# The design process and how it is changed by Additive Manufacturing

Prof. Richard Bibb

DDMC, Berlin, March 2016

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# Introduction

**Professor of Medical Applications of Design**

BSc Industrial Design 1995
PhD Rapid Prototyping Selection 1999

Design, CAD, 3D Scanning and Additive Manufacturing research since 1995
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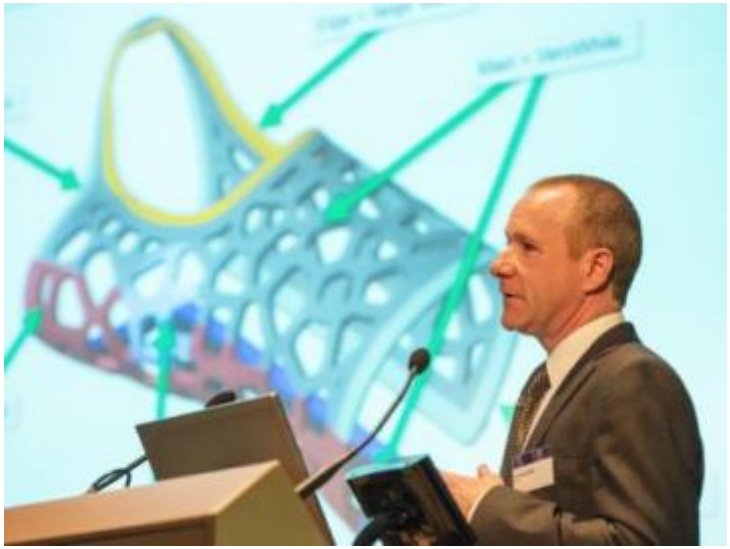

Leader of the **Design for Digital Fabrication** research group
http://www.lboro.ac.uk/departments/lds/research/groups/d4df/
*7 Academics; 3 Research Associates; 10 PhD students*

Member of Loughborough University's **Additive Manufacturing Research Group**
http://www.lboro.ac.uk/research/amrg/amrg-group/


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# Introduction



This presentation is based in part on work conducted in the EPSRC funded project “Design for Additive Manufacturing” (EP/N005953/1)



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# Introduction

Most 3D printing products have been single part decorative, art, craft, homewares.

Most D4AM stuff has been engineering design at the component level


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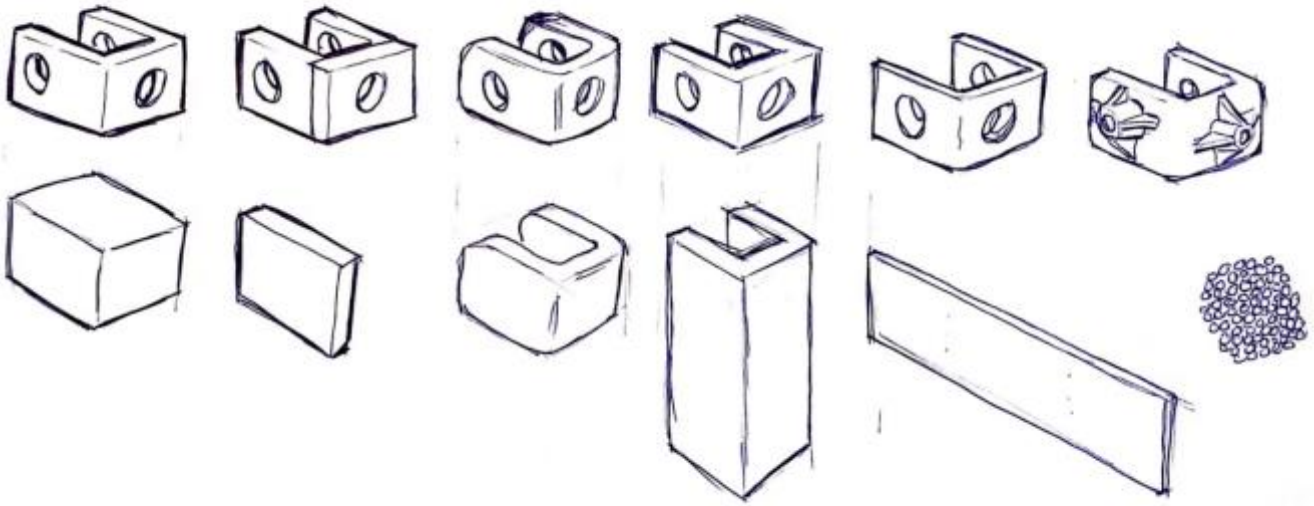
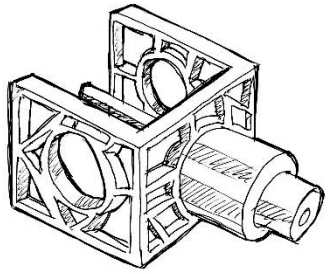
# Introduction

What about normal, everyday products and components?





**AM?**



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# Introduction

- **Myths**
- you can’t 3D Print “anything”
- you don't have complete “design freedom”
- AM will not replace every other manufacturing process

- **My aim**
- AM to be a mainstream manufacturing option with an equal place the range of available manufacturing processes


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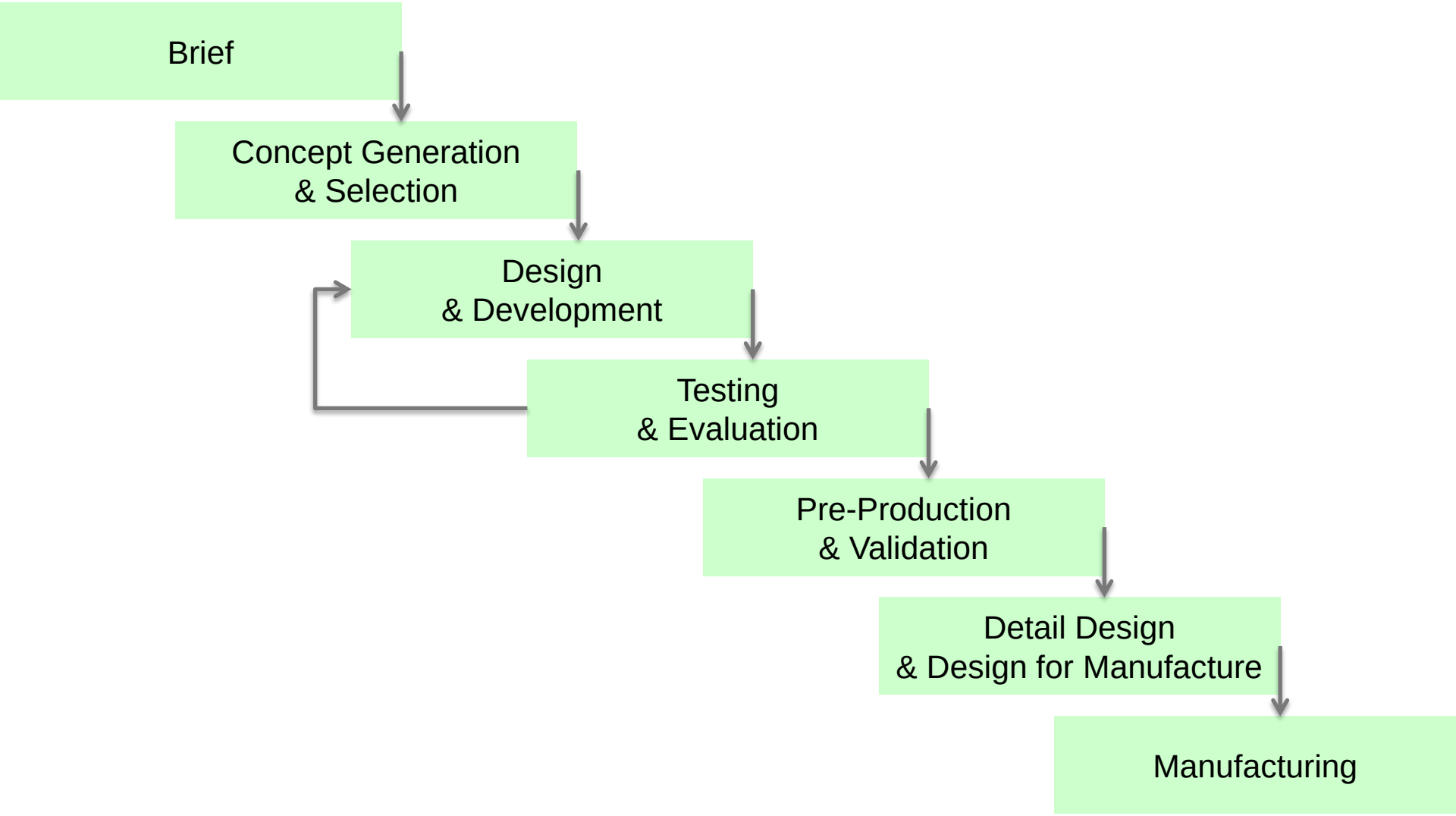
# Product Development Process



