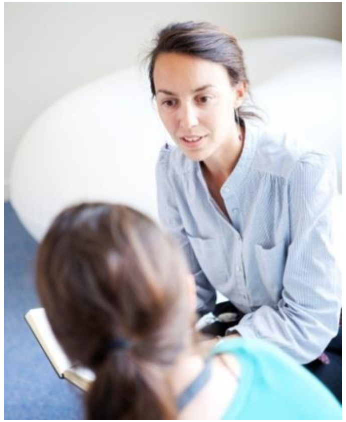
如何通过建模和仿真模拟来支持增材制造认证

达索系统simulia 资深技术经理 焦中华

Our Company

a **Scientific** company

Combining **Science, Technology** and **Art** for a sustainable society



13,300 passionate people

- 117 nationalities / 178 sites
- One global R&D / 54 labs
- Game changing **3D**EXPERIENCE solutions

190,000 enterprise customers

- 12 industries in 140 countries
- 18 million users

10,000 partners

- Software, Technology & Architecture
- Content & Online Services
- Sales
- Consulting & System Integrators
- Education
- Research

Long-term driven

- Majority shareholder control
- **Revenue**: $3.2 Bn*
- Operating margin: 29.8%*

** Figures as of FY 2014 / Non-IFRS*

Our Clients: Industry leaders at the heart of Innovation

Transportation & Mobility

Aerospace & Defense

Marine & Offshore

Industrial Equipment

High-Tech

Consumer Goods
- Retail

Consumer Packaged Goods
- Retail

Life Sciences

Energy, Process & Utilities

Architecture, Engineering & Construction

Financial & Business Services

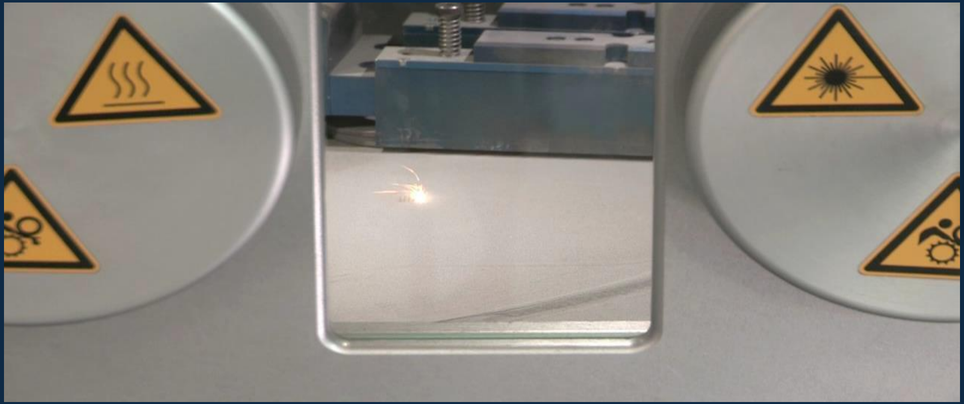
Natural Resources

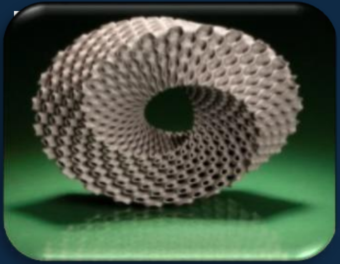
DASSAULT SYSTEMES | The 3DEXPERIENCE Company

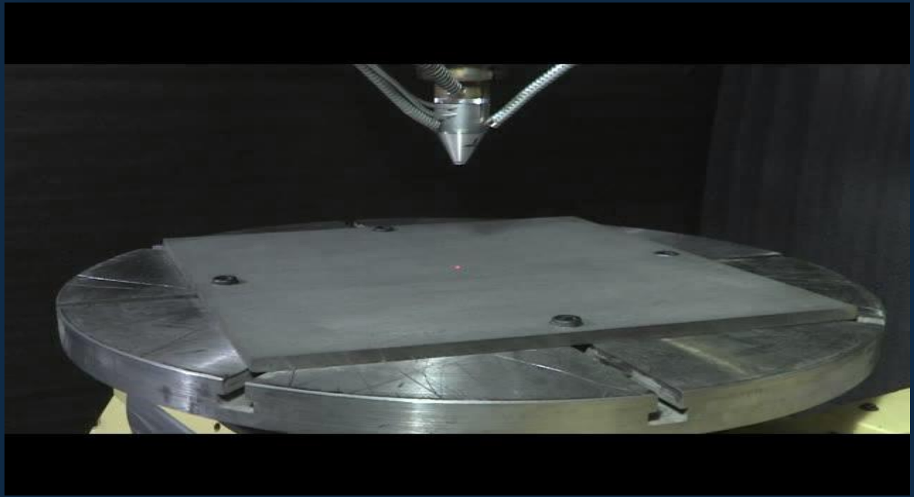
Our Purpose

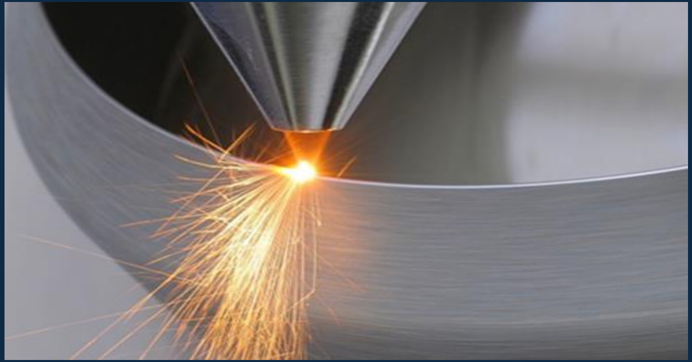
“ Dassault Systèmes provides business & people with **3D**EXPERIENCE universes to imagine sustainable innovations capable of harmonizing product, nature and life. ”

TWI: SLM 和 LDED工艺



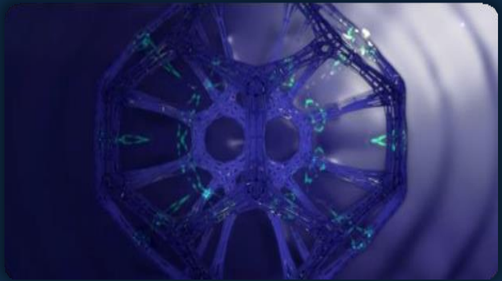






增材制造：革命性技术

新设备/ 新材料

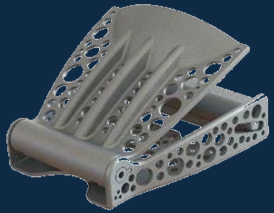


Carbon3D's Super Fast 3D Printer

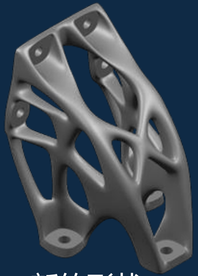
全新的加工方法

MX3D Bridge Printing

全新方法来设计



新的装配体结构



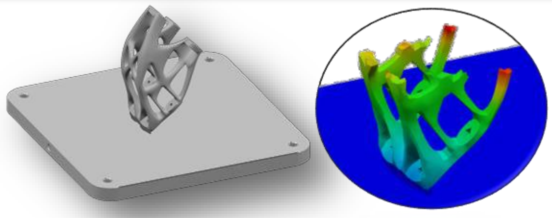
新的形状

多功能集成的设计

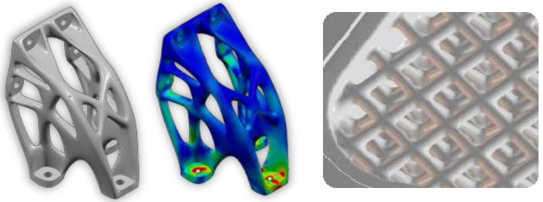
全新的生态系统

策略 | 数字连续、基于科学

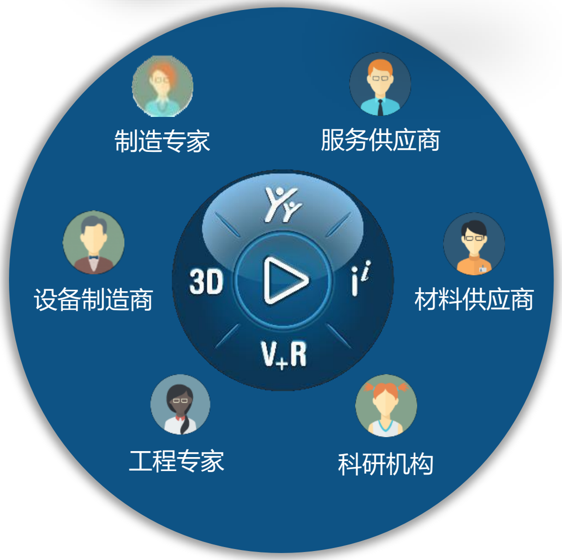
3 工艺规划和工艺过程仿真



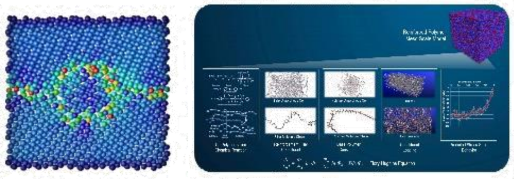
2 面向增材制造的设计



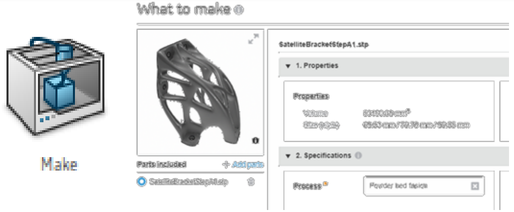
4 Global Production System



1 材料基因工程



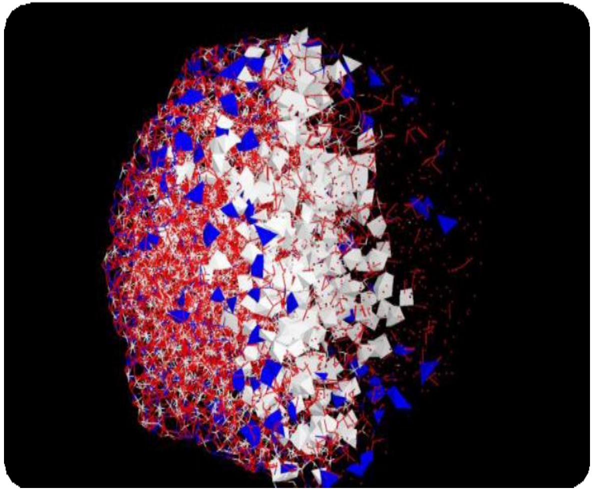
5 3DEXPERIENCE Marketplace



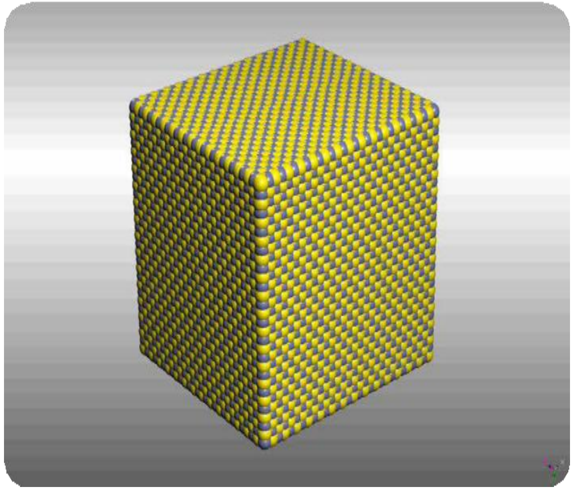
材料基因工程

虚拟材料实验室:

- 为 AM **认证**现有材料
- 工程师增材**研发**新材料
- **控制**加工材料的微观结构

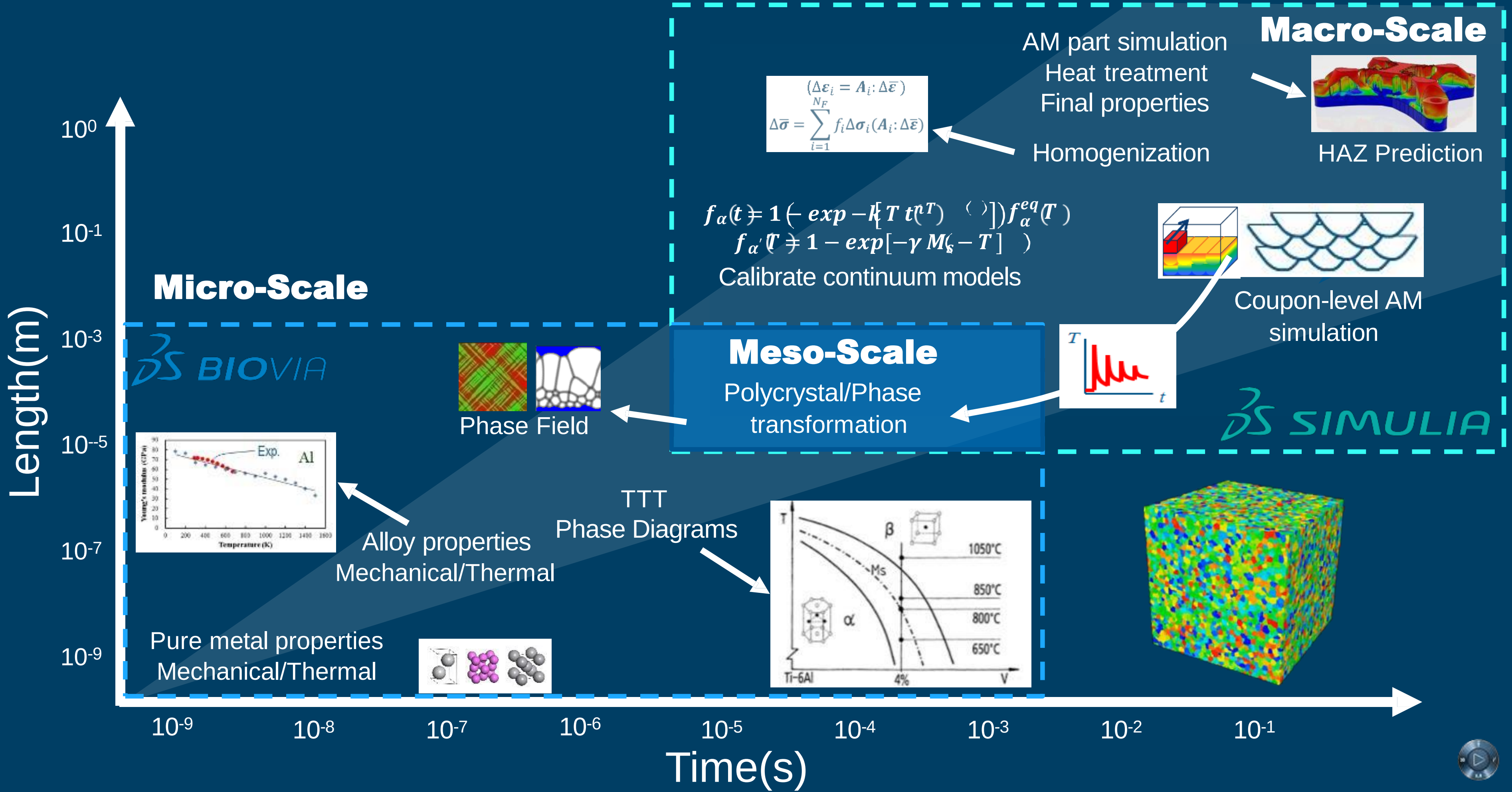


Grain segregation of a Titanium Alloy



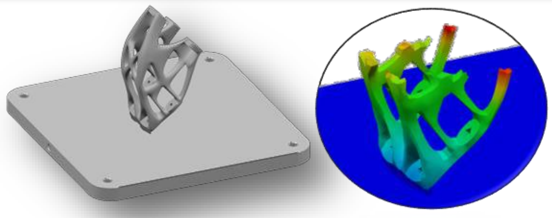
Melting & Thermal conductivity of a Nickel Alloy

