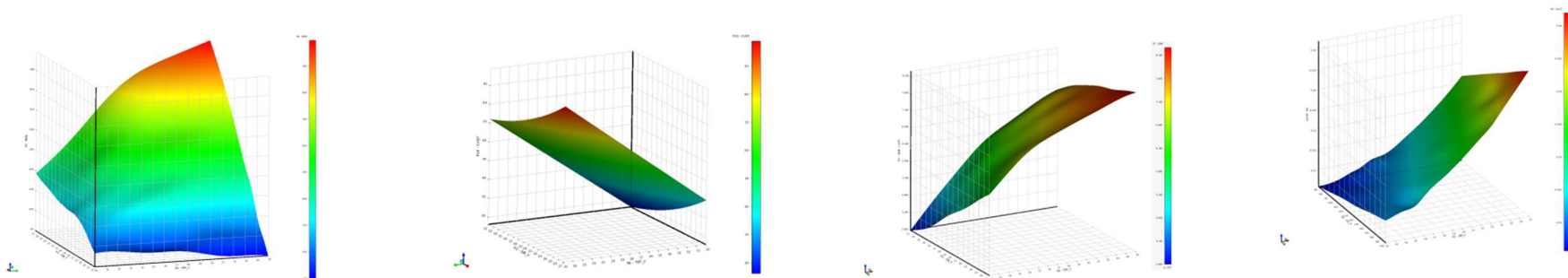
- $ngen$ = número de generaciones (MOGA)
- $npop$ = tamaño inicial de la población (MOGA)
- $time_mef$ = coste computacional del modelo de elementos finitos

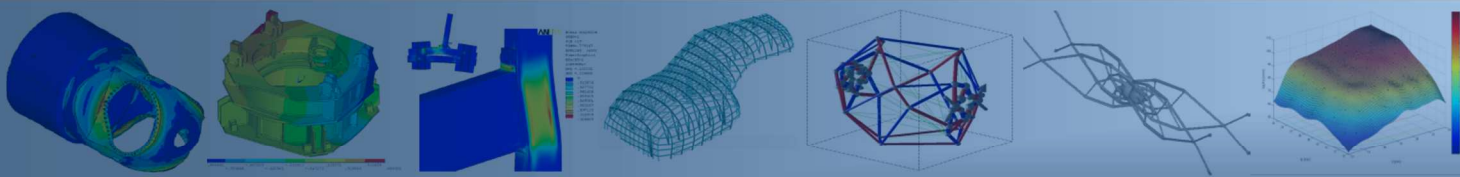
CPUtime = $ndoe \times time_mef + nge \times npop \times time_kg = 100 \times 2 + 100 \times 50 \times 2.7e-7 = 200$ horas = **8.3 días**

- $ndoe$ = tamaño del DOE
- $time_kg$ = coste computacional de una evaluación del modelo Kriging

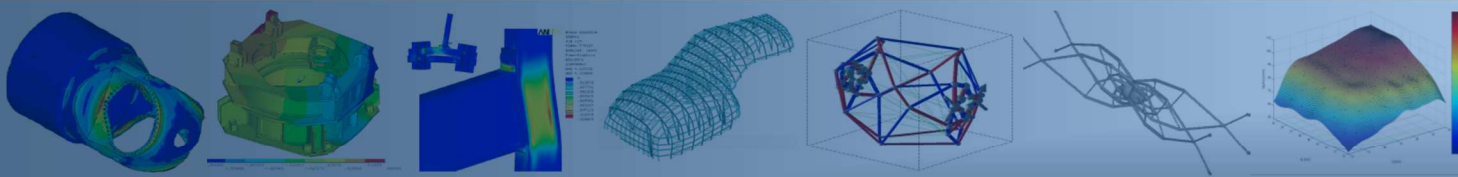
CPUtime = $(ndoe \times time_mef) / speedup + nge \times npop \times time_kg = (100 \times 2) / 10 + 100 \times 50 \times 2.7e-7 = 20$ h

Metamodelos reutilizables



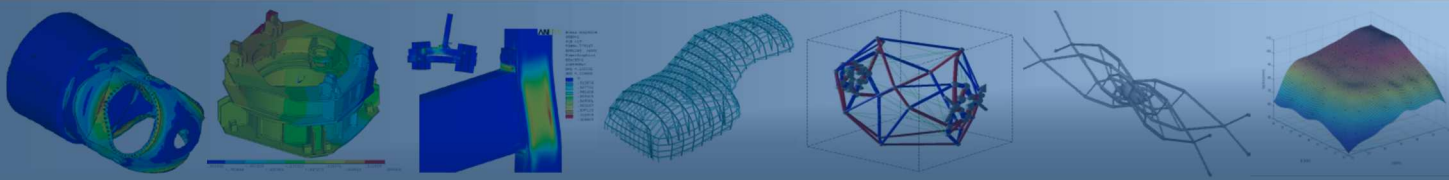


Conclusiones



Conclusiones

- El entorno **ANSYS Workbench** puede utilizarse como un **laboratorio virtual**, que proporciona al diseñador unas herramientas eficientes, que posibilitan un **mejor conocimiento** del problema y la obtención de **mejores diseños**.
- La utilización de **Meta-modelos** se ha mostrado como una solución eficaz para reducir el coste computacional de procesos de diseño con modelos de elementos finitos complejos. De esta forma, resuelven necesidades de la industria tales como **la optimización global, multidisciplinar o probabilista**.
- Para la aplicación desarrollada, la utilización de Meta-modelos proporciona **mayor información acerca del comportamiento** de la unión y de los modos de fallo involucrados en la misma.
- La combinación de **Meta-modelos** con **cálculo distribuido** (Centro de Supercomputación Ben Arabí) permite disminuir en mayor medida el coste computacional, **aumentando la productividad y competitividad** en el proceso de diseño.



Gracias por su atención

Agradecimientos



PARQUE CIENTÍFICO MURCIA
CENTRO DE SUPERCOMPUTACIÓN



Proyecto DPI 2011-26394