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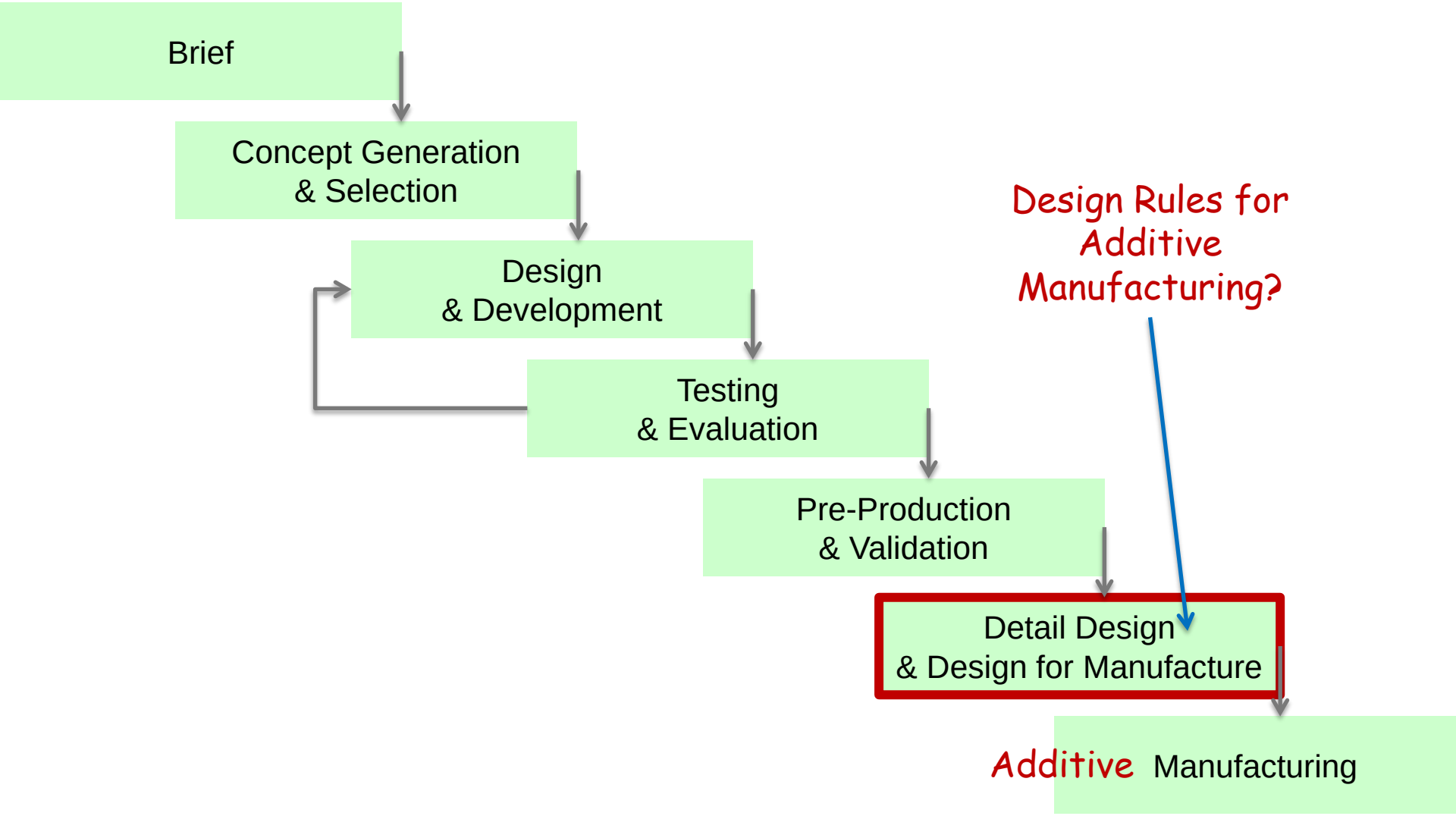
# Product Development Process



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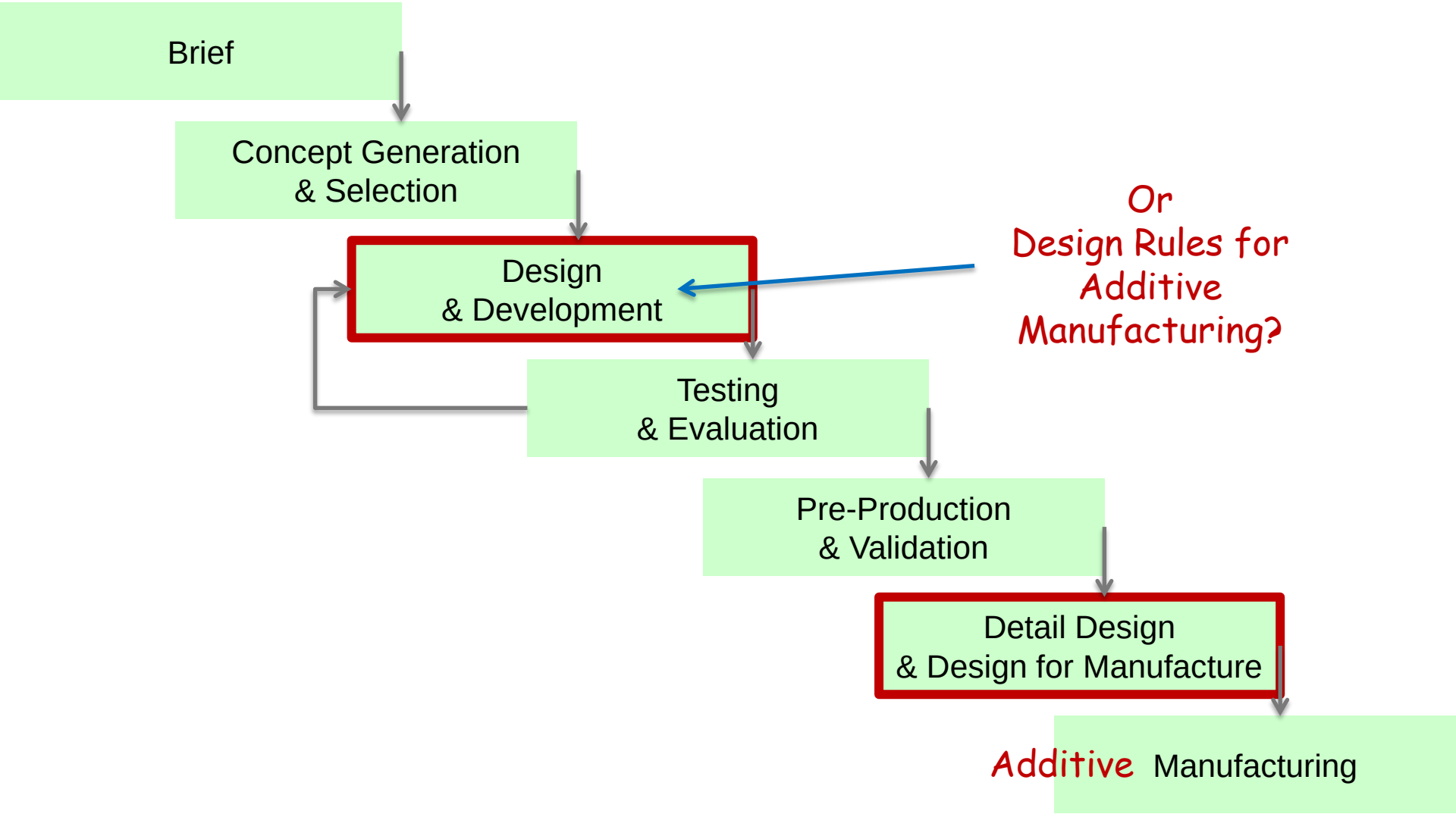
# Product Development Process