金属增材制造工艺跨尺度分析

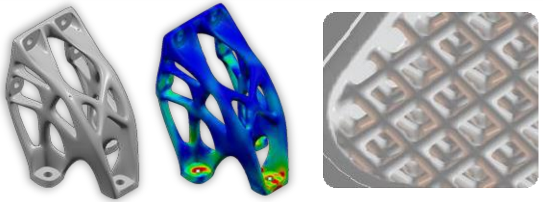


策略 | 数字连续、基于科学

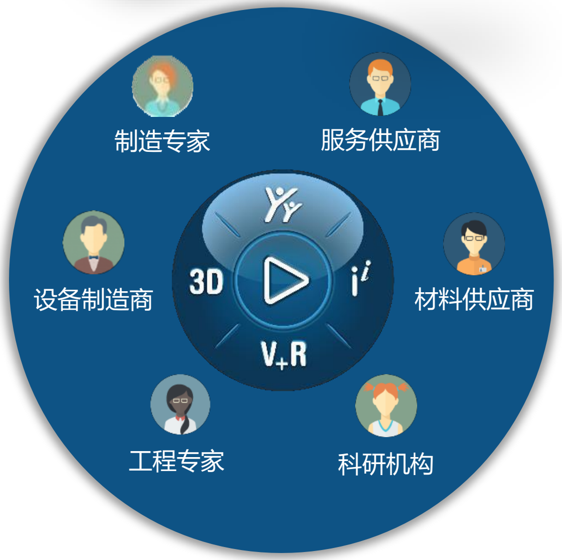
3 工艺规划和工艺过程仿真



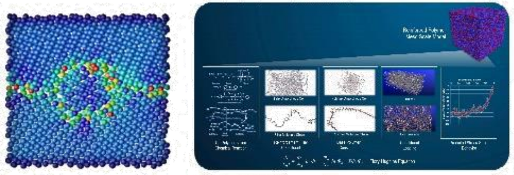
2 面向增材制造的设计



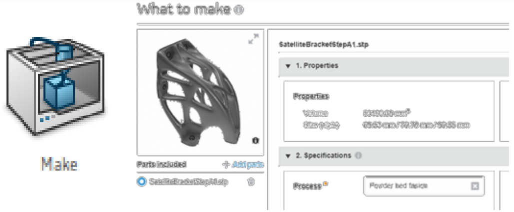
4 Global Production System



1 材料基因工程



5 3DEXPERIENCE Marketplace



什么是面向增材制造的设计?

面向增材制造的设计

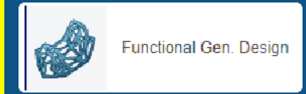
利用增材制造带来的可能性创建复杂的设计

性能驱动的创成式设计

自动生成一个或多个满足工程规范的设计解决方案

结构创成式设计

基于结构分析

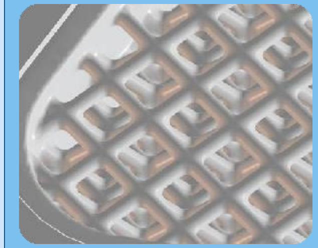


流体创成式设计

基于流体仿真

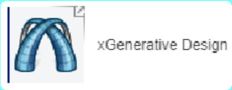
点阵设计

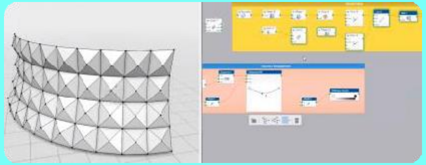
用点阵结构填充设计以减轻其重量或者实现功能性设计



算法创成式设计

基于脚本的方法，生成的形状取决于用户规范

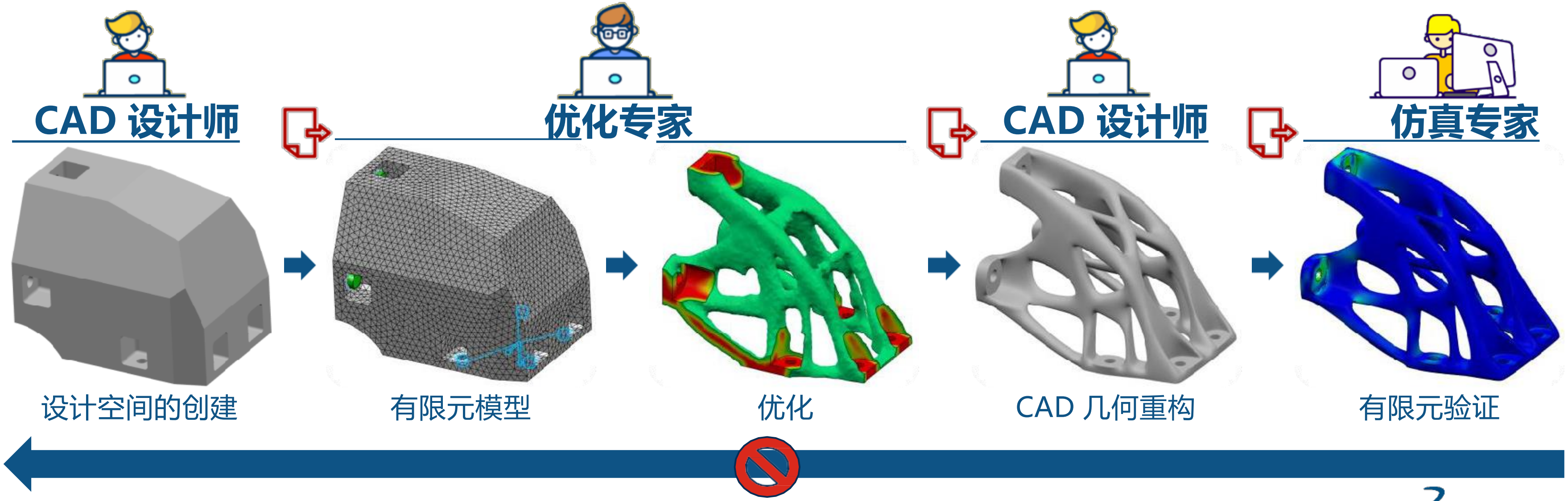




优化：一个复杂并且不联系的过程

设计、仿真和优化的独特世界：

- 没有数字连续性
- 几个不同软件
- 不同的用户



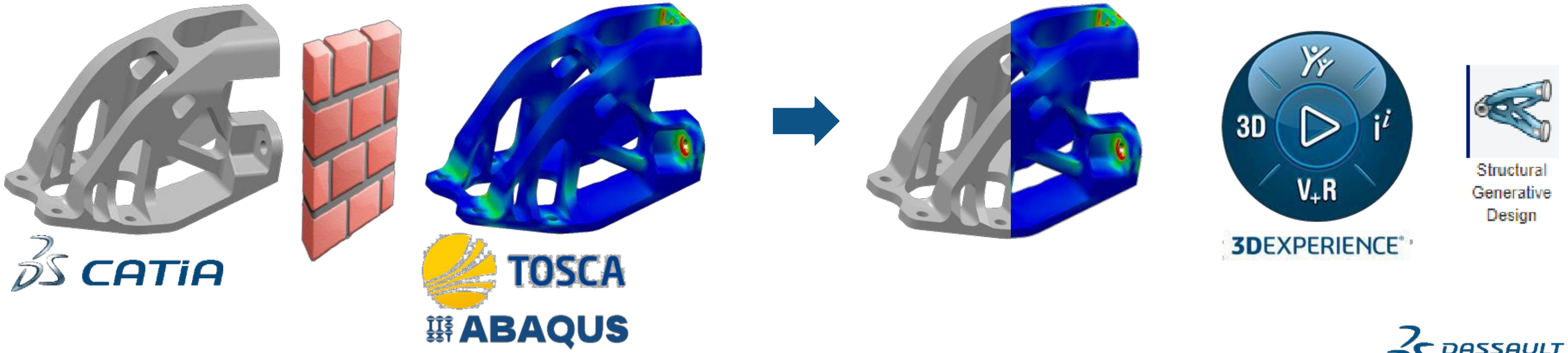
DASSAULT SYSTEMES

单一用户, 单一界面, 可扩展的求解性能

设计、**仿真**和**优化**为集成的一体化环境:

- 数字**连续**
- **向导式流程**
- **自动生成实体**
- 无缝协同

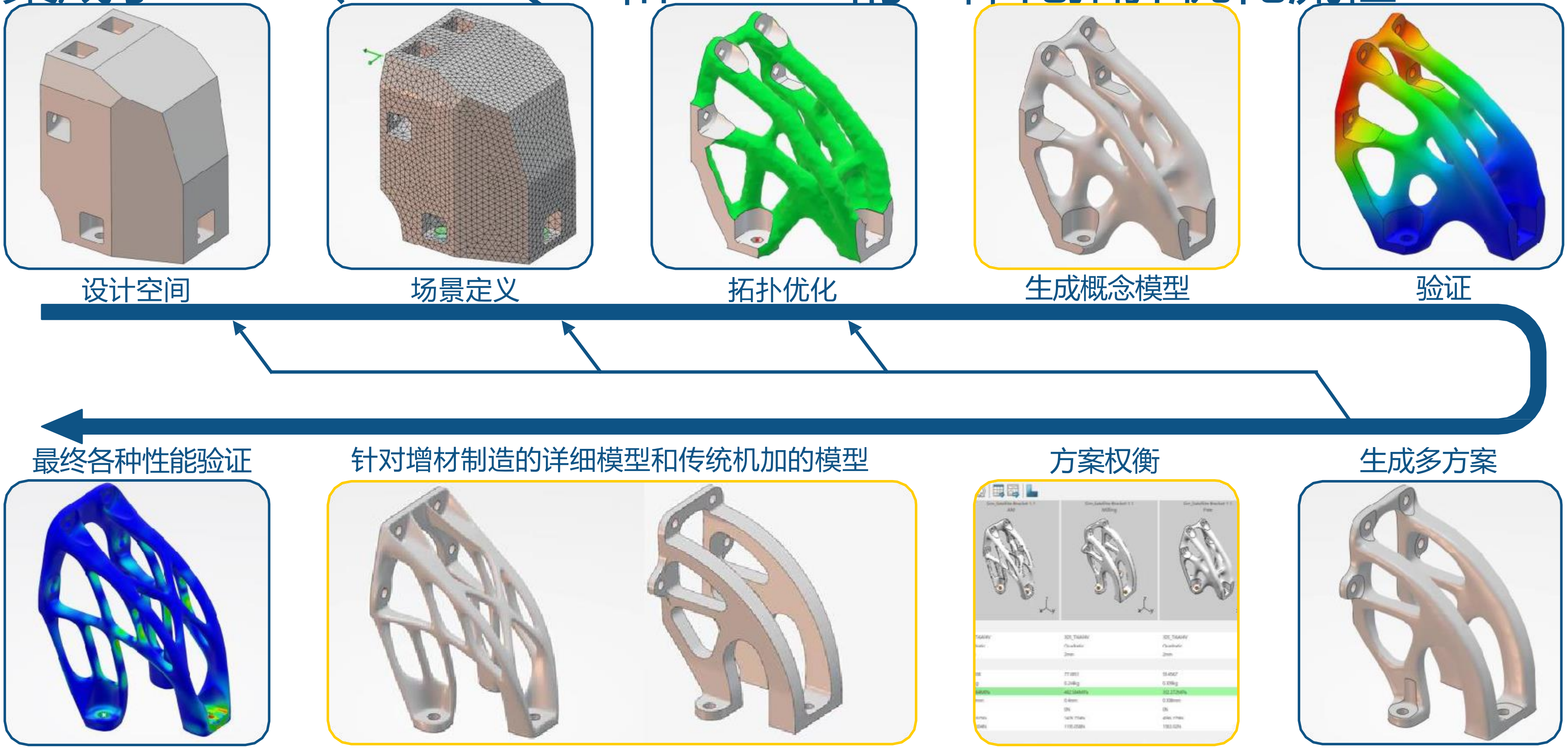
设计师　　分析师　　产品工程师



DASSAULT SYSTEMES

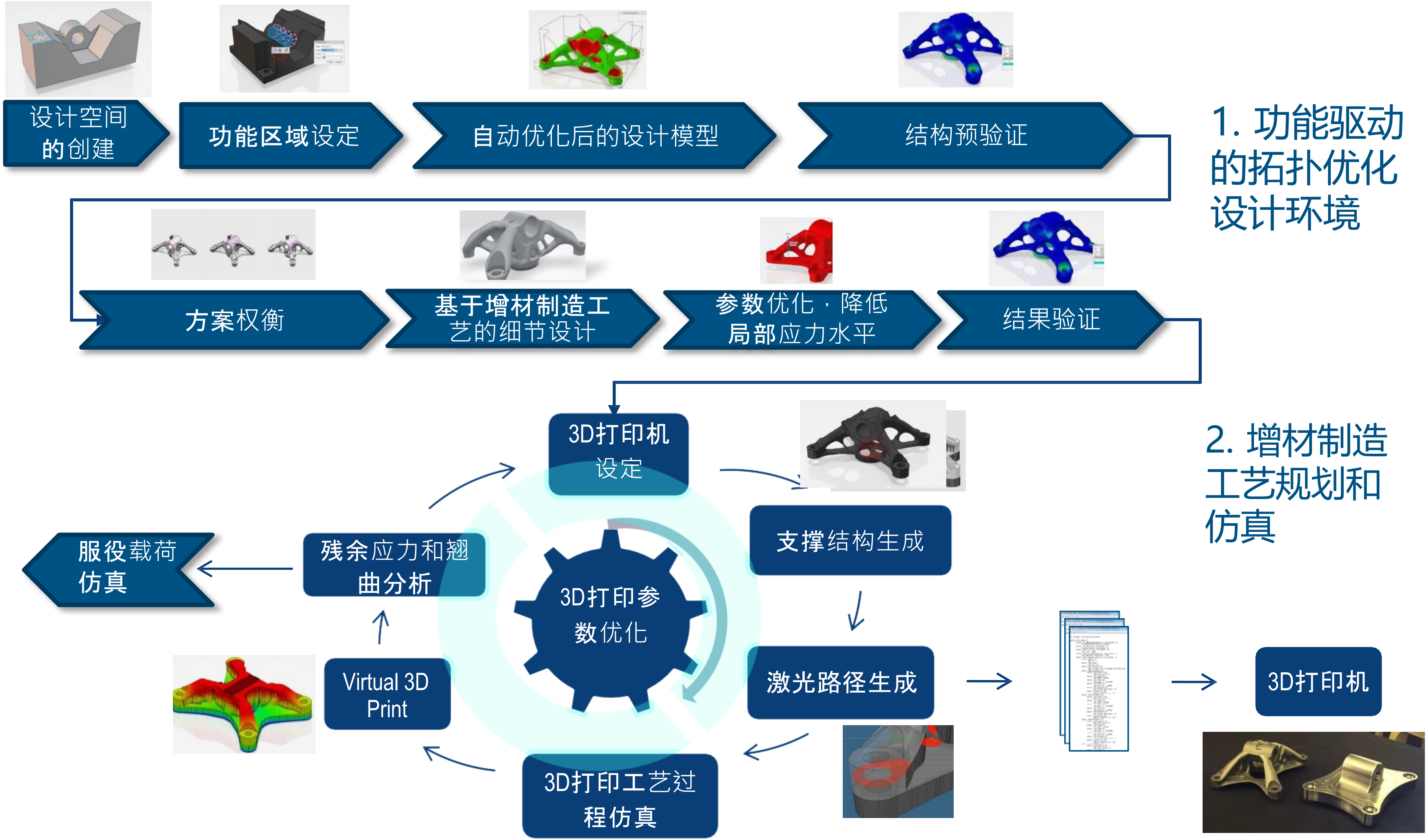
Unique Capabilities

集成了CATIA、ABAQUS和TOSCA的一体化拓扑优化流程



1. 功能驱动的拓扑优化设计环境

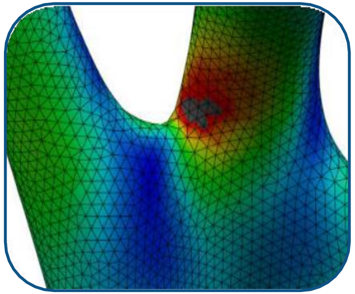
2. 增材制造工艺规划和仿真

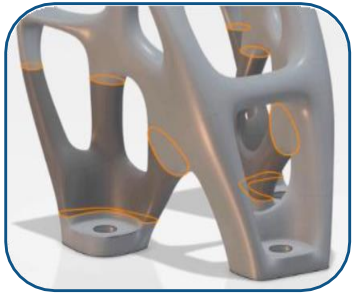


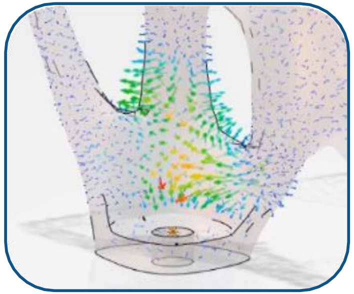
通过形貌优化获得详细设计方案

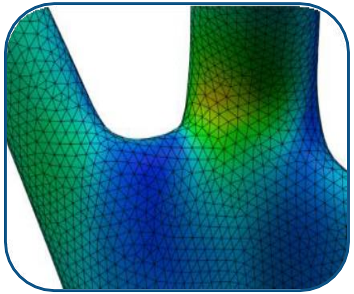
- 通过形貌优化降低局部应力集中


详细设计


局部应力峰值

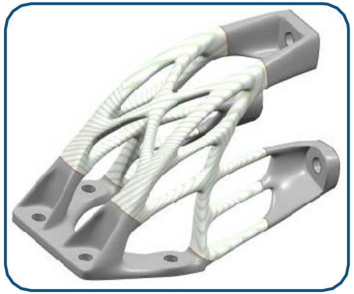

优化区域定义

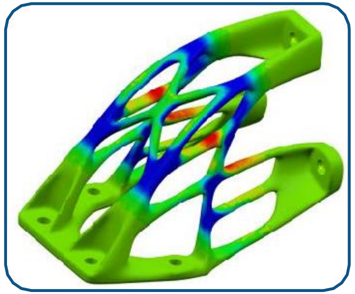

形貌优化

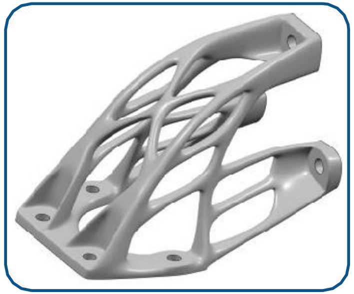

Validation

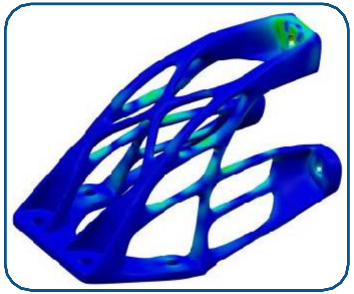
- 或者通过自动化设计/验证循环来优化整个部分：


详细设计


优化区域设定


形貌优化

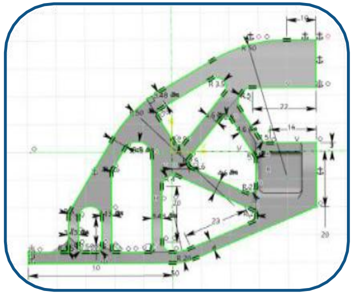

更新设计


Validation

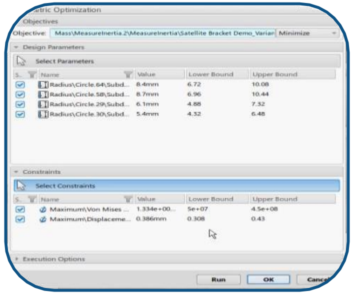
利用参数优化获得详细设计方案

- 机械形状的附加参数改进：

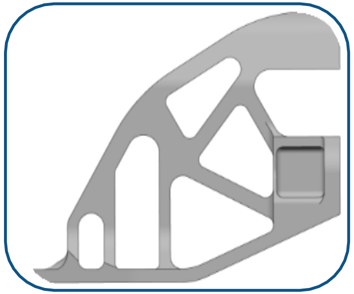
详细设计



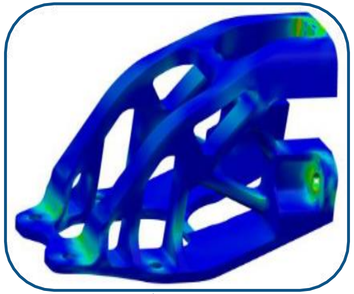
参数化的草绘图



参数优化

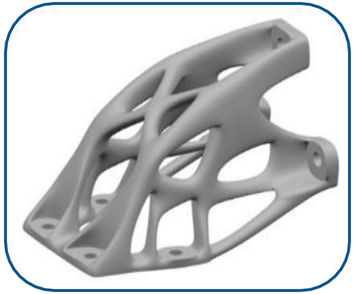


最优化设计

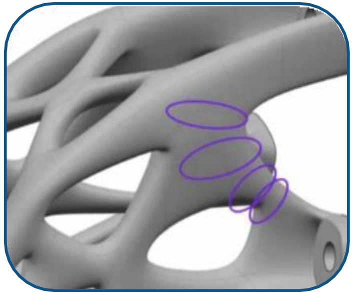


性能验证

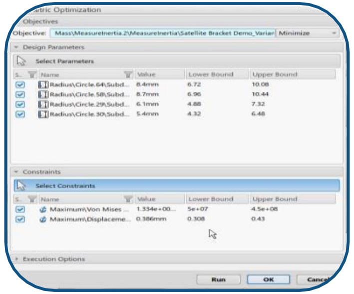
- 也可以针对原始设计:



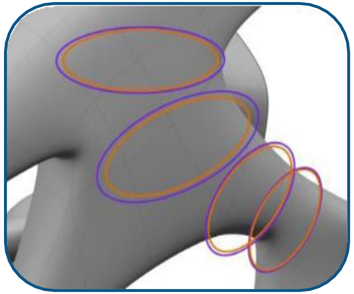
详细设计



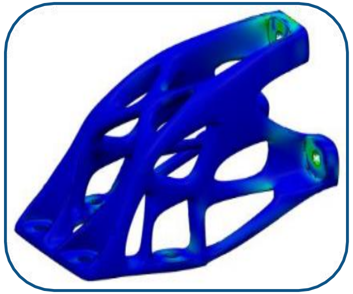
参数关联



参数优化



最优化设计

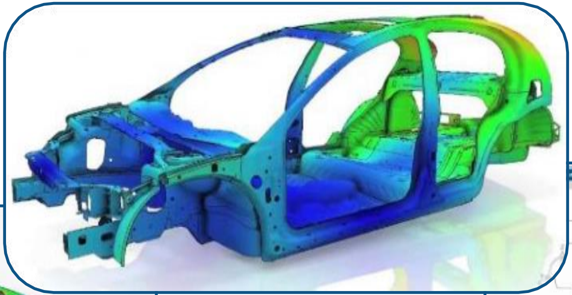


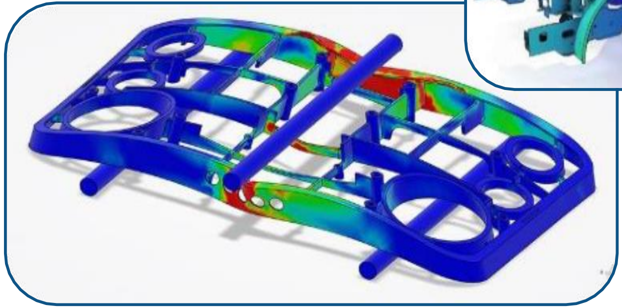
验证

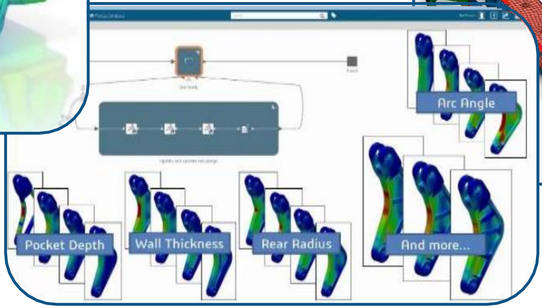
与其他仿真模块的扩展性

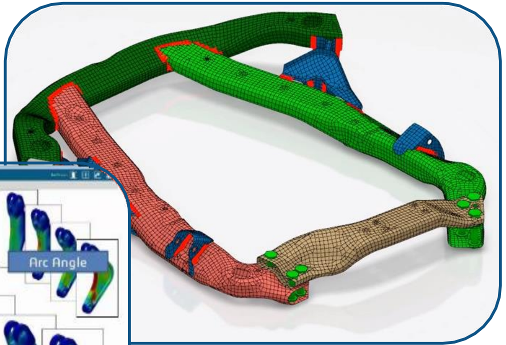
具有高级模拟角色的可扩展性：

- 扩展结构创成式设计的功能可以涵盖更加复杂的工况，例如扫频、随机振动、流体等
- 允许高级有限元建模（1D/2D/3D）
- 重用结构创成式设计设置以进行认证和疲劳仿真
- 借助 Simulation Checker，在应用程序之间切换时可确保完全兼容





