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PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA DE PRODUÇÃO
ESCOLA DE ENGENHARIA DE SÃO CARLOS - EESC

MANUFACTURABILITY ANALYSIS TO COMBINE ADDITIVE AND SUBTRACTIVE PROCESSES

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SÃO CARLOS
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AGENDA

- ✓ Objetivo
- ✓ Introdução/conceitos
- ✓ Modelo
- ✓ Validação
- ✓ Conclusão
- ✓ Referência

ARTIGO

Manufacturability analysis to combine additive and subtractive processes

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OBJETIVO

- Methodology to estimate manufacturing complexity for both machining and layered manufacturing by a combination of a subtractive process (high-speed machining) and an additive process (selective laser sintering)

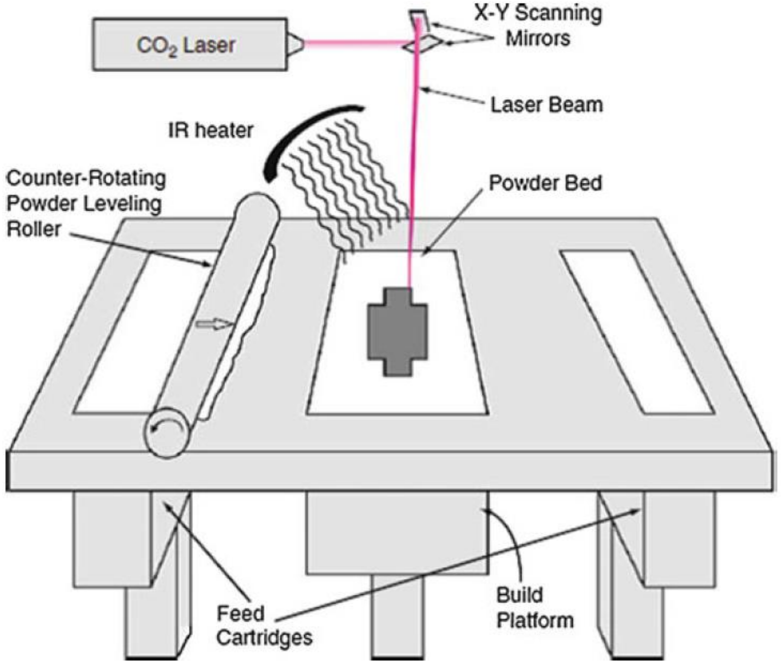
OBJETIVO

PROCESSO DE ADIÇÃO

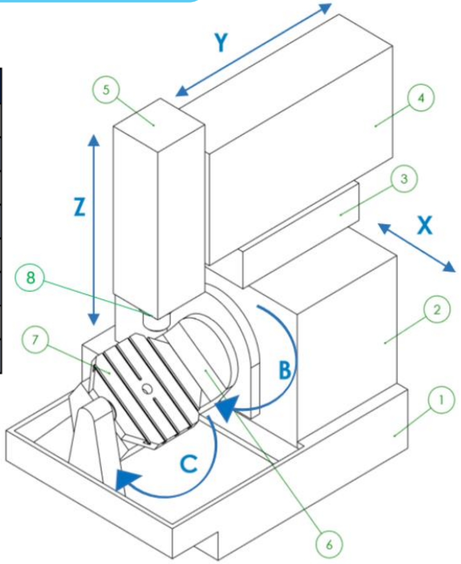
Sinterização Seletiva a Laser - SLS

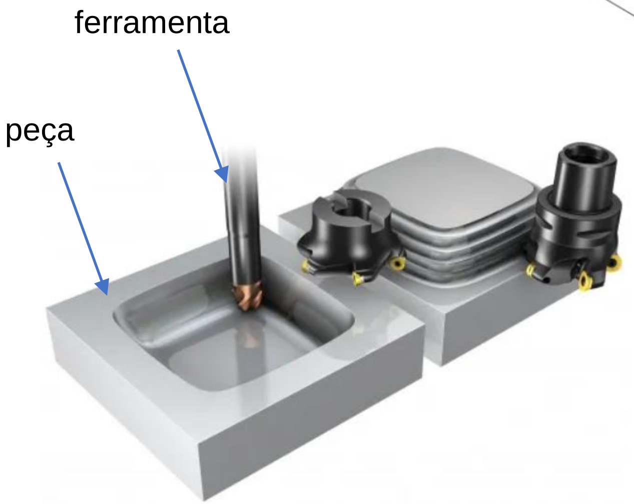
PROCESSO DE REMOÇÃO

usinagem



Item	Componente
1	base
2	coluna
3	carro X
4	carro Y
5	cabeçote
6	mesa
7	mesa de trabalho *(pallet)*
8	eixo árvore *(spindle)*