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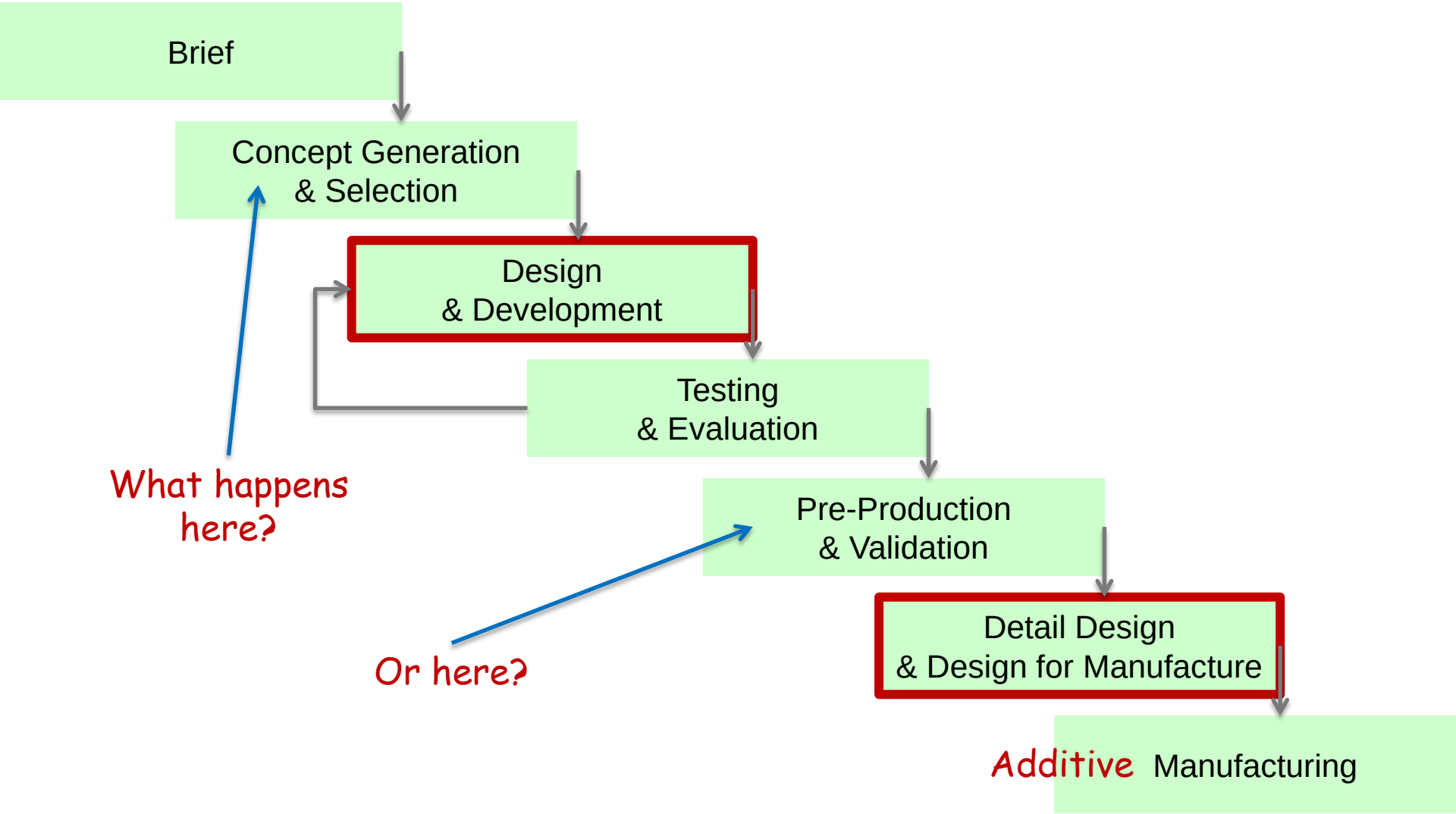
# Product Development Process



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# Possible Impacts

The main design impacts on the design process or practice

1. Design thinking and prioritisation
2. Design Tools
3. Design process, procedure and control
4. Separating designing from making


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# Design Rules

**When is a design rule a design rule?**

- When it is not a 3D Printing rule
- When it is not a manufacturing rule
- When it is not a specification


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# Design Rules

**For example: FDM and in-fill**

- Not created by the designer
- Not controlled by the designer
- Does the designer even know about it?
- Is an assumption better than redesigning the part?
- What about design intent, speed, materials use, strength, stiffness, robustness, etc?


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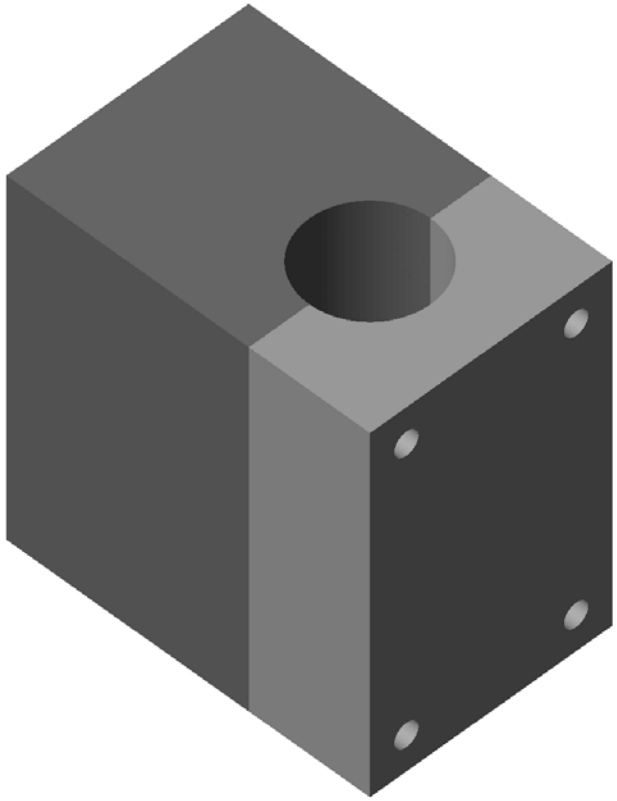