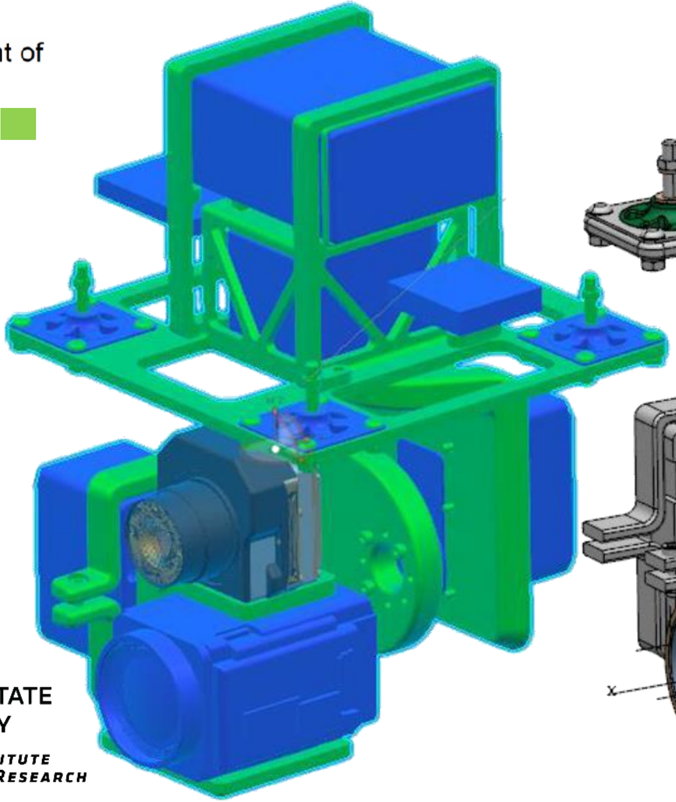


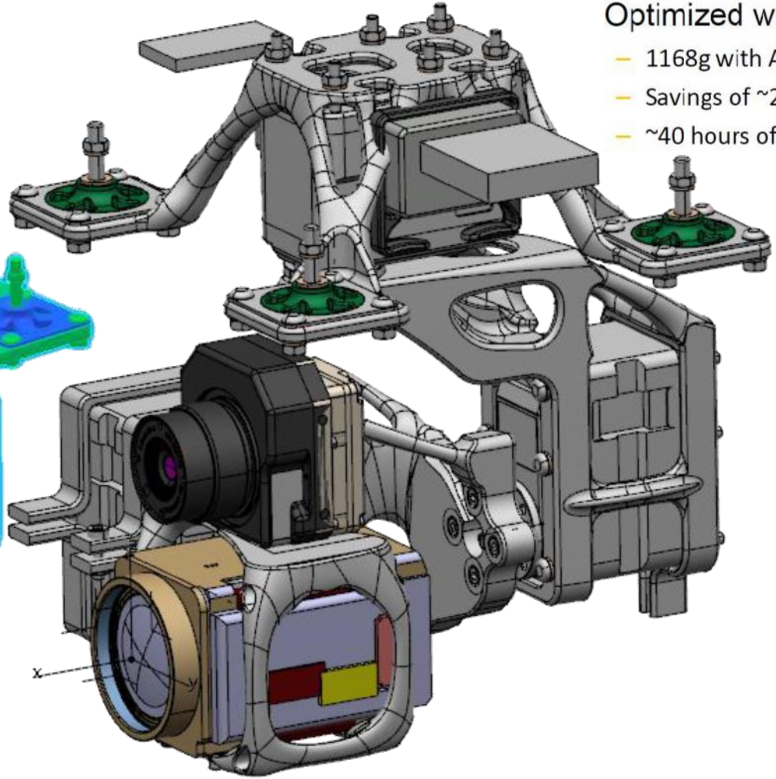


无人机相机云台的轻量化设计

Un-optimized weight of 1402g

- Bracket weight ~400g





Optimized weight of 1204g

- 1168g with Al fasteners
- Savings of ~200g
- ~40 hours of modeling time

NIAR® Wichita State University

National Institute for Aviation Research

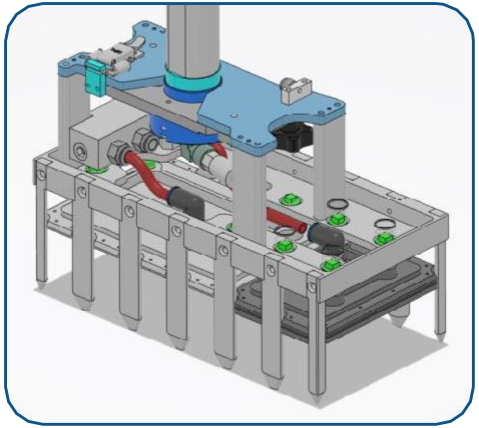
DASSAULT SYSTEMES

前轮支架轻量化设计

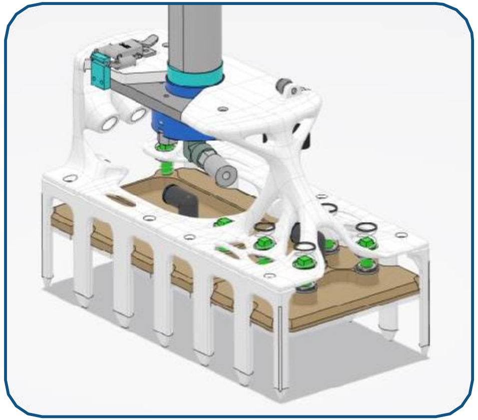
4 Components / **1121g**

1 Component / **542g** (-52%)

搬运工装的轻量化设计

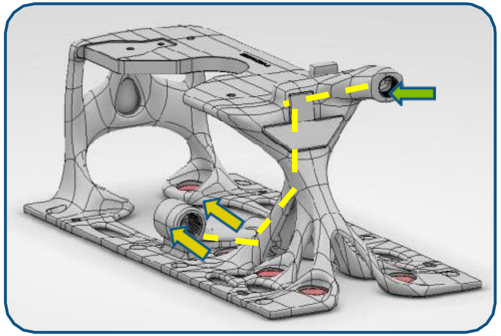


22 部件 / **4,71** Kg



3 部件 / **1,59** Kg (-66%)

we are GROUP



压缩空气系统的集成

流体创成式设计

面向增材制造的设计

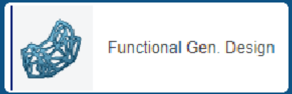
利用增材制造带来的可能性创建复杂的设计

性能驱动的创成式设计

自动生成一个或多个满足工程规范的设计解决方案

结构创成式设计

基于结构分析

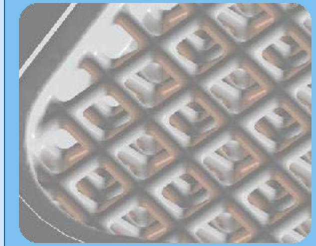


流体创成式设计

基于流体仿真

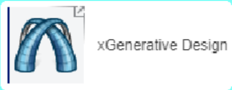
点阵设计

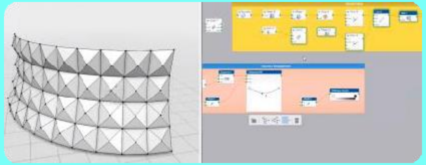
用点阵结构填充设计以减轻其重量或者实现功能性设计



算法创成式设计

基于脚本的方法，生成的形状取决于用户规范





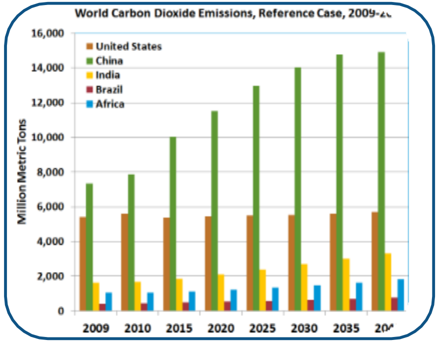
商业挑战

跟上不断发展的世界：

降低 CO2 排放 — 严格的政府法规

改进发动机性能 — 有竞争力的燃油效率

平衡能源消耗和乘客舒适度 — 复杂的暖通空调系统

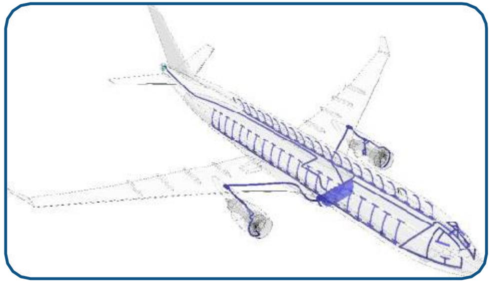


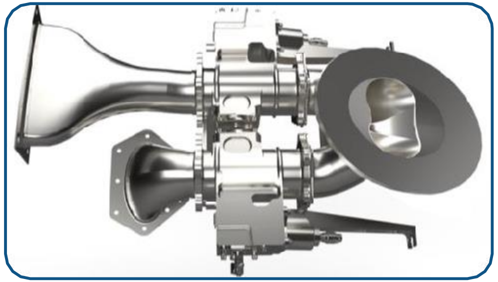
Excel data sources:
U.S. Energy Information Administration, International Energy - Outlook 2013

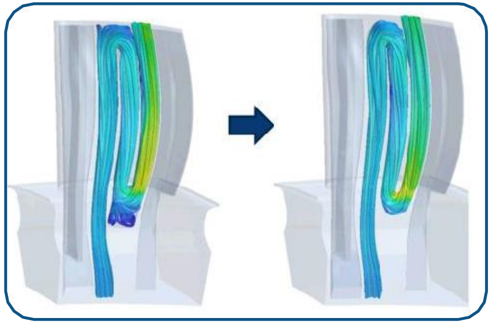
EXAMPLES OF APPLICATIONS

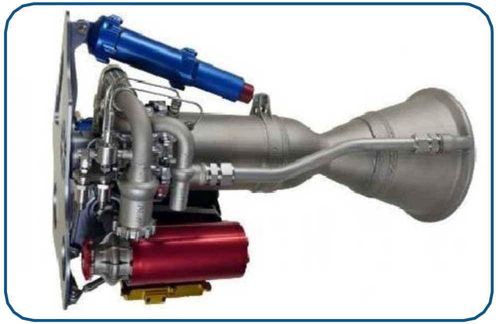
Aerospace & Defense: 

- Environmental Control Systems (ECS):
  - HVAC duct optimization
- Jet Propulsion:
  - Turbine active clearance control, convective cooling of turbine blades
- Rocket Propulsion:
  - Cooling channels around rocket nozzle

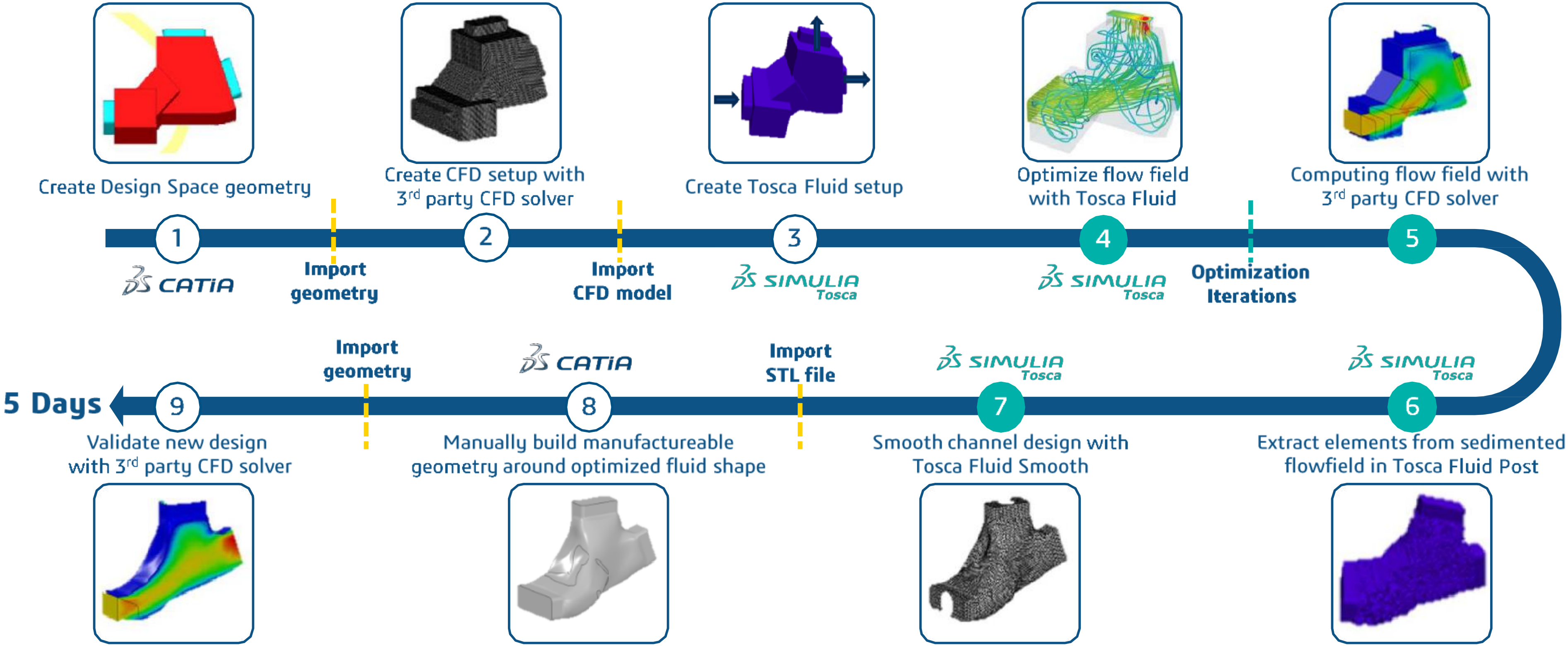






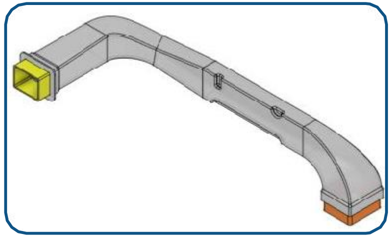


AS IS WORKFLOW

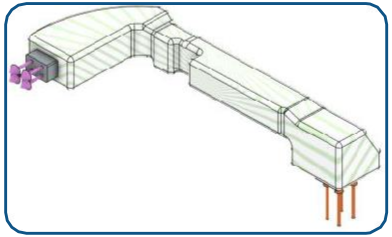


A Automatic M Manual Data translation from one application to another

A FULLY INTEGRATED WORKFLOW

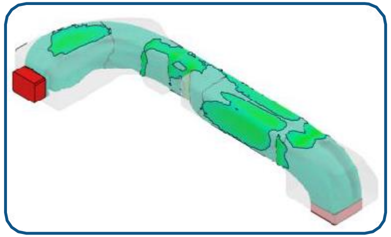


1. Design space geometry creation & seamless preparation for CFD



2. Define setup for CFD & flow optimization within one application

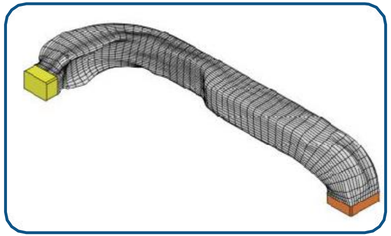
3. Flow field computation & optimization within one application



4. Extract elements from sedimented flowfield

CATIA Flow Driven Gen. Design

5. Automatic exact solid generation



6. Validate new design within same application

0,5 Days

10x faster turn-around-time !!!

- **No** data translations
- **No** software transitions
- **Minimal** user interactions
- **Automatic** solid generation
- **Intuitive** user experience