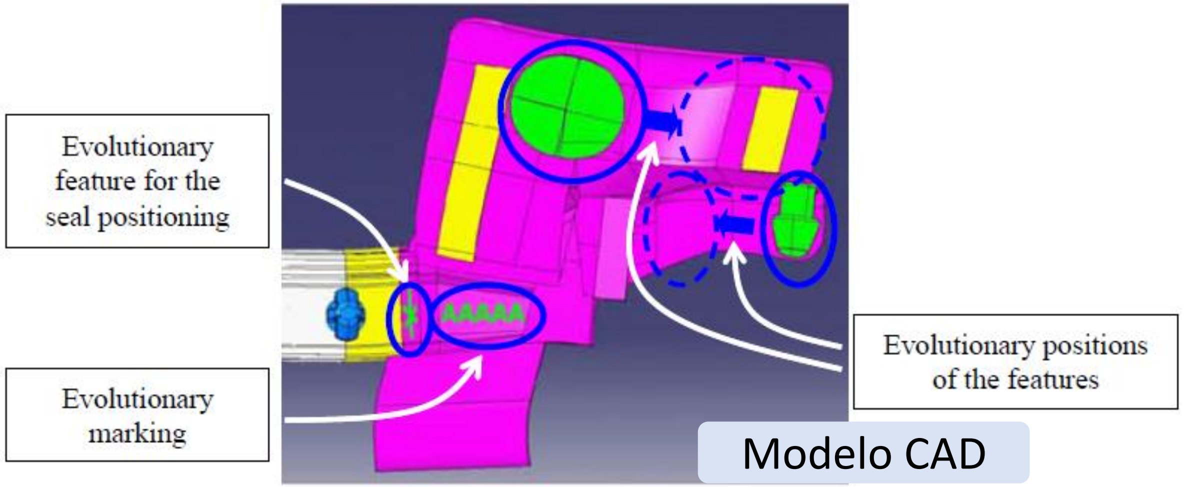


INTRODUÇÃO

➢ Processo modular X Processo híbrido

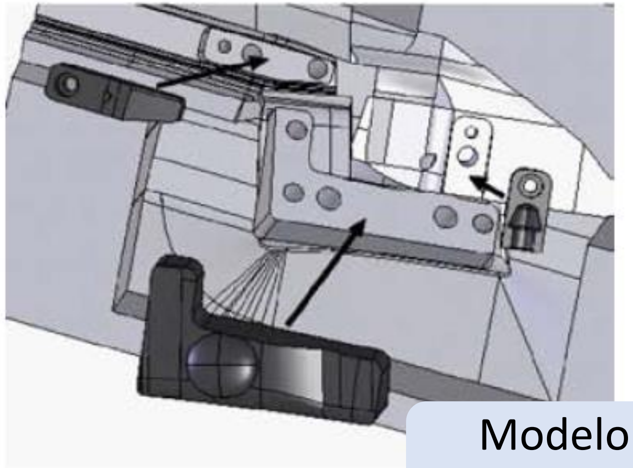
Peça

(a)



Modelo CAD

(b)



(c)

Modelo CAD do molde híbrido

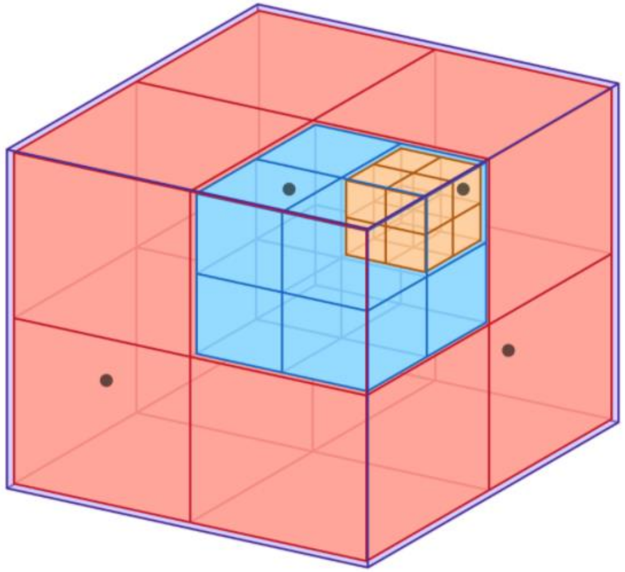
(d)