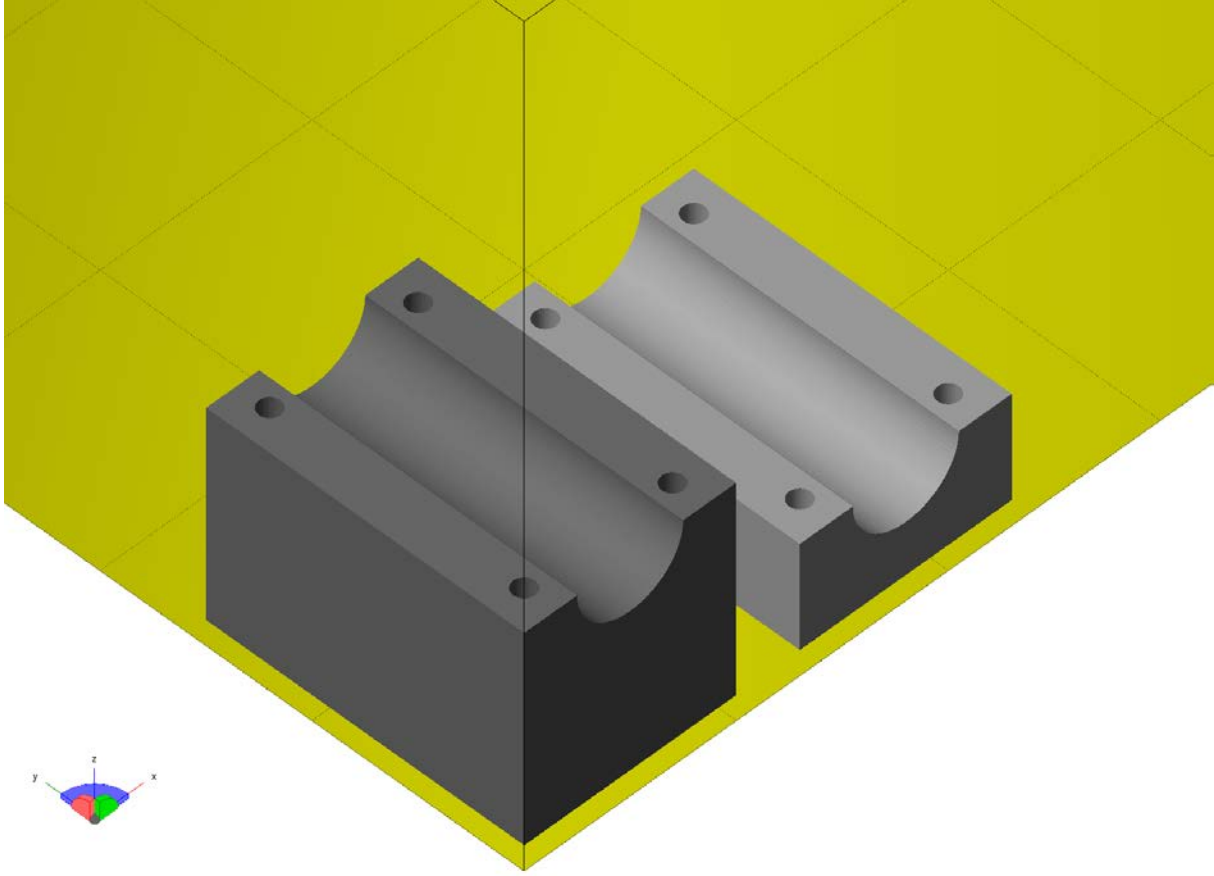

This obeys 3D Printing rules!

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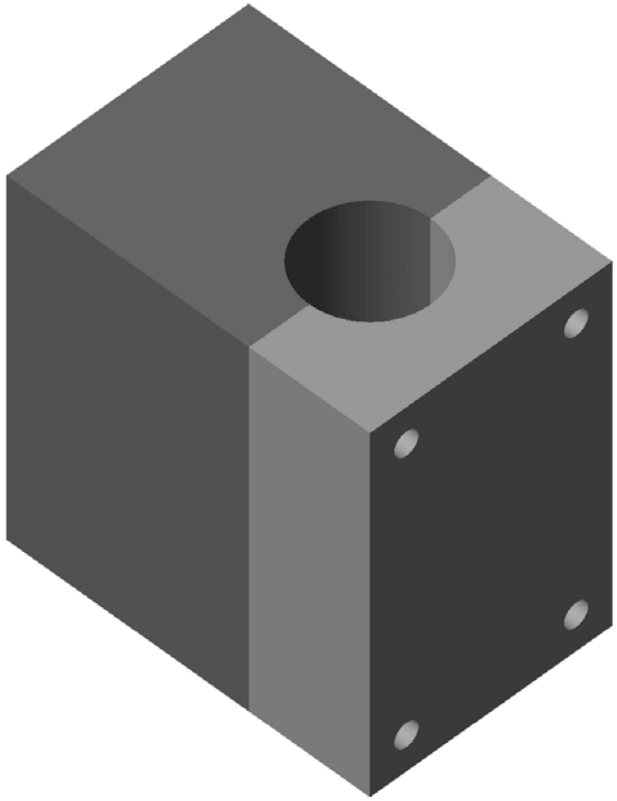
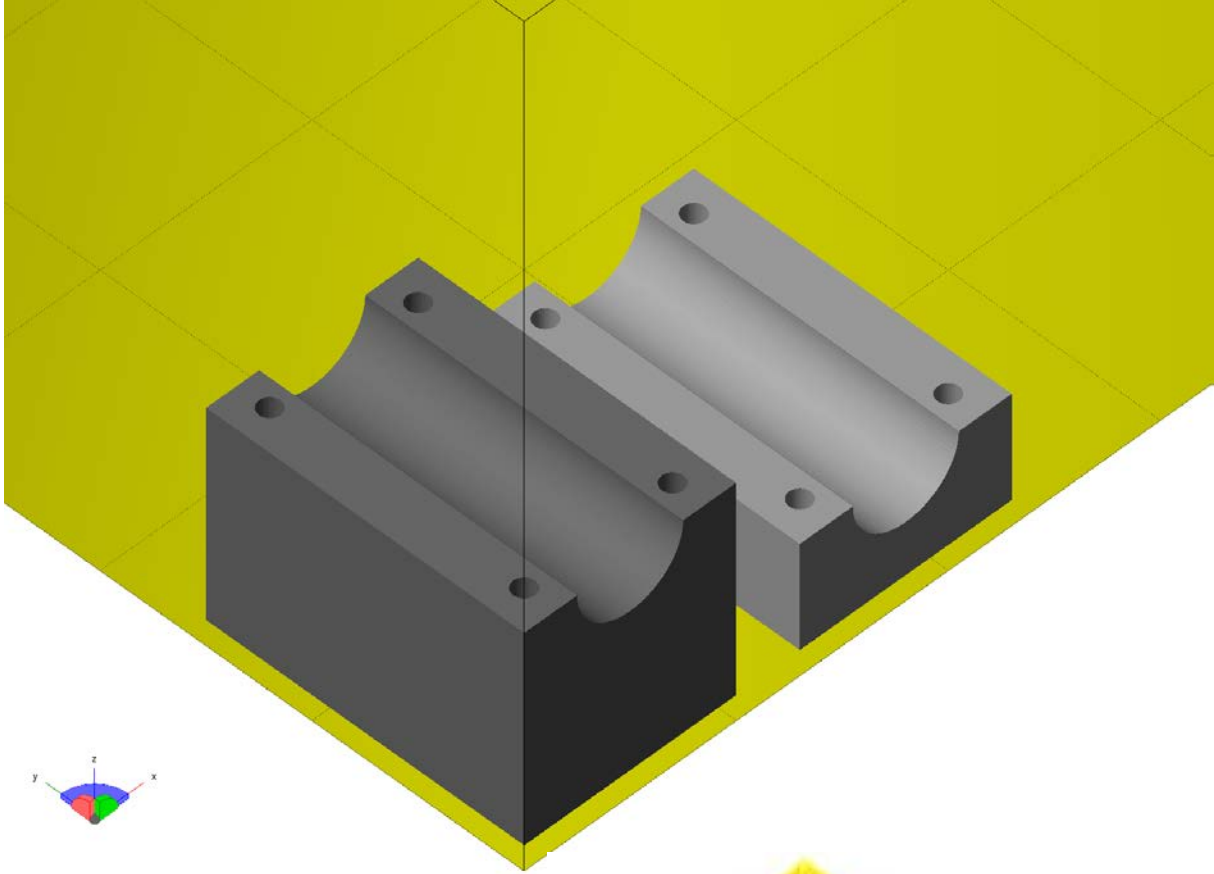
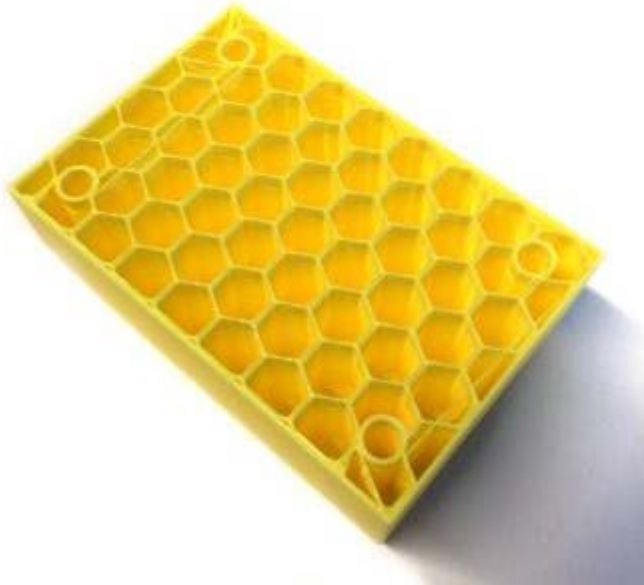






But what about in-fill?