A Automatic

M Fully integrated within **3DEXPERIENCE Platform**

点阵设计

面向增材制造的设计

利用增材制造带来的可能性创建复杂的设计

性能驱动的创成式设计

自动生成一个或多个满足工程规范的设计解决方案

结构创成式设计

基于结构分析

Functional Gen. Design

流体创成式设计

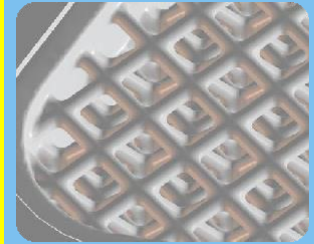
基于流体仿真

Flow Driven Gen. Design

点阵设计

用点阵结构填充设计以减轻其重量或者实现功能性设计

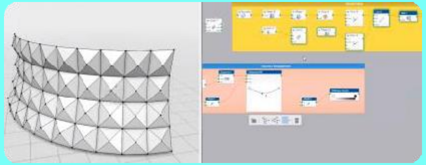
Lattice Design



算法创成式设计

基于脚本的方法，生成的形状取决于用户规范

xGenerative Design

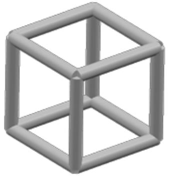


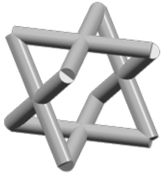
Lattice Design

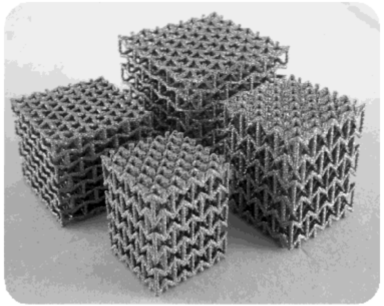
点阵设计

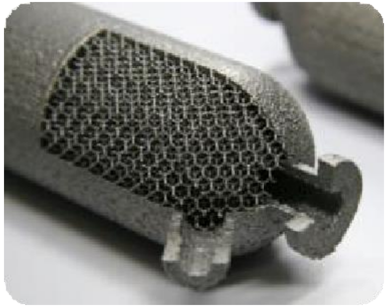
Lattice Design 应用的当前范围：：

- 3D梁的阵列
- 梁是具有恒定半径的圆柱形（截至今天）
- 阵列是在多个方向上复制（截至今天）









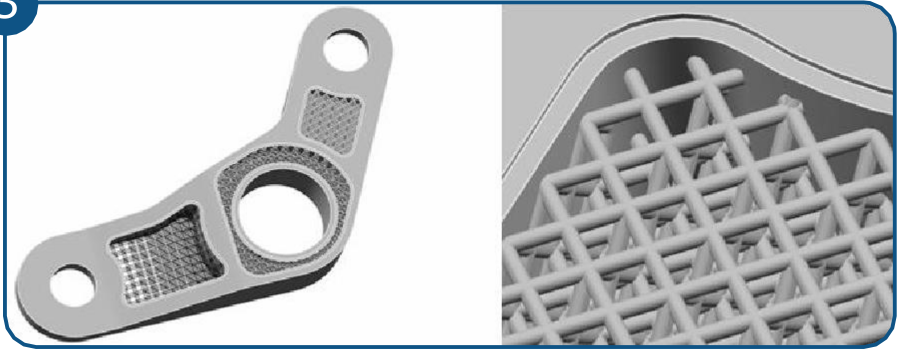
点阵设计流程

1

要填充点阵的几何

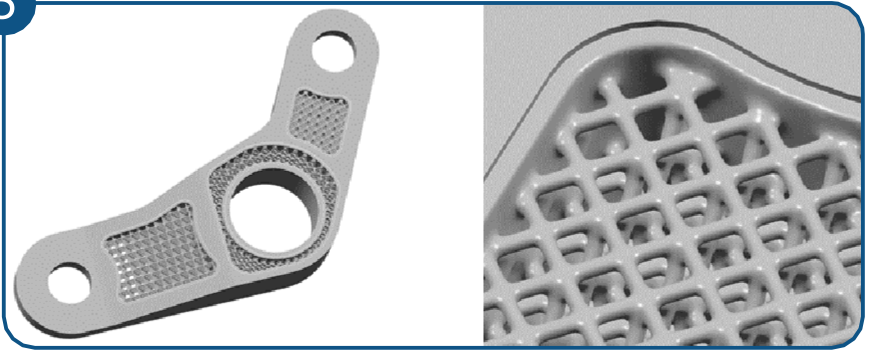
2

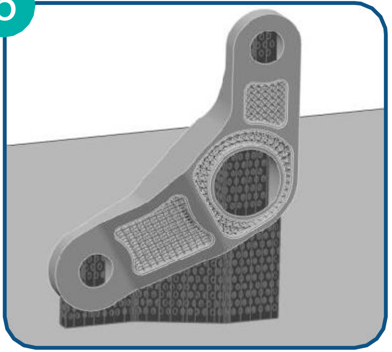
定义点阵区域

3

点阵结构的轻量化展示

4

CAE分析

5

点阵结构倒角

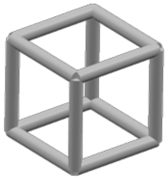
6

点阵结构的工艺规划

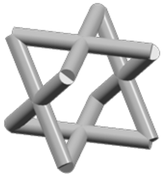
Not included in **Lattice Designer** (LTX)

点阵区域定义和点阵参数定义

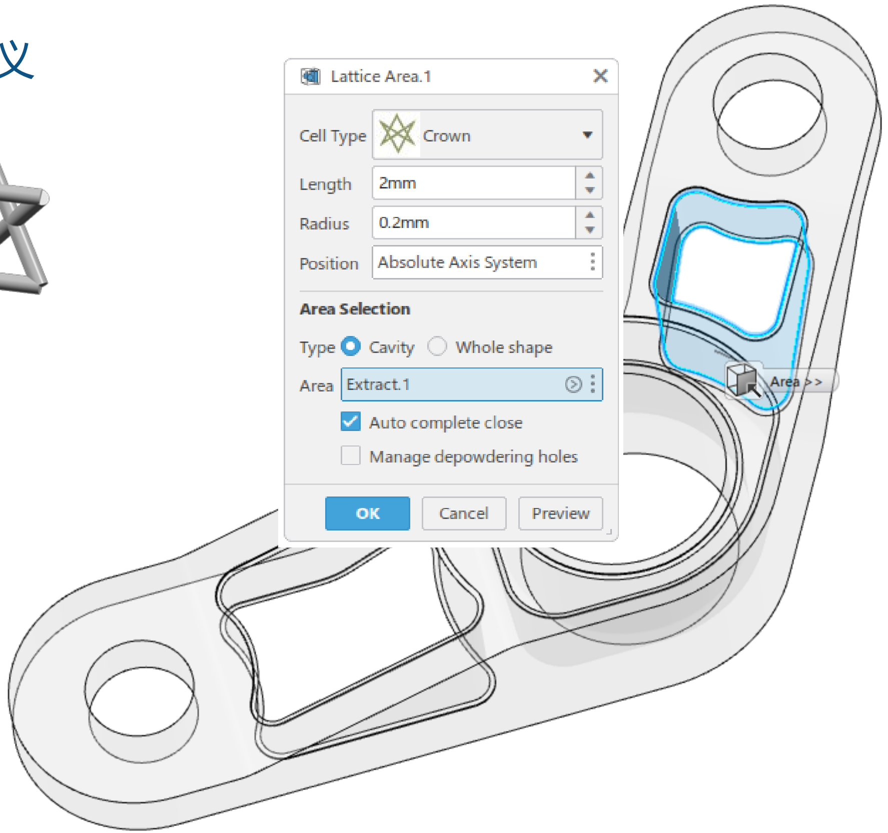
用户可以选择一个或多个区域来填充 Lattice 并定义 Lattice 参数：

- 单胞类型
- 尺寸
- 取向和位置





每一个点阵区域可以有不同的参数



无缝集成CAE验证

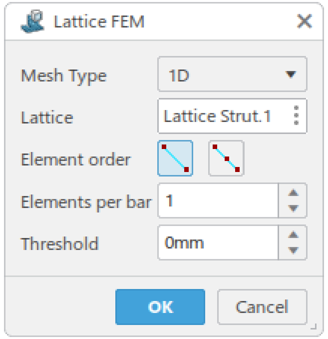
点阵结构的有限元模型可以自动创建:

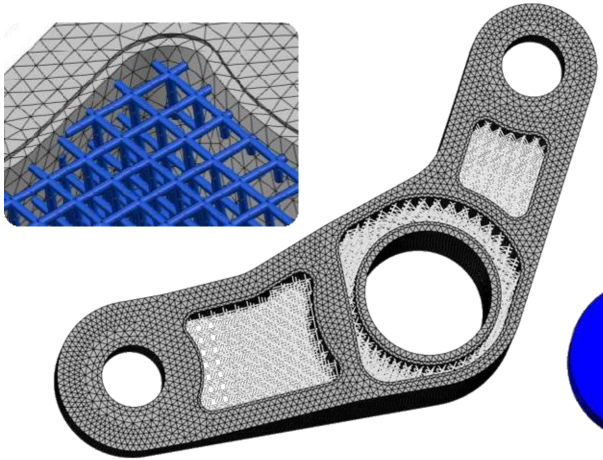
•创建梁单元**Beam（1D）Elements**

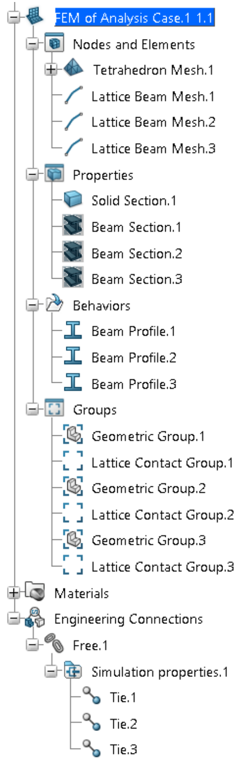
•自动创建 点阵与实体的**Tie 连接关系**

•与点阵结构保持全面关联，只要lattice参数修改，有限元模型也会自动更新

点阵结构的有限元模型可以进行结构性能仿真



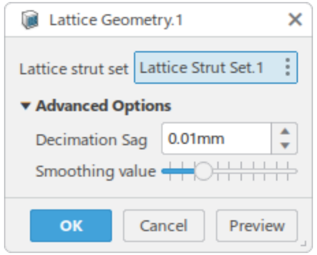


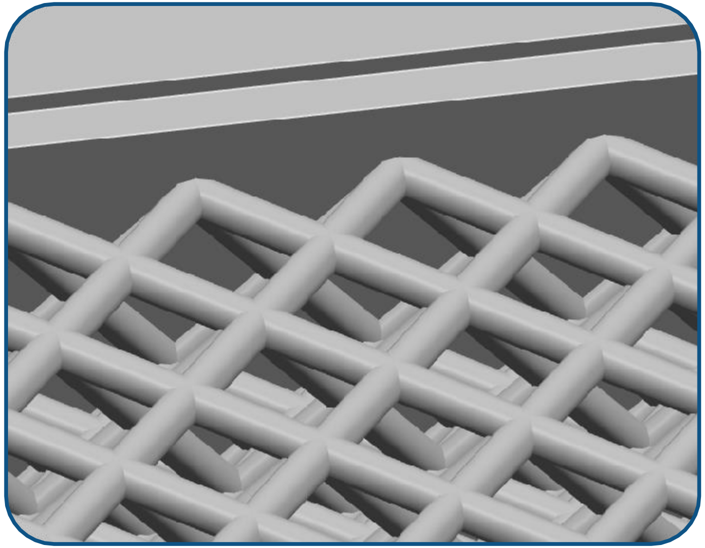


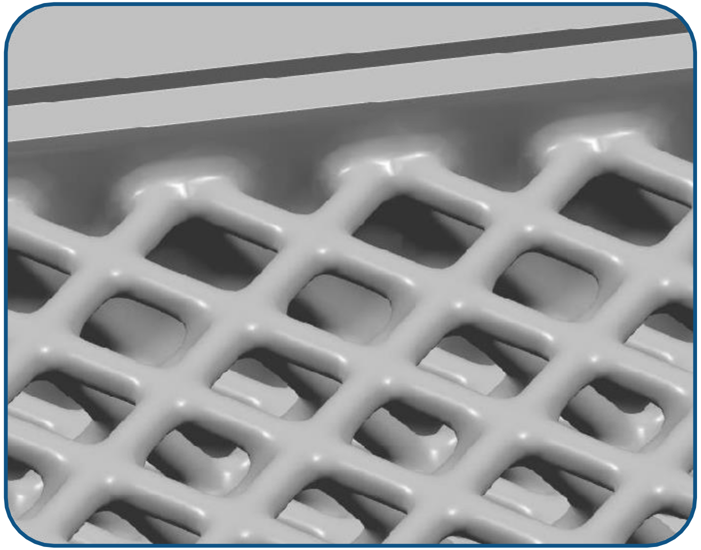
点阵结构的倒角处理

把轻量化模型转成光顺多面体几何结构:

- **混合Blending** 了杆之间和杆与实体之间的区域
- 自动移除孤立杆



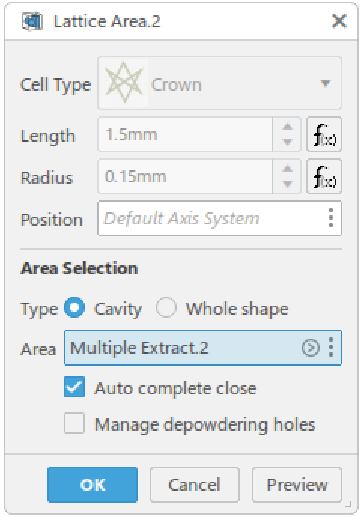


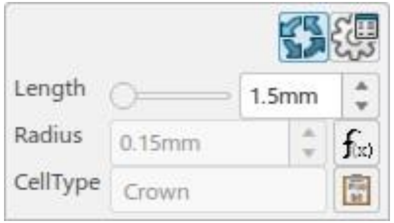


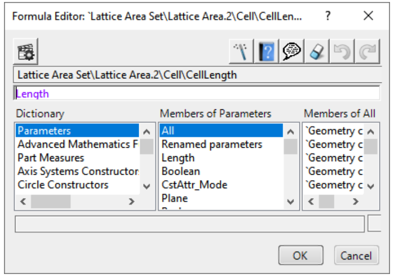
与CATIA的知识工程保持兼容性

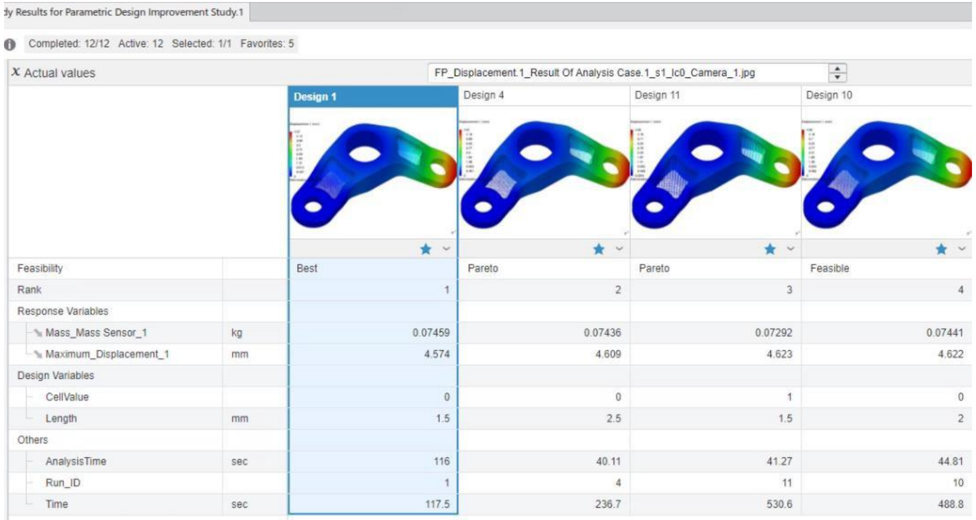
多有点阵结构的参数都可以关联到**CATIA Knowledge 的参数化工具**:

- **可以轻松快速地修改点阵形状、尺寸、方向、位置…**
- 可以进行实验设计(DoE来进一步改善性能





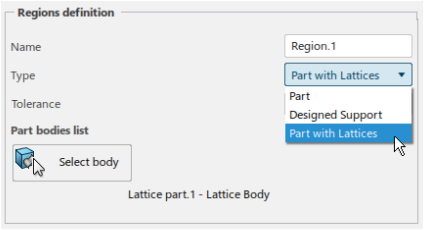


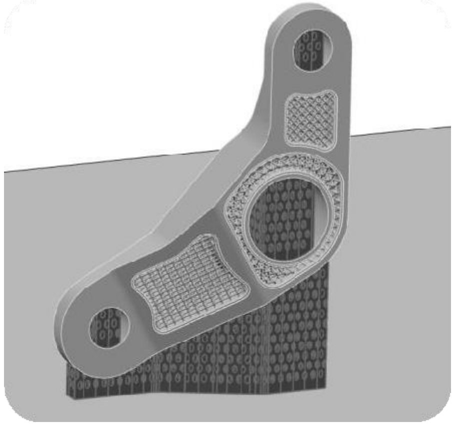


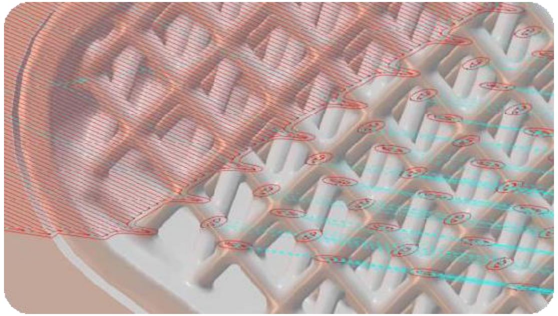
为制造做准备

接下来填充好的点阵结构可以直接用在粉末床工艺规划中:

- 不需要数据交互和转化，并且保持关联性
- 零件被自动标记为“带格子的零件”-> 在方向优化期间忽略格子区域或支持计算以保持流畅的体验



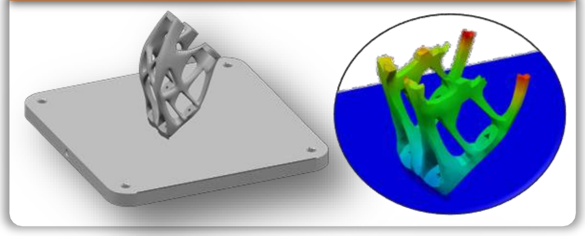




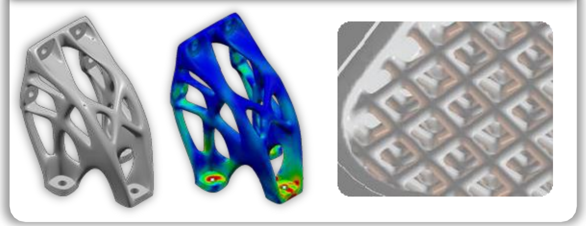
对于外部使用，点阵和零件几何可以导出为 STL、AMF 或 3MF 格式的高质量和封闭网格

策略 | 数字连续、基于科学

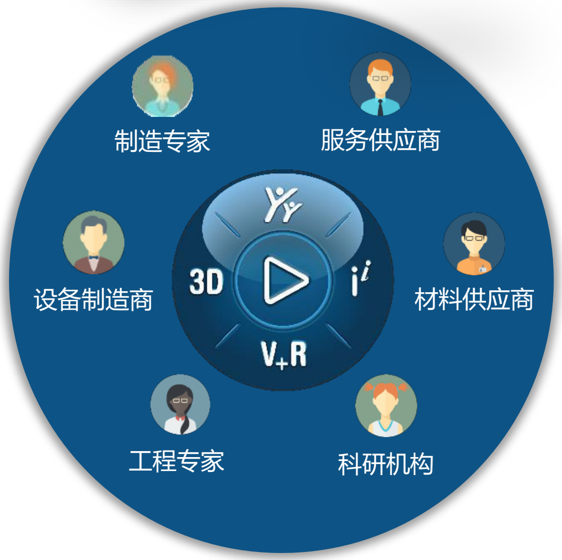
3 工艺规划和工艺过程仿真



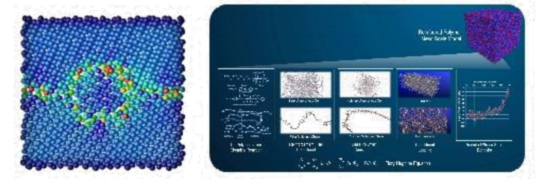
2 面向增材制造的设计



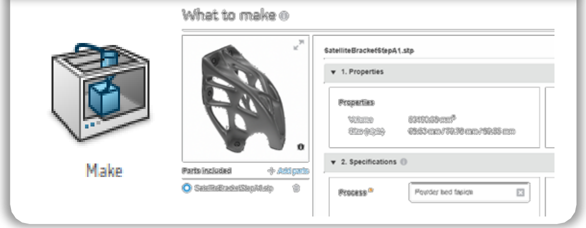
4 Global Production System



1 材料基因工程

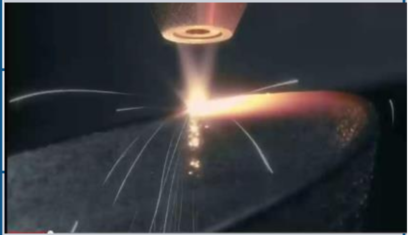


5 3DEXPERIENCE Marketplace



...拥有众多机器和技术

增材制造技术	金属	非金属	其他材料
Powder Bed Fusion (Thermal energy selectively fuses regions of a powder bed)	Processes : Selective Laser Melting, Direct Metal Laser Sintering, Electron Beam Melting Machines : AddUp, EOS, Renishaw, SLM...	Processes : Selective Laser Sintering, Selective Laser Printing, ... Machines : EOS, 3D Systems, Renishaw...	
Binder Jetting (A liquid bonding agent is deposited to join powder materials)	Processes : Binder Jetting Machines : ExOne, Desktop Metal, HP...	Processes : 3D Printing Machines : Voxel Jet...	
Directed Energy Deposition (Focused thermal energy fuses materials as they are deposited)	Processes : Laser Engineered Net Shape, Laser Deposition, ... Machines : BeAM, Trumpf, DMG, Optomec...		
Material Jetting (Droplets of Build Materials are selectively deposited)		Processes: PhotoPolymerization Jetting Multi Jet Modeling, Multi-Jet Fusion Machines : Stratasys, 3D Systems, HP...	
Photo Polymerization (Liquid photopolymer is selectively cured by light-activated polymerization)		Processes : StereoLithography, Digital Light Processing Machines : 3D Systems, Envisiontec...	
Material Extrusion (Melted Materials are dispensed through a nozzle)		Processes : Fused Deposition Modeling Machines : Stratasys, Markforged...	
Sheet Lamination (Sheets of material are bonded to form an object)	Processes : Laminated Object Modeling, Ultrasonic Consolidation Machines : MCOR, Fabrisonic...		

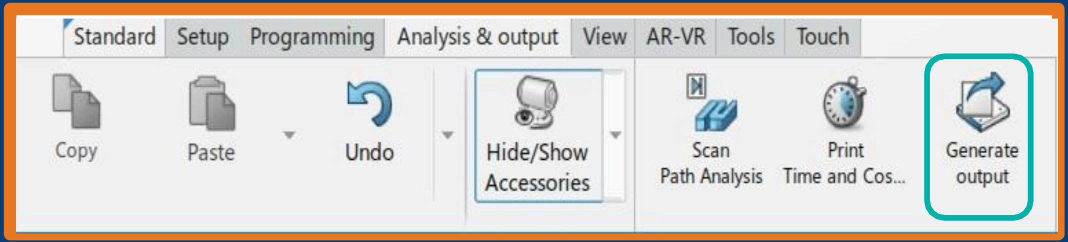


Available within 3DEXPERIENCE

分析 & 输出

分析 & 输出

导出



- 通过导出功能，能输出一下格式：
  - STL
  - AMF
  - 3MF
  - SLC
    - SLiCe format (3D Systems, ARCAM)
  - CLI
    - Common Layer Interface (EOS)
  - MTT
    - 与Renishaw打印机一直的扫描路径格式
- 例如MTT格式能够直接输给 Renishaw的粉末床打印设备

Note:
通过生成必要的机器信息后，用户可以切换到增材制造工艺仿真界面进行基于有限元法的热-**机耦合仿真来**预测整个过程的热历史和翘曲变形、残余应力等

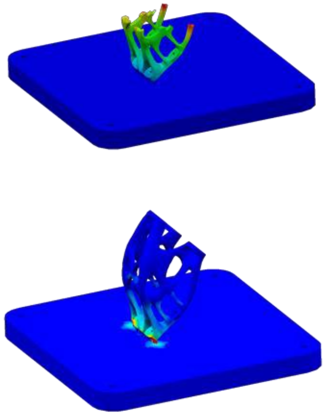
一体化端到端解决方案的必要性

从面向增材制造的设计、制造和仿真在一体化环境中的可扩展的解决方案

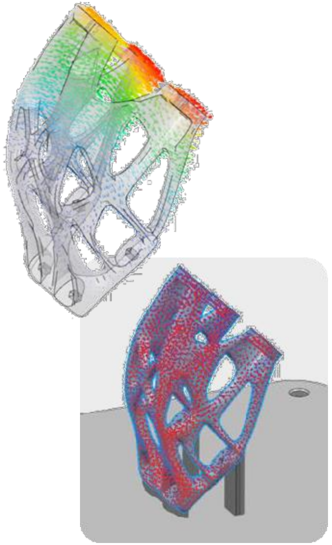
1 增材设计

2 工艺过程规划

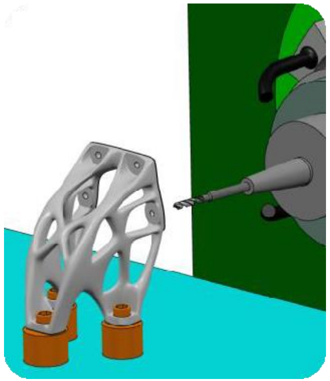
3 工艺过程仿真



4 反变形补偿



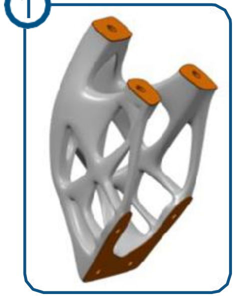
5 后处理



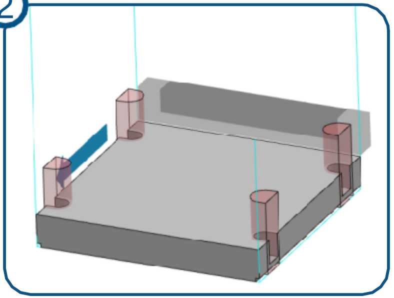
增材制造工艺规划

进行打印机参数的设定、支撑结构的生成和编辑、打印姿态的优化和摆放、切片和激光路径生成以及成本和打印时间预估等

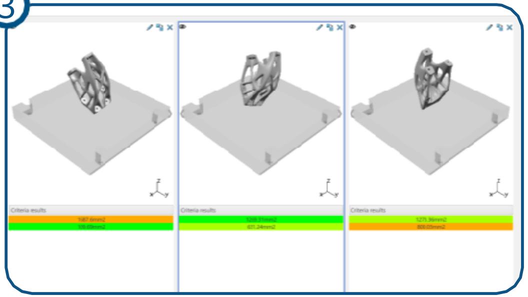
Powder Bed Fabrication



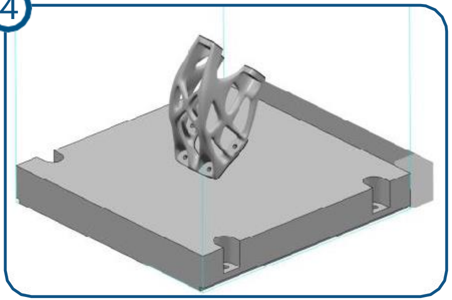
① 部件准备



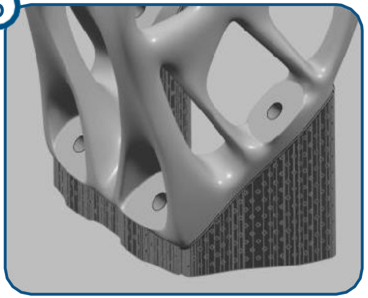
② 工艺重用



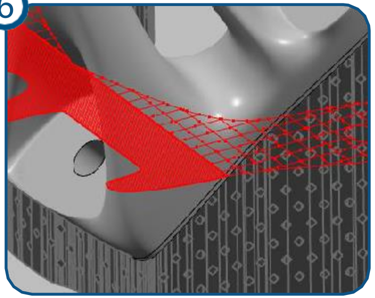
③ 部件选择和姿态优化



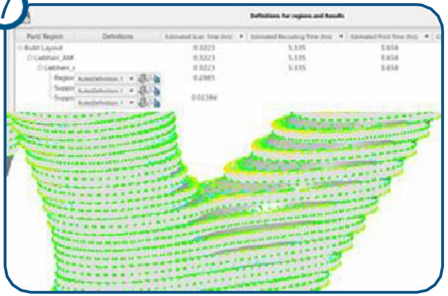
④ 摆放



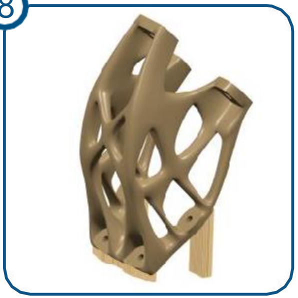
⑤ 支撑结构生成和编辑



⑥ 扫描路径生成



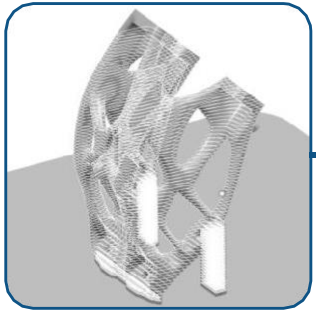
⑦ 扫描路径分析和模拟



⑧ 结果输出

增材制造工艺过程仿真

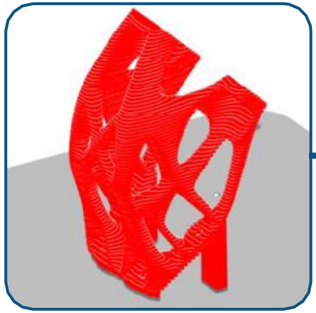
两种不同仿真方法: **固有应变法和热机耦合的有限元法**



只有切片信息

Distortion Checker

- 固有应变法（Eigenstrain）粗略预估翘曲变形
- 快速易用
- 自动生成仿真模型



含有详细的激光路径等信息

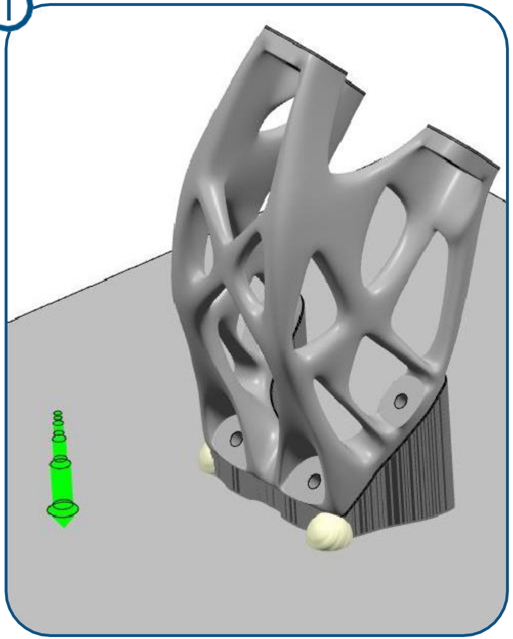
Additive Manufacturing Scenario Creation