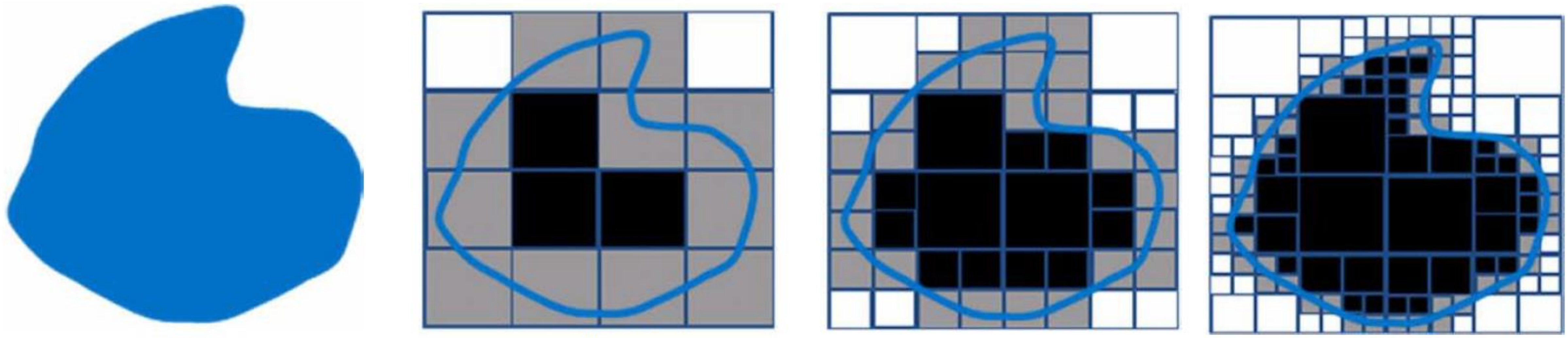
Molde da peça híbrida

PROCESSO HÍBRIDO

Design For Manufactring - DFM

- CSG
- STL
- **OCTREE**





(a) (b) (c) (d)

COMPLEXIDADE DA MANUFATURA

- Superfície com baixa rugosidade
- Faces de referência para usinagem e áreas com necessidade de adição como suporte

INFLUÊNCIA NO PROCESSO

PROCESSO DE ADIÇÃO

- Volume da peça
- Orientação de superfície
- Distância do centro da mesa (plataforma)
- Superfície de casca
- Perfil com dimensões mínima e máxima

PROCESSO DE REMOÇÃO

- Volume da peça
- Volume do blank
- Geometria
- Perfil de canal estreito com raio
- Superfície de forma livre

PARÂMETROS DE MANUFATURA

- Tipo do material
- Tolerâncias dimensionais e geométricas
- Microestrutura do material
- Dureza
- Condutividade térmica