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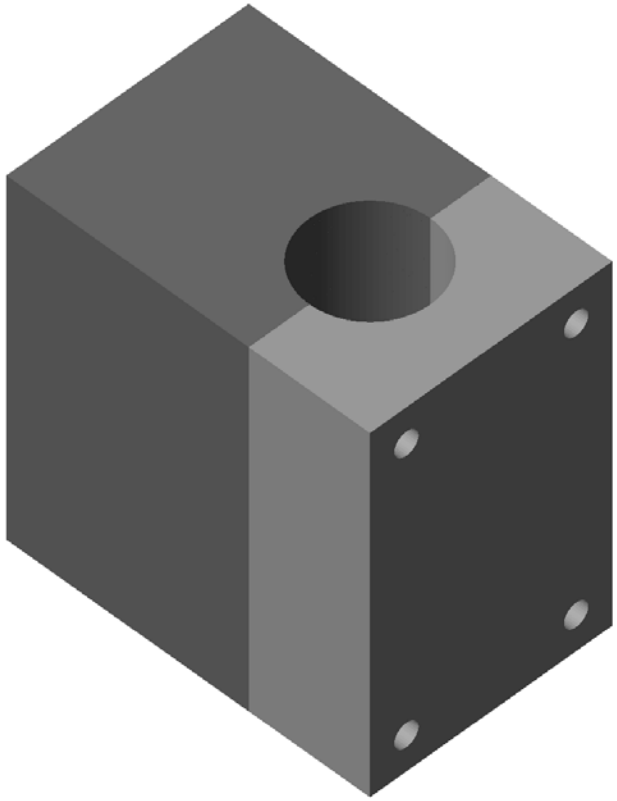
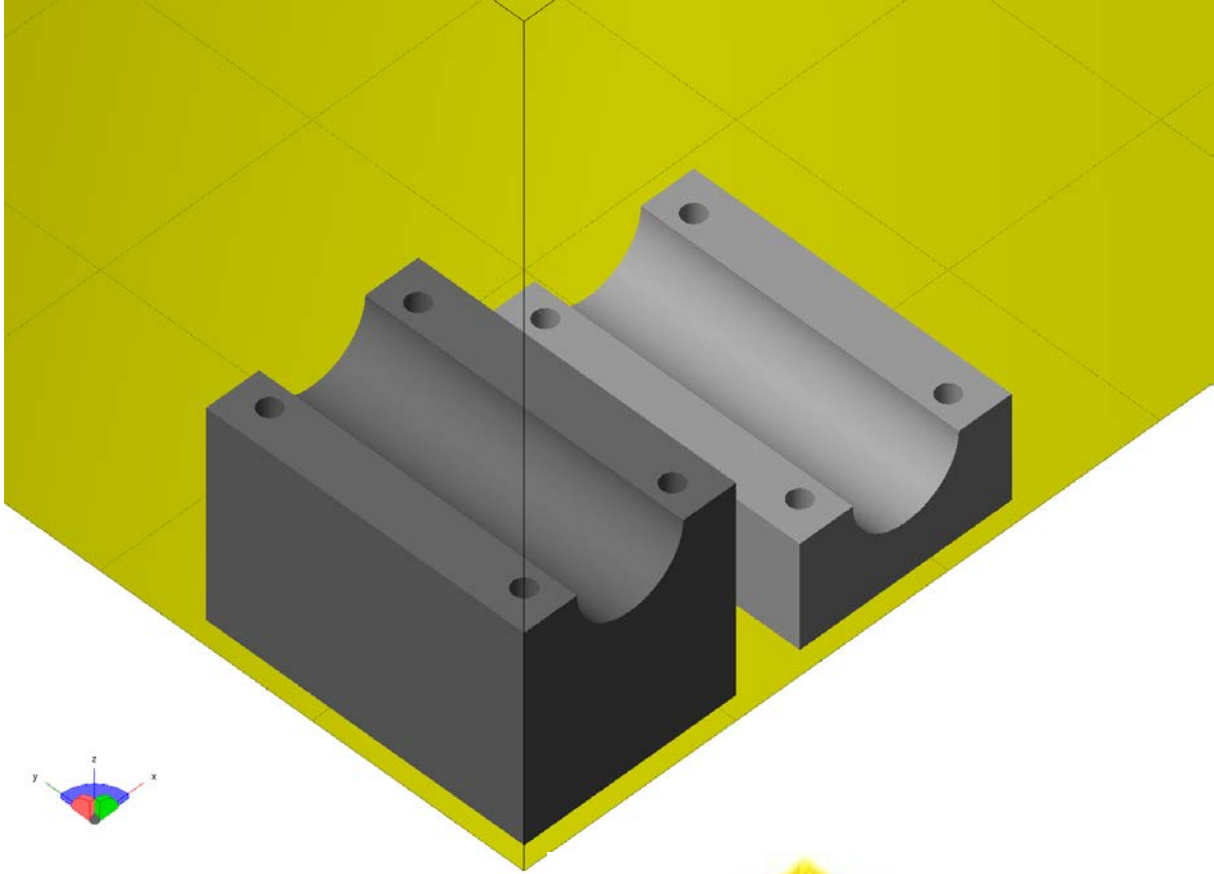
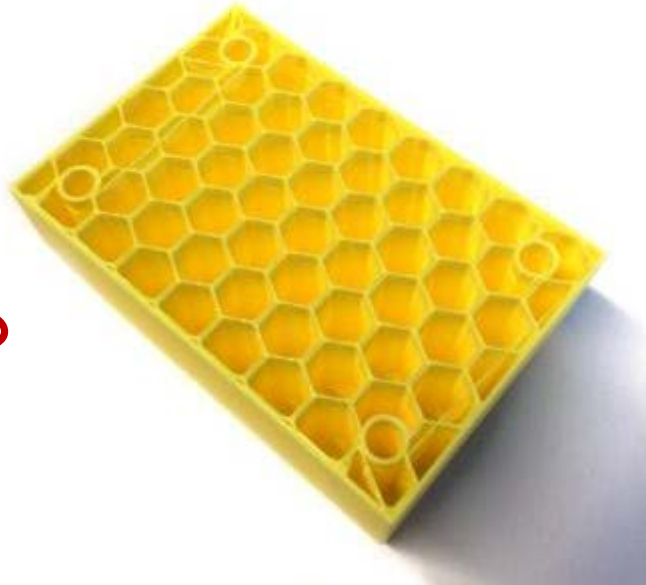




What happens when I drive a self tapping screw into this?



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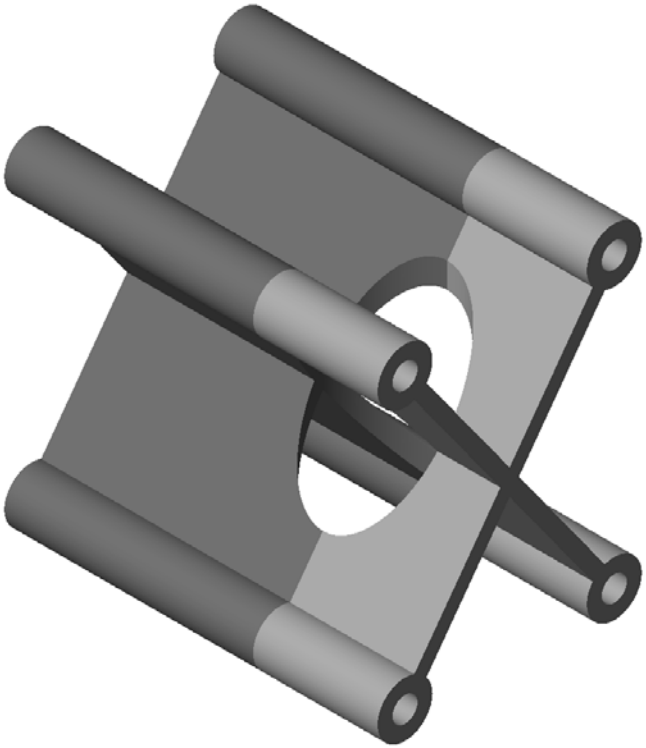