- 完全热-机耦合分析
- 更高的准确度
- 适合复杂问题

固有应变法

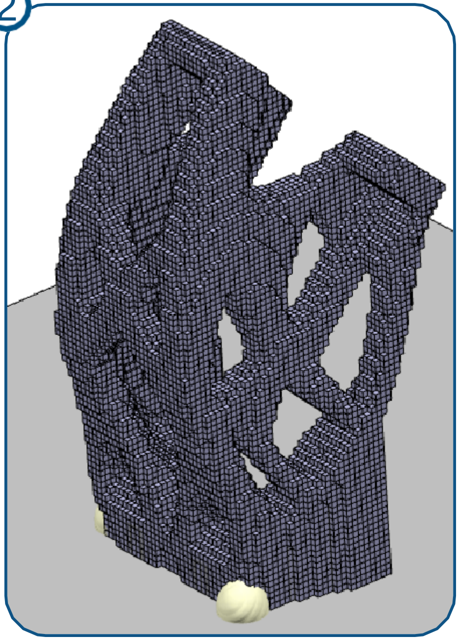
针对非专家想粗略预估一下翘曲变形:

1



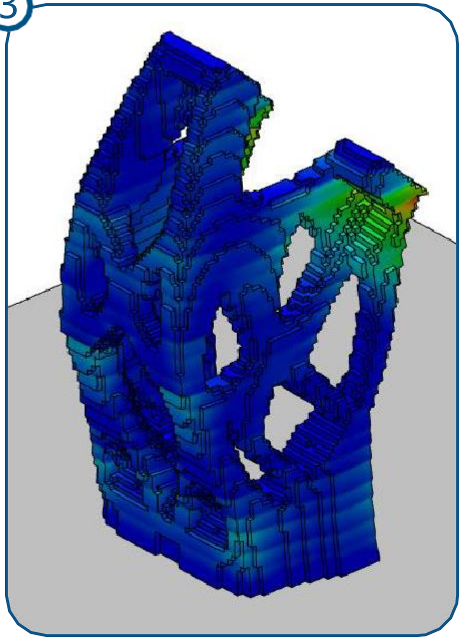
自动仿真设置

2



自动体素元网格划分

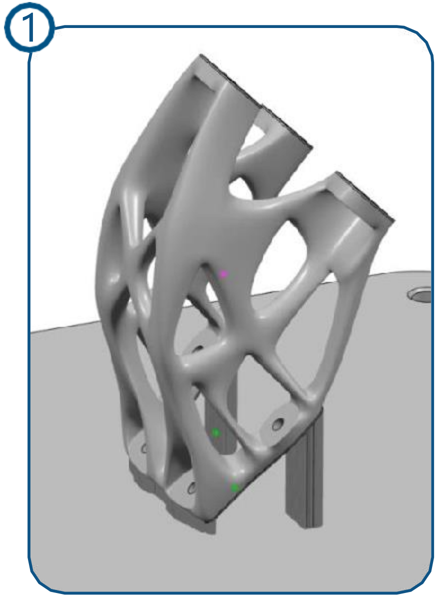
3



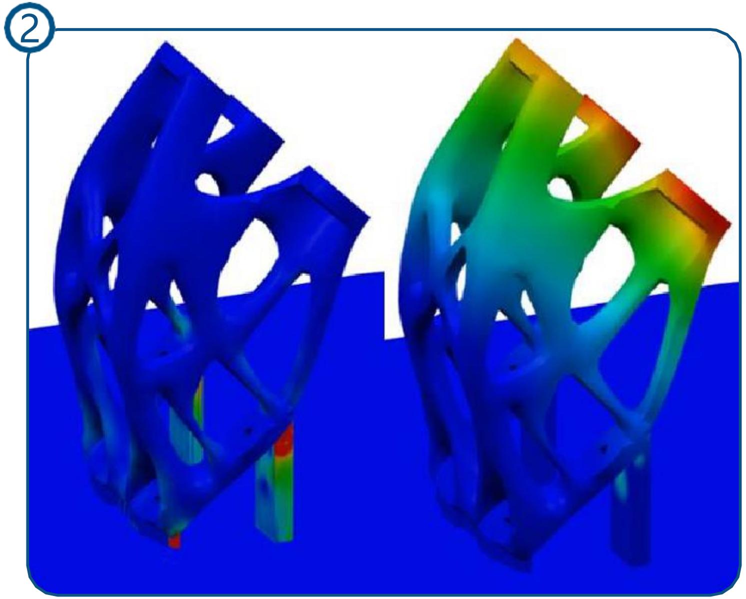
翘曲变形

热-机耦合仿真

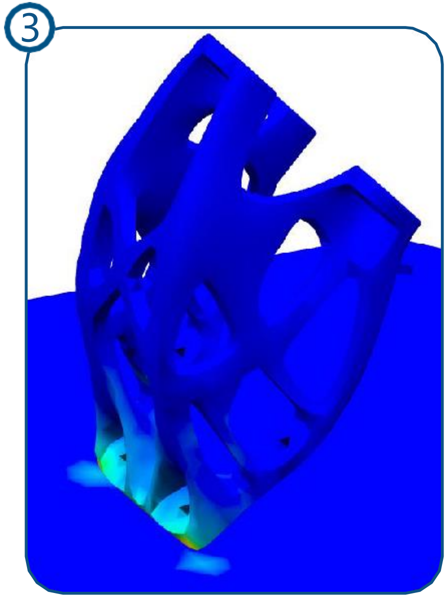
在增材制造打印过程中，针对仿真专家想获得更加真实的更加准确的仿真结果，同时可以考虑热历史:



打印设定



热-机耦合仿真



后处理仿真

达索增材制造解决方案的成功客户案例

增材制造工艺 (Pr)
- FFF
- SLM
- LDED
- FDM™
- EDAM
- MJF™
- SLS

仿真应用 (Ph)
- 温度
- 翘曲变形
- 残余应力
- 微观结构

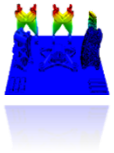
材料 (Ma)

<u>Polymers</u>
- PEI (ULTEM)
- ABS
- PA 11/12
- CFRP

<u>Metals</u>
- Ti-6Al-4V
- Aluminum
- Steel
- Inconel 718
- Inconel 625

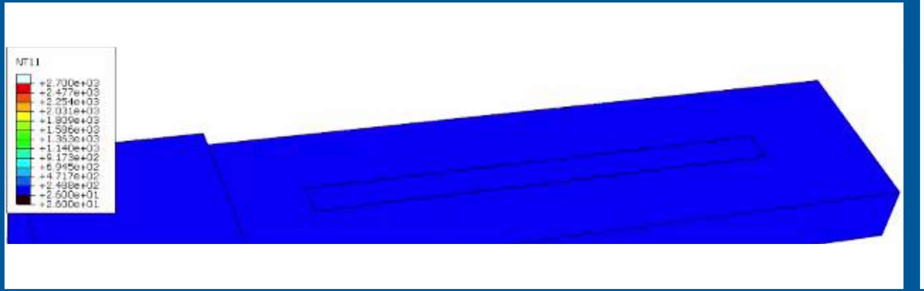
- *Predicting the Properties of Additively Manufactured Parts*, London et al., **TWI**, Science in the Age of Experience, Chicago, May 2017
- *Influence of Surrounding Powder Bed and Build Platform on Thermal Cooling Characteristics in 3D Printed Parts via Selective Laser Melting*, Feih et al., **SIMTech**, Science in the Age of Experience, Chicago, May 2017 (SLM | Selective Laser Melting)
- *Simulation of Residual Stresses and Distortions in a 17-4 PH Part Produced by Laser Powder Bed Fusion*, Galles et al., **ARL**, Science in the Age of Experience, Chicago, May 2017 (SLM | Selective Laser Melting)
- *Process Modeling and Validation for Metal Big Area Additive Manufacturing*, Simunovic et al., **ORNL**, NAFEMS World Congress, Stockholm, June 2017 (LDED | Laser Direct Energy Deposition)
- *Finite Element Simulation of the Fused Deposition Modelling (FDM) Process*, Courter et al., **Stratasys**, NAFEMS World Congress, Stockholm, June 2017
- *Simulation of Polymeric Composites Additive Manufacturing using Abaqus*, Favoloro et al., **Purdue**, Science in the Age of Experience, Chicago, May 2017 (EDAM | Extrusion Deposition Additive Manufacturing)
- *Finite Element Simulation of the Multi Jet Fusion (MJF™) Process using Abaqus*, Fradl et al., **HP**, Science in the Age of Experience, Chicago, May 2017

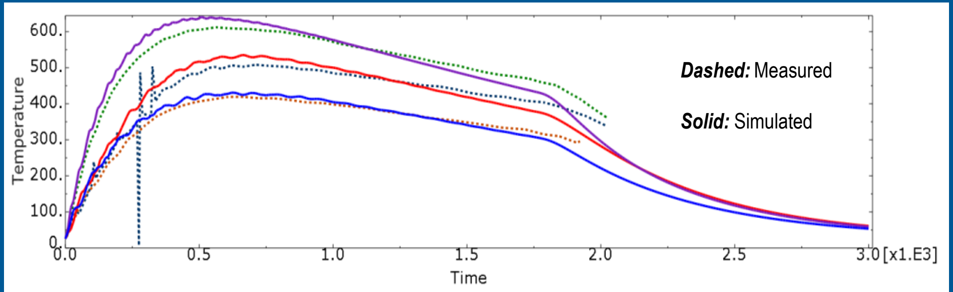
Validations| Summary



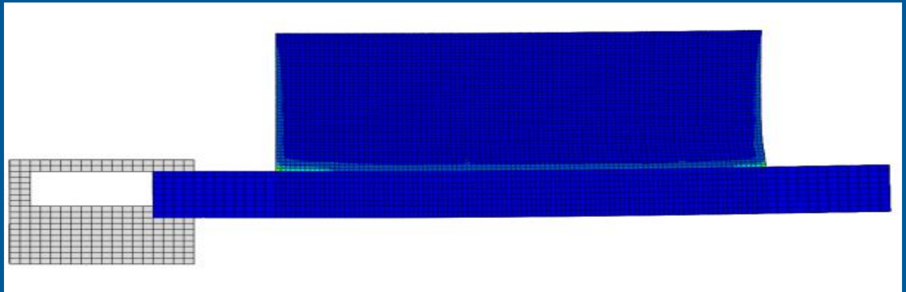
Materials	AM Process Types
Metals: Ti64, Aluminum, Steel, Inconel 718	• Predicting the Properties of Additively Manufactured Parts , London et al., TWI, Science in the Age of Experience, Chicago, May 2017 (SLM | Selective Laser Melting) • Influence of Surrounding Powder Bed and Build Platform on Thermal Cooling Characteristics in 3D Printed Parts via Selective Laser Melting , Feih et al., SIMTech, Science in the Age of Experience, Chicago, May 2017 (SLM | Selective Laser Melting) • Simulation of Residual Stresses and Distortions in a 17-4 PH Part Produced by Laser Powder Bed Fusion, Galles et al., ARL, Science in the Age of Experience, Chicago, May 2017 (SLM | Selective Laser Melting)
Metals: Ti64, Inconel625	• Process Modeling and Validation for Metal Big Area Additive Manufacturing, Simunovic et al., ORNL, NAFEMS World Congress, Stockholm, June 2017 (LDED | Laser Direct Energy Deposition)
Polymers: ULTEM, ABS, carbon fiber reinforced polyphenylene sulfide, carbon fiber reinforced ABS	• Finite Element Simulation of the Fused Deposition Modelling (FDM) Process, Courter et al., Stratasys, NAFEMS World Congress, Stockholm, June 2017 • Simulation of Polymeric Composites Additive Manufacturing using Abaqus, Favoloro et al., Purdue, Science in the Age of Experience, Chicago, May 2017 (EDAM | Extrusion Deposition Additive) • ORNL (BAAM | Big Area Additive Manufacturing)
Polymers: Nylon 11/12	• Finite Element Simulation of the Multi Jet Fusion (MJF™) Process using Abaqus, Fradl et al., HP, Science in the Age of Experience, Chicago, May 2017

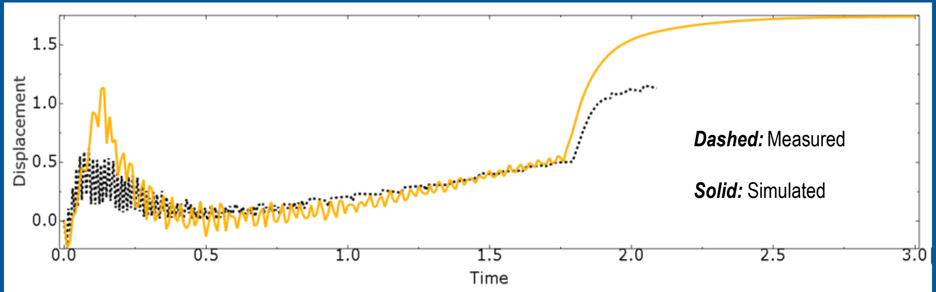
Direct Energy Deposition| Ti-6Al-4V





Thermal History: Abaqus Thermal Analysis correlation with experiments**

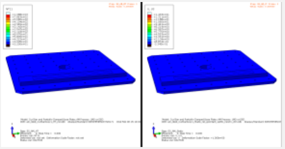


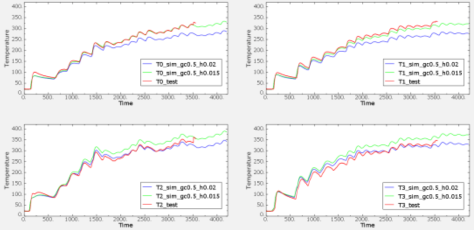


Mechanical Deflections: Abaqus Static Analysis correlation with experiments**

** Denlinger, E. R., Heigel, J. C., Michaleris, P., & Palmer, T. A. (2015). *Journal of Materials Processing Technology*, *215*, 123-131.