MODELO - PARÂMETROS

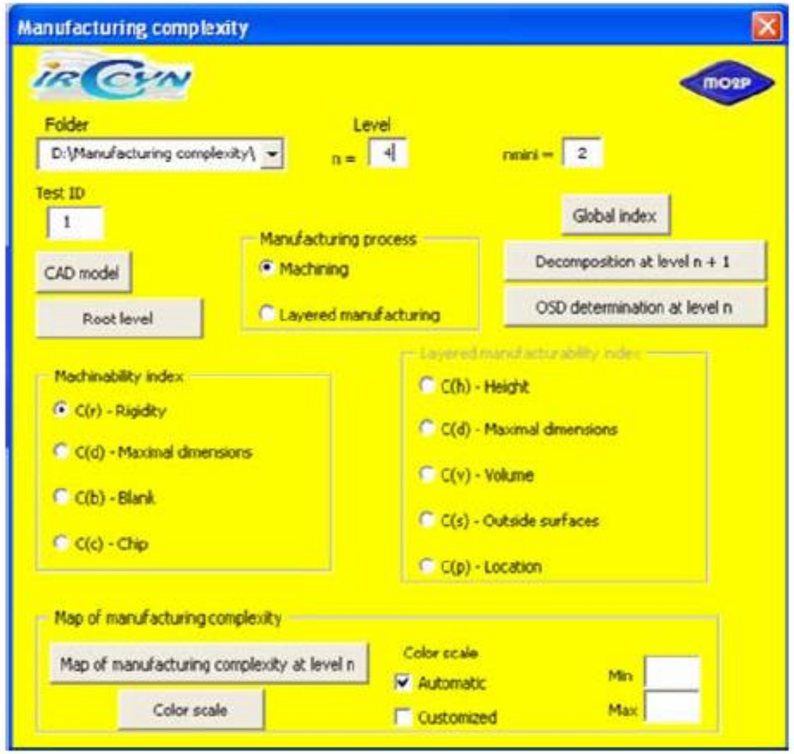
- Tipo global: para toda a peça
- Tipo local: para cada área da peça, baseado na decomposição

Table I Manufacturability indexes for machining process

Index	Linked to	Type
$C(d_x)C(d_y)C(d_z)$	Maximal dimensions	Global
$C(r)$	Tool rigidity	Local
$C(b)$	Blank volume	Global
$C(c)$	Chip quantity	Global

Table II Manufacturability indexes for layered manufacturing process

Index	Linked to	Type
$C(d_x)C(d_y)C(d_z)$	Maximal dimensions	Global
$C(v)$	Volume	Global
$C(s)$	Skin surface	Global
$C(h)$	Height	Local
$C(\rho)$	Distance from the centre of the platform	Local



MODELO - PARÂMETROS (EQUAÇÕES)

$$C(d_x) = \frac{LX_{\text{max}}}{X_{\text{machine}}} \quad (1)$$

where:

LX_{max} the maximal dimension of the tool in x-direction; and

X_{machine} the length of the X-axis of the machine.

$$C(r) = \frac{L}{D} \quad (2)$$

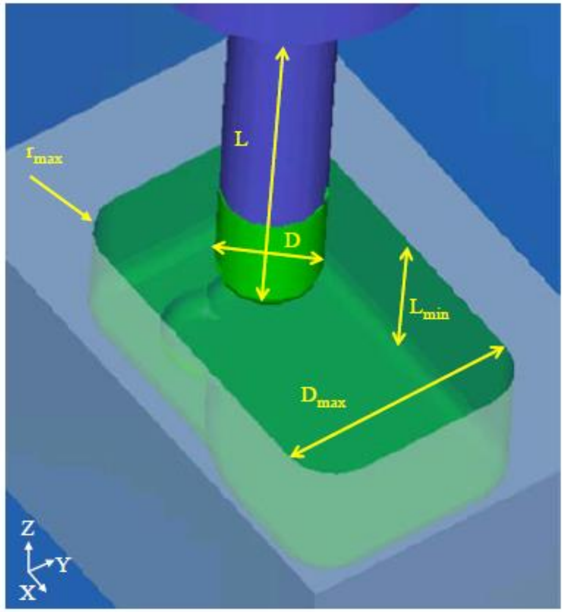
where: L, the minimal length of the milling tool that can machine the surface included in the octant; and D, the maximal diameter of the milling tool that can machine the surface included in the octant.

$$C(b) = LX_{\text{max}} \times LY_{\text{max}} \times LZ_{\text{max}} \quad (3)$$

$C(b)$ represents the volume of the blank part. The higher $C(b)$ is, the more expensive the rough part is and consequently the more difficult-to-machine the tool is considered:

$$C(c) = \frac{LX_{\text{max}} \times LY_{\text{max}} \times LZ_{\text{max}}}{V} \quad (4)$$

where: V, the volume of the tool.



$$C(v) = V \quad (5)$$

$$C(s) = S_{\text{ext}} \quad (6)$$

where: S_{ext}, the area of the whole skin surface of the tool:

$$C(h) = z - Z_0 \quad (7)$$

where: z, the z-coordinate of the centre of gravity of the volume of the tool contained in the octant; and Z_0, the z-coordinate of the bottom face of the tool:

$$C(\rho) = \sqrt{(x - X_0)^2 + (y - Y_0)^2} \quad (8)$$

where: x and y, the coordinate in the X-Y plane of the centre of gravity of the volume of the tool contained in the octant; and X_0 and Y_0, the coordinate of the centre of the tool, considering that the tool will be manufactured with its centre exactly at the centre of the platform.