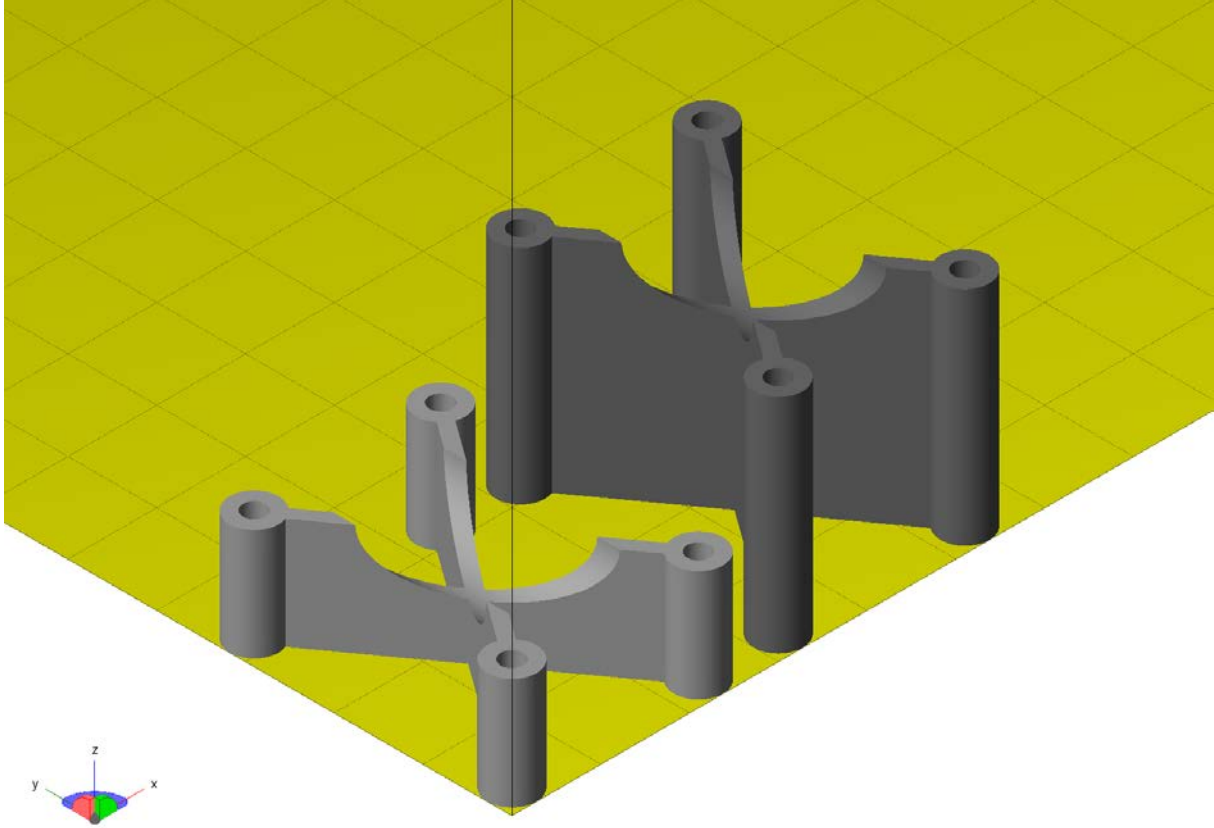


This obeys "Design rules" for 3D Printing!

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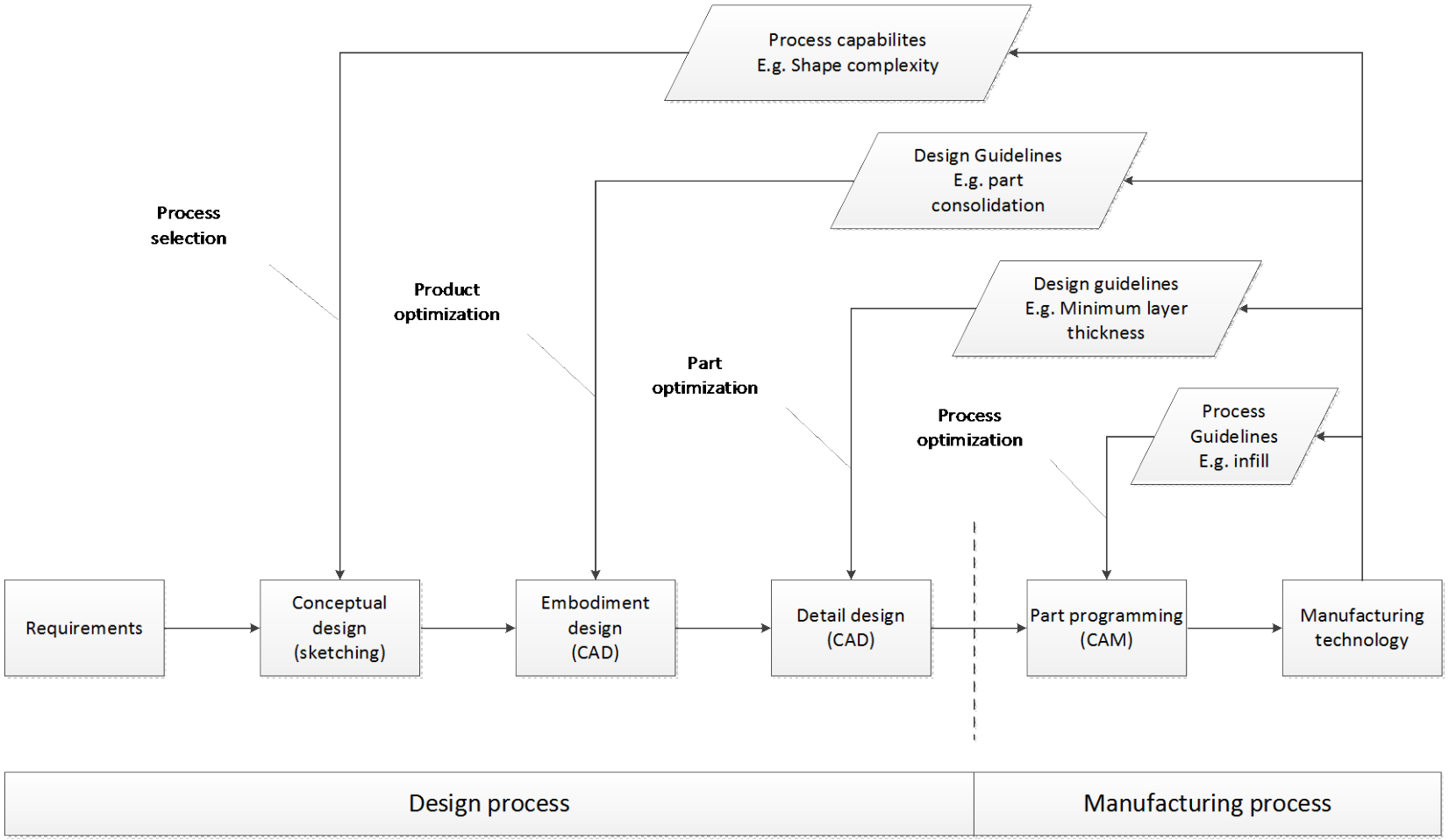
# When is a design rule a design rule?