Validations| LDED Laser Direct Energy Deposition

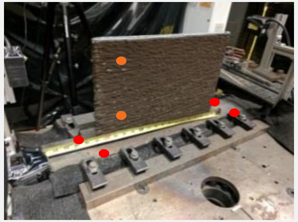


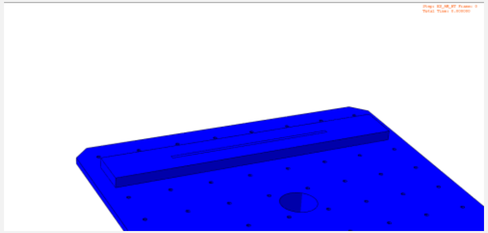


Temperatures: experiment in red + simulation in green

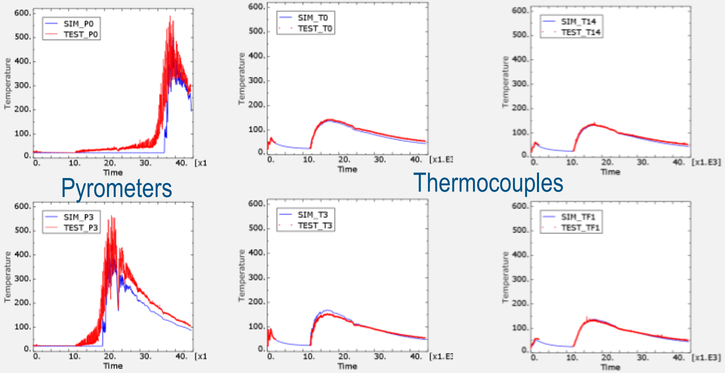
Distortions: experiment in red + simulation in green

Calibration (thermo-couple sensor data) and Validation

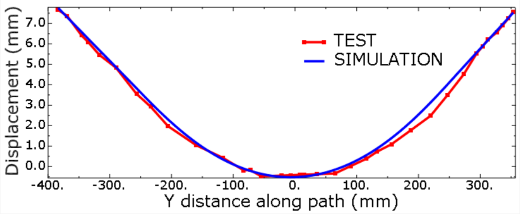




Temperatures: experiment in red + simulation in blue

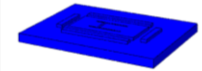


Distortions: experiment in red + simulation in blue



Temperature and distortion prediction

Excavator Arm

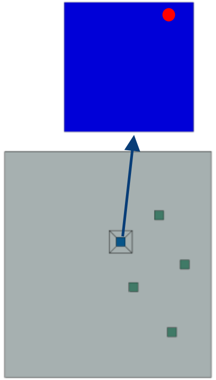


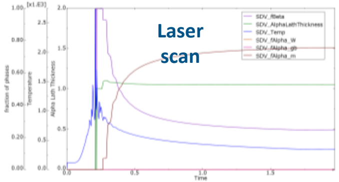
"Process Modeling and Validation for Metal Big Area Additive Manufacturing", Simunovic et al, ORNL, NAFEMS World Congress, Stockholm, June 2017"

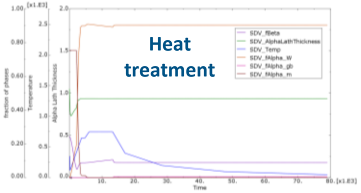
Simulation Validations | TWI

Column Printing Model

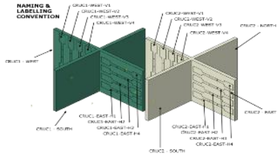
Metallurgical Phase Prediction
- HT analysis
- Phase transformations

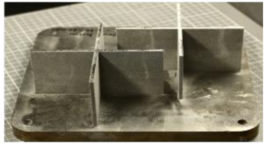






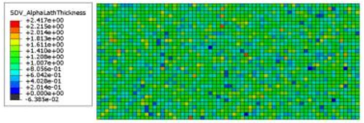
Cruciform Model

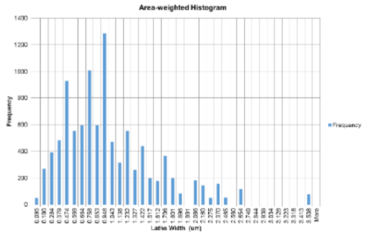


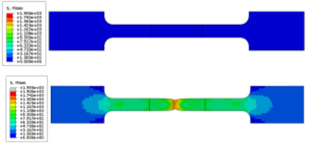


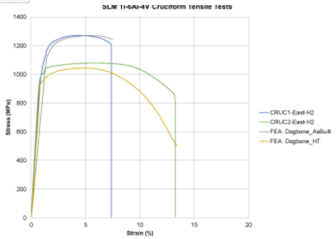
Microstructure Morphology Prediction

Mechanical Property Prediction
- Stress-Strain curves
- Yielding, UTS, etc.







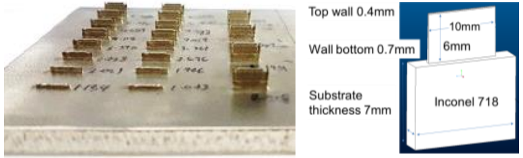


"Validation of a Generic Metallurgical Phase Transformation Framework Applied to Additive Manufacturing Processes" T. London et al., Science in the Age of Experience, Boston, June 2018

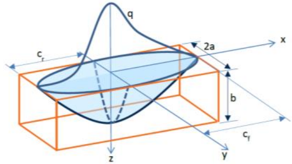
Simulation Validations | SIMTech

Utilizing the Abaqus AM module for LDED and SLM process evaluation

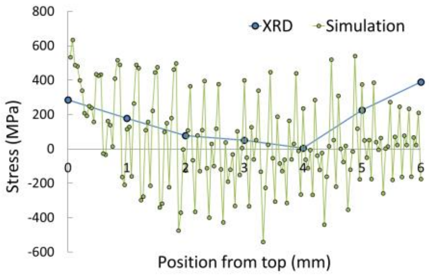
Direct Energy Deposition of thin wall



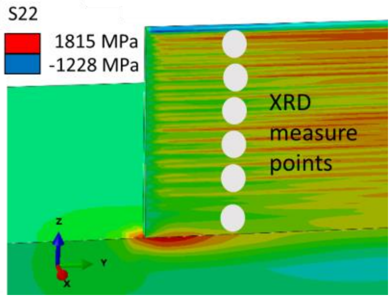
Goldak model



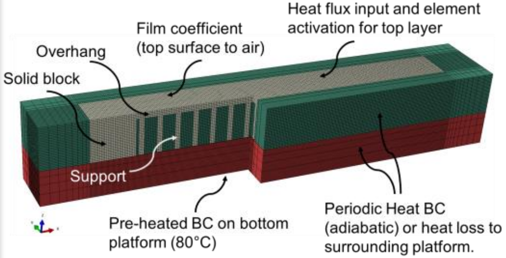
Comparison of residual stresses between simulation and XRD



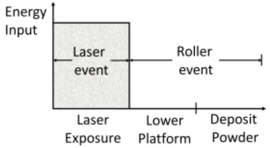
Stress contour in Y-direction with intra-layer variation



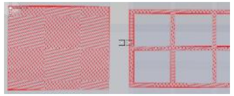
Thermal SLM model with powder bed



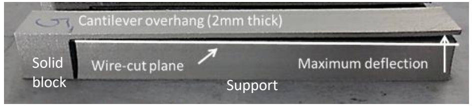
Event series definition



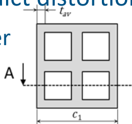
Laser path programming



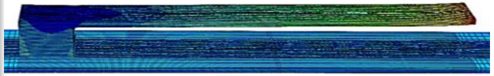
Structural SLM model with removed support to predict distortion



Cantilever with support



Support structure unit cell



Support thickness controls distortion

Support thickness (mm)	Max. displ. prediction (mm)
0.4	4.5
0.7	3.2
1.6	2.3

“Advances in AM Process Simulation: Residual Stress Predictions for Laser Direct Energy Deposited Thin Components and Overhanging Structures Manufactured via Selective Laser Melting” S. Feih et al., Science in the Age of Experience, Boston, June 2018

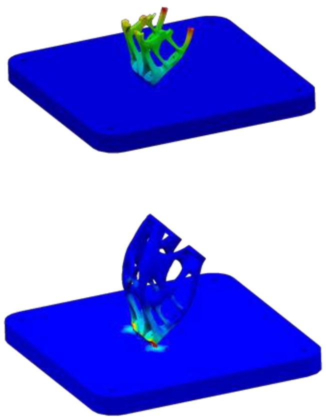
一体化端到端解决方案的必要性

从面向增材制造的设计、制造和仿真在一体化环境中的可扩展的解决方案

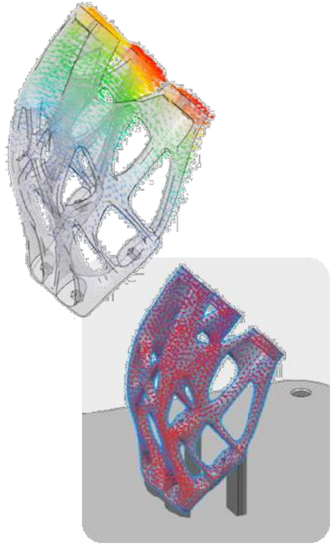
1 Design for AM

2 Process Preparation

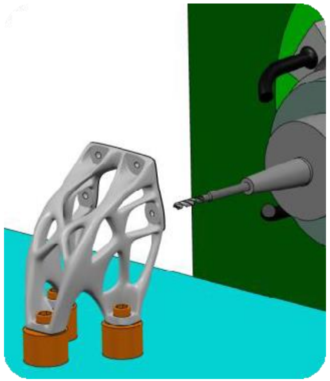
3 Process Simulation



4 Shape Compensation



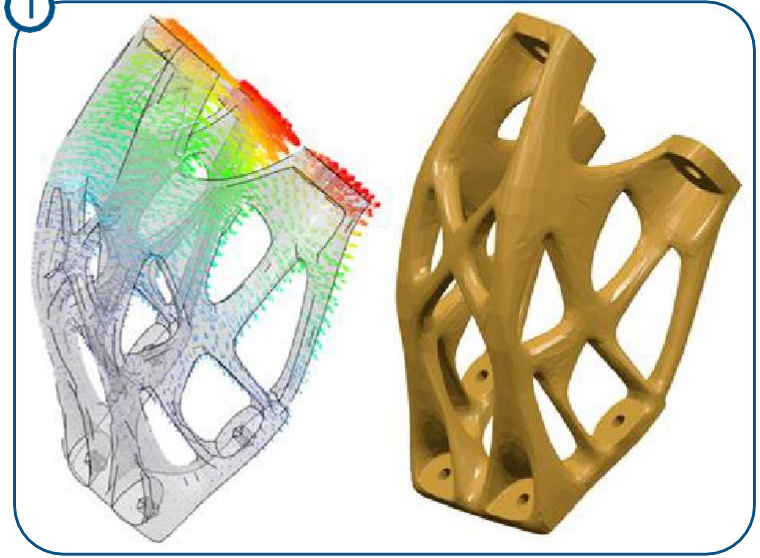
5 Post-Processing

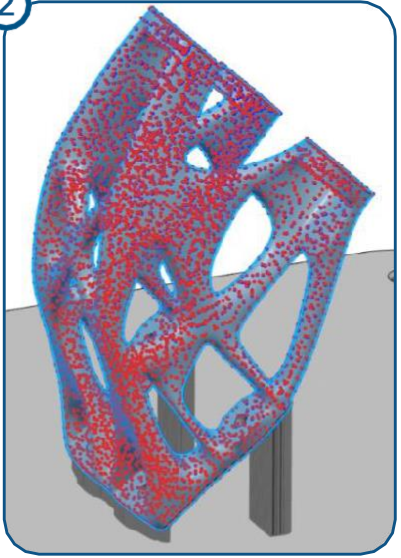


反变形补偿

Print the wrong part to get it right based on simulation results or 3D scan:


Virtual to Real Shape Morphing

①

Displacement Vectors coming from Simulation or from a Scan

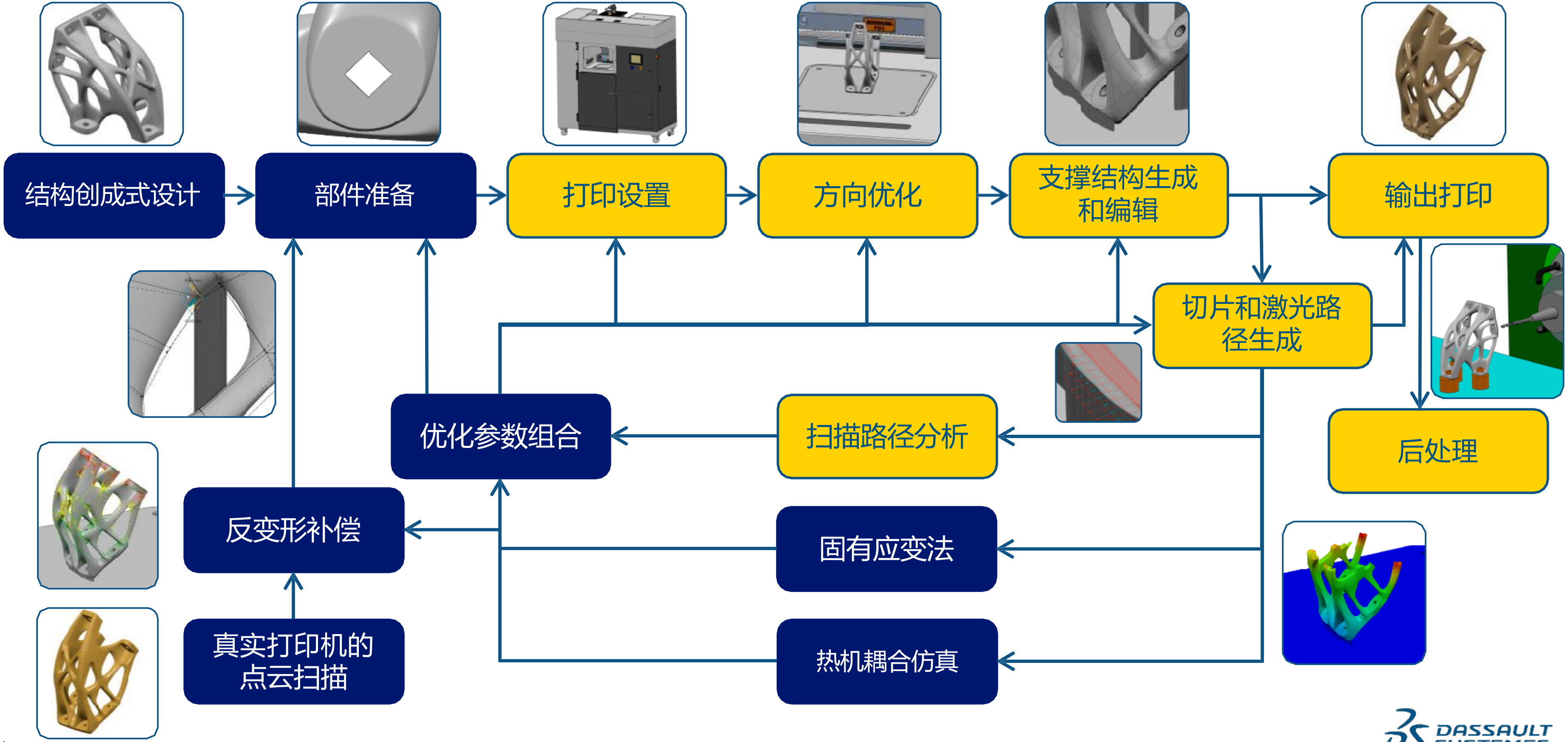
②

Vectors Field Positioning

③

Global Morphing

DASSAULT SYSTEMES

增材制造全流程



DASSAULT SYSTEMES

IF WE™