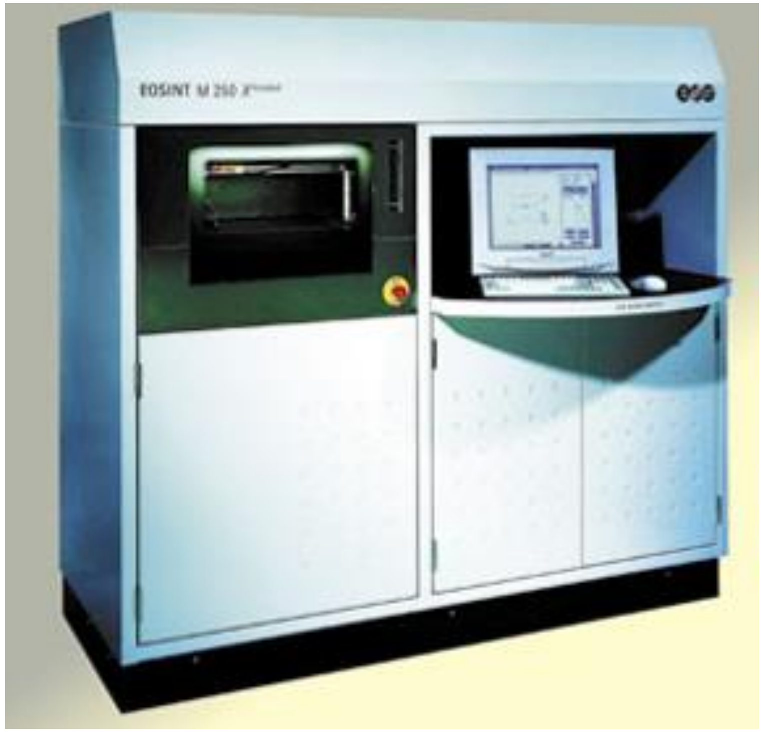
$$C(i_{\text{global}}) = \frac{\sum_j (C(i_{\text{local}})_j \times V_j)}{\sum_j V_j} \quad (9)$$

where: V_j, the volume of the fraction of the tool contained in the octant for which $C(i_{\text{local}})_j$ is calculated.