## Not a 3D Printing rule, not a manufacturing rule or specification



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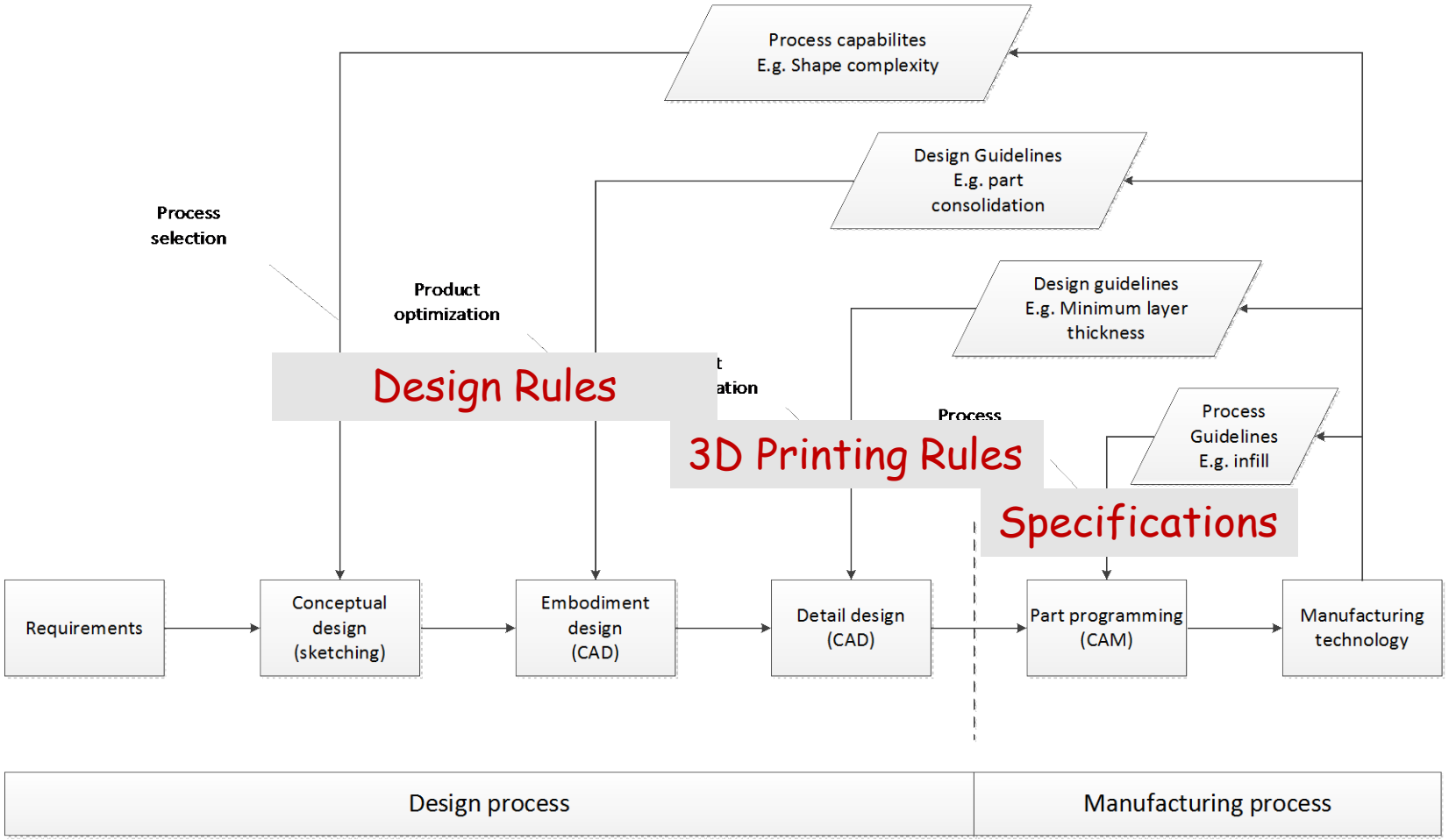




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# When is a design rule a design rule?

## Design Rules for AM

- These are applied at the designing stage
- Applied from the beginning by the designer
- Applied to concept design and design development
- Directly within the control of the designer
- Applied through form giving (shape)
- Achieved through CAD


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# When is a design rule a design rule?

**3D Printing Rules**

- Detail design, refinement – engineering design
- The optimisation of geometrical features
- The application of AM material / process specific parameters
- Precise definition of fillets, radii, wall thicknesses, etc.
- Directly within the control of the designer
- Applied through form giving
- Achieved through CAD


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# When is a design rule a design rule?

**3D Printing Specifications – manufacturing parameters**

- Orientation, layer thickness, in-fill, scan strategy, etc.
- Cannot be expressed through form
- Cannot be not modelled in CAD
- Not in the direct control of the designer
- Must be communicated as a specification


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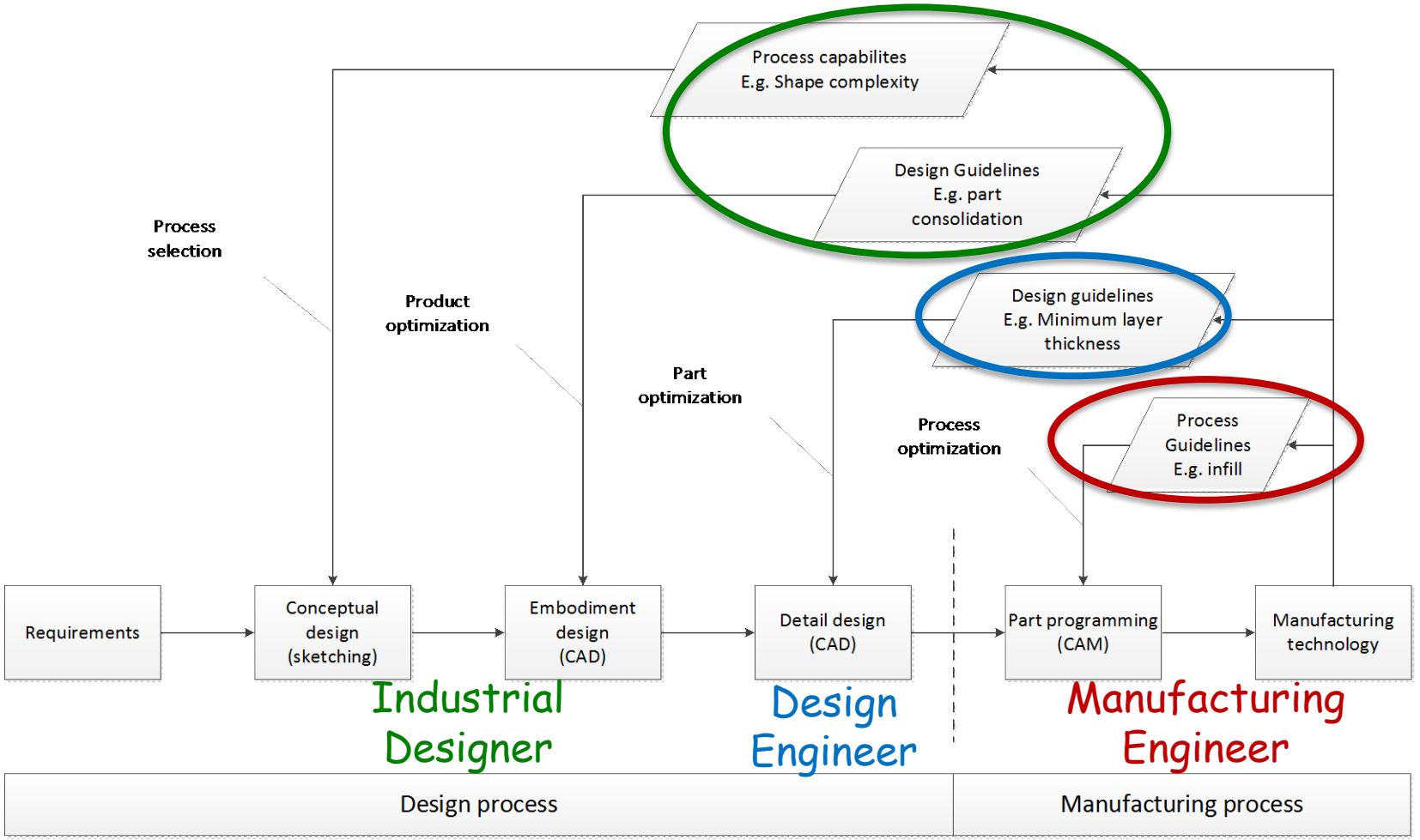
# When is a design rule a design rule?

Not a 3D Printing rule, not a manufacturing rule or specification



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# 1. Designing Thinking and Decision Making

- AM provides new / different design opportunities
    - Part complexity
    - Part consolidation
    - Multiple / Graded Materials
- But…
    - Just because you can do it doesn't mean you should do it
    - What are the design choices being made?
    - What are the consequences of design choices?


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# 1. Designing Thinking and Decision Making

**This is a medical device**

How do you clean it?

How do you sterilise it?

**This is a safety critical aerospace part**

How do you inspect it?

What if one tiny strut breaks?

How many can break before it fails?

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# 1. Designing Thinking and Decision Making

Consequences of design decisions

- How is the design generated? Is it efficient? Do you have the tools and skills necessary?
- Does the added complexity actually have a benefit?
- What about quality control? How do you inspect the part?
- What about maintenance and service life? Again, how do you inspect the part?
- What about corrosion from massive surface area? How do you keep it clean?
- What about end of life, disposal, disassembly, recycling?