EQUIPAMENTOS

PROCESSO DE ADIÇÃO

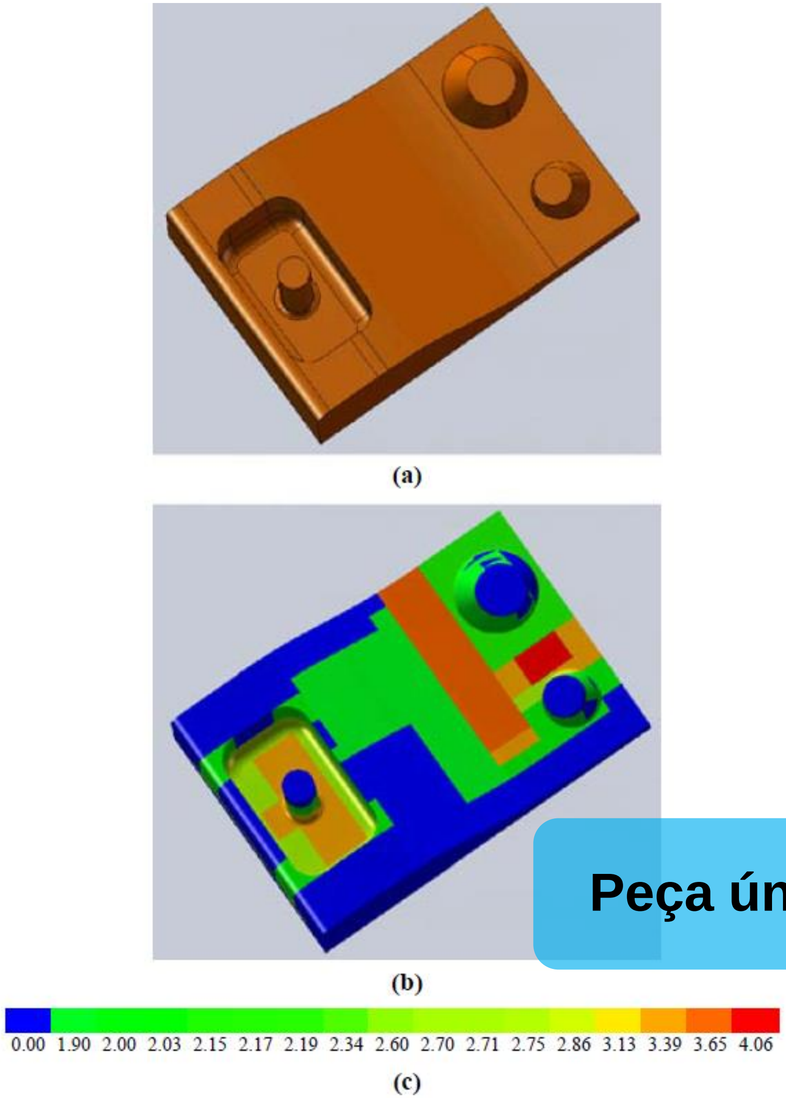
EOS 250 Xtend



PROCESSO DE REMOÇÃO

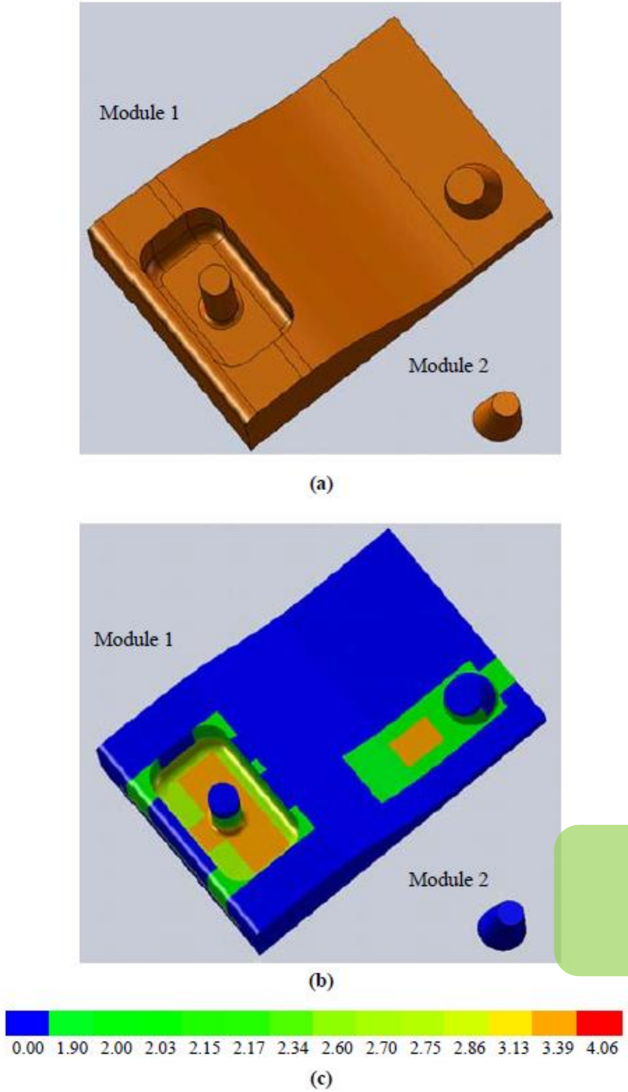
Hermle C30U HSM

PEÇA ÚNICA x PEÇA MODULAR - USINAGEM



Notes: (a) CAD model; (b) map of manufacturing complexity; (c) color scale

Peça única



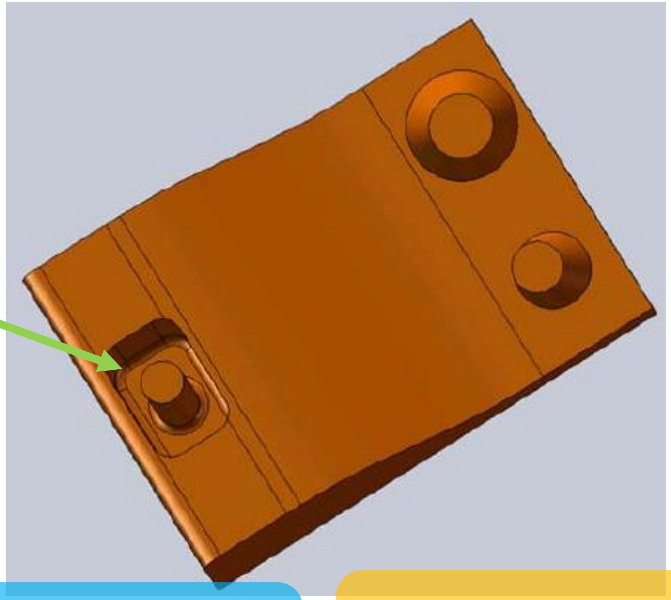
Notes: (a) CAD model; (b) map of manufacturing complexity; (c) color scale

Peça modular

Table III Comparison of $C(r_{global})$ for the two CAD models

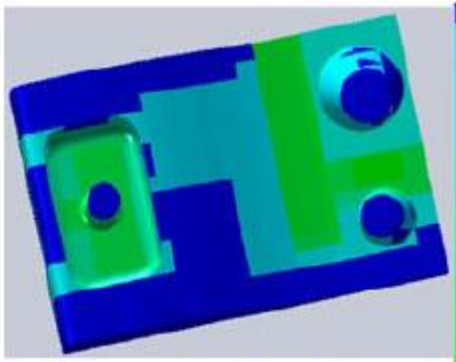
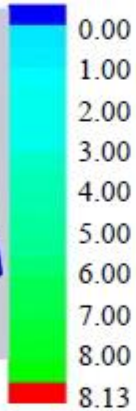
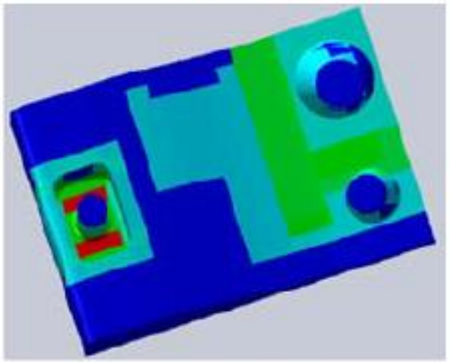
	Single-piece test part	Modular test-part			Comparison (%)
		Module 1	Module 2	Total	
$C(d_x)$	0.185	0.185	0.043	0.178	− 4
$C(d_y)$	0.133	0.133	0.043	0.129	− 3
$C(d_z)$	0.100	0.100	0.06	0.098	− 2
$C(r_{global})$	1.700	0.998	0	0.998	− 40
$C(b)$	480,000	480,000	20,280	457,273	− 5
$C(c)$	2.35	2.09	2.01	2.09	− 11

PEÇA ÚNICA x PEÇA ÚNICA REBAIXO MENOR - USINAGEM

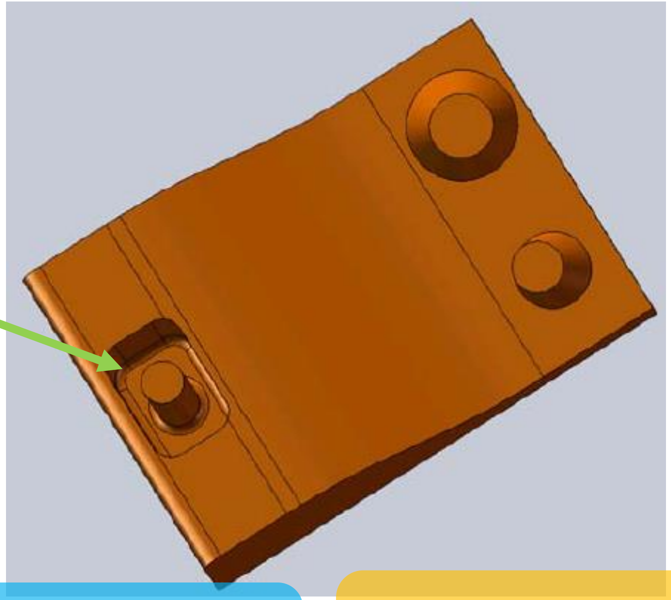


Fresado: 30x50x30mm

Fresado: 20x30x30mm

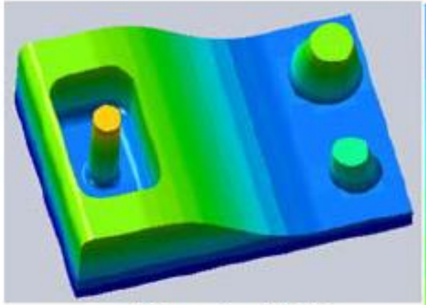
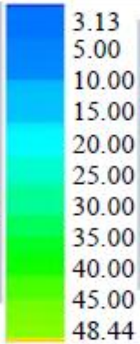
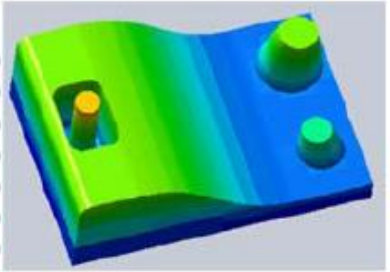
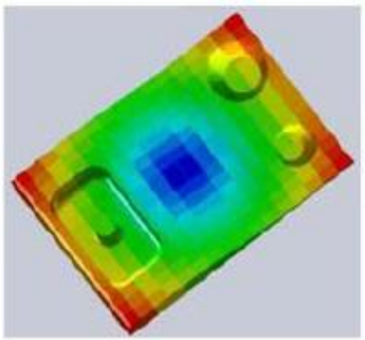
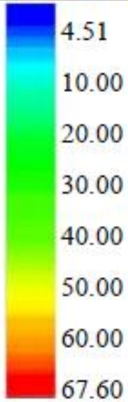
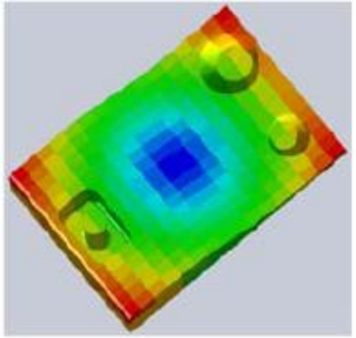
		Pocket dimensions: 30×50×30	Pocket dimensions: 20×30×30	Comparison
Machining	$C(d_x)$	0.185	0.185	=
	$C(d_y)$	0.133	0.133	=
	$C(d_z)$	0.100	0.100	=
	$C(r)$	 $C(r_{global}) = 1.700$	  $C(r_{global}) = 2.071$	$C(r_{max})$ + 100% $C(r_{global})$ + 22%
	$C(b)$	480 000	480 000	=
	$C(c)$	2.35	2.09	–11 %

PEÇA ÚNICA x PEÇA ÚNICA REBAIXO MENOR - SLS



Fresado: 30x50x30mm

Fresado: 20x30x30mm

		Pocket dimensions: 30×50×30	Pocket dimensions: 20×30×30	Comparison
Layered manufacturing	$C(d_x)$	0.48	0.48	=
	$C(d_y)$	0.32	0.32	=
	$C(d_z)$	0.28	0.28	=
	$C(v)$	204 183	229 177	+ 12 %
	$C(s)$	36 866	35 557	–4 %
	$C(h)$	 $C(h_{global}) = 14.250$	  $C(h_{global}) = 15.259$	+ 7 %
	$C(\rho)$	 $C(\rho_{global}) = 39.018$	  $C(\rho_{global}) = 39.042$	≈

CONCLUSÃO

- Parâmetros de manufatura calculados por meio do modelo 3D (CAD)
- Estimativa dos perfis complexos para manufatura
- Modelo testado para peça única e modular, ambas em usinagem
- Modelo testado para peça com processo de adição SLS
- Peça modular e híbrida são menos complexas que peça única

REFERÊNCIAS BIBLIOGRÁFICAS

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Olivier Kerbrat, Pascal Mognol, Jean-Yves Hascoët. **Manufacturability analysis to combine additive and subtractive processes.** Rapid Prototyping Journal, Emerald, 2010, 16 (1), pp.63-72.

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