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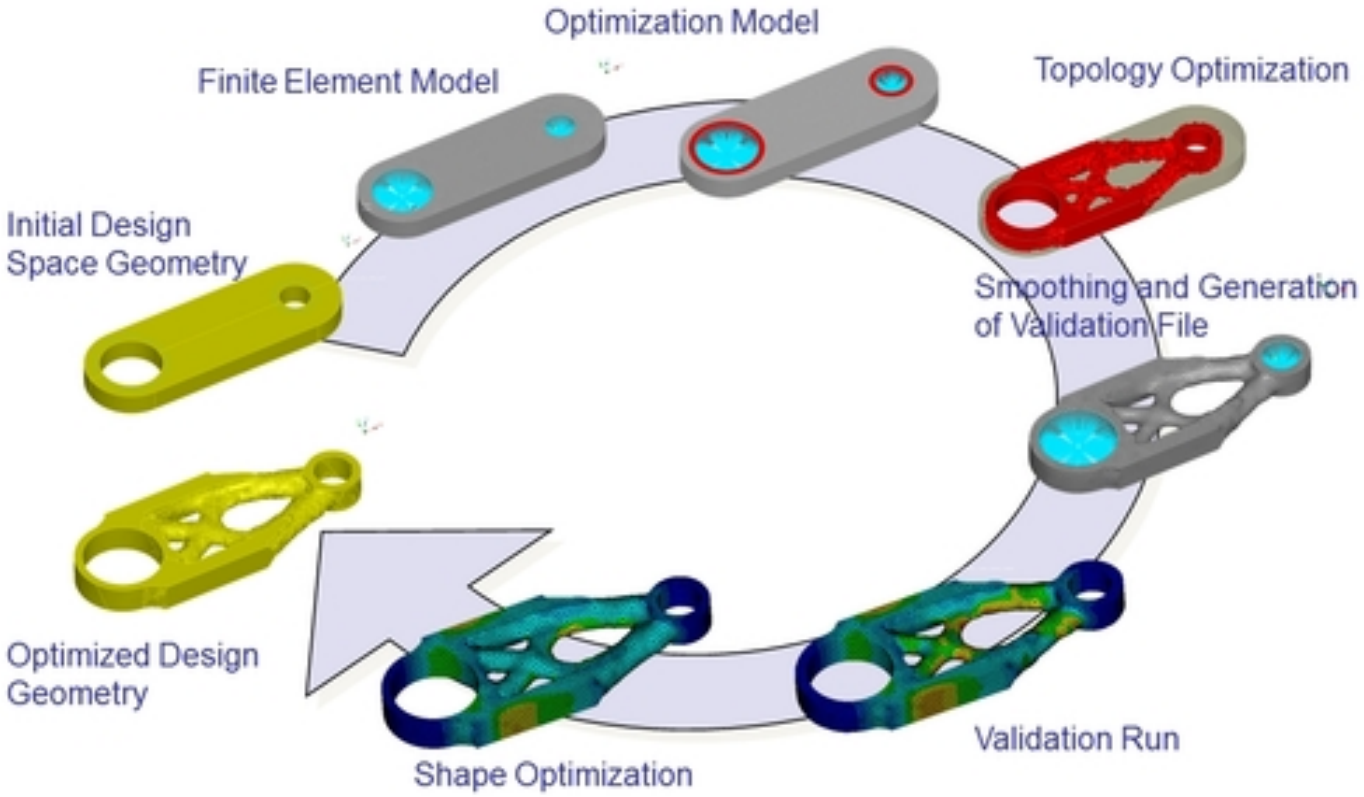
# 2. Design Tools

## Topology optimisation –
## *requires new efficient tools*




*TOSCA Structure Topology Optimisation Workflow – Wilde Analysis*



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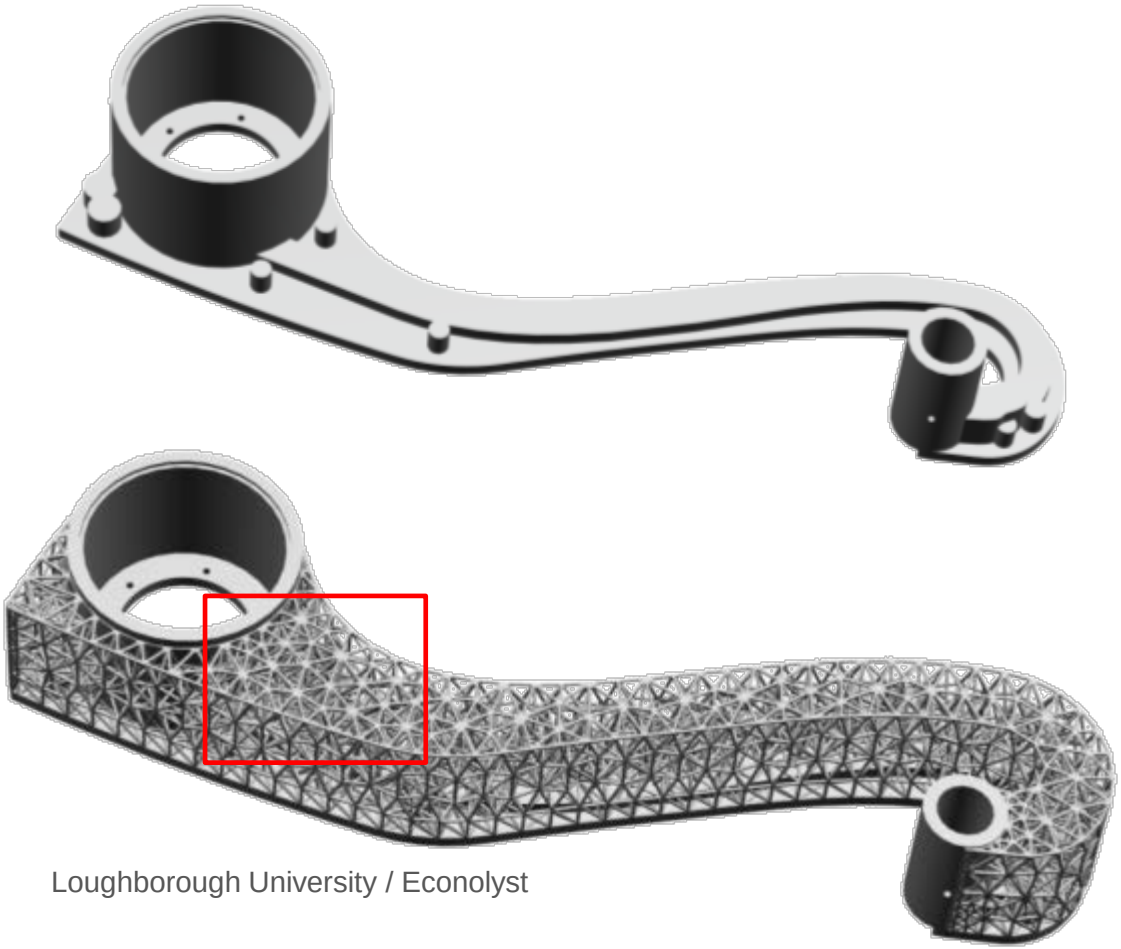
# 2. Design Tools

## Lattices structures – *requires new tools*



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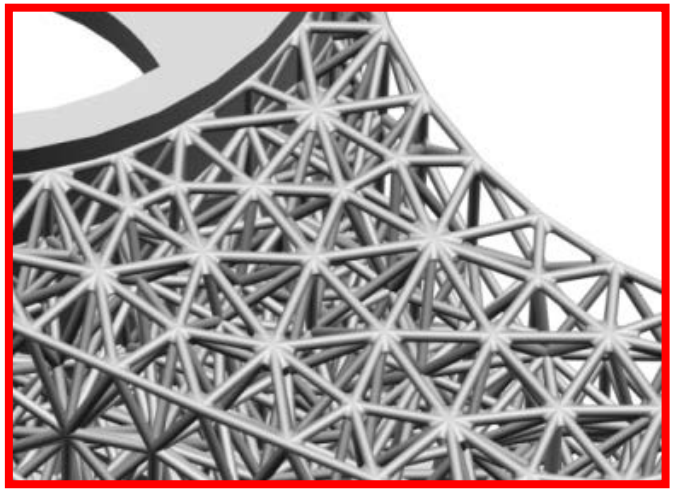

*e.g. presentation by Umesh Gandhi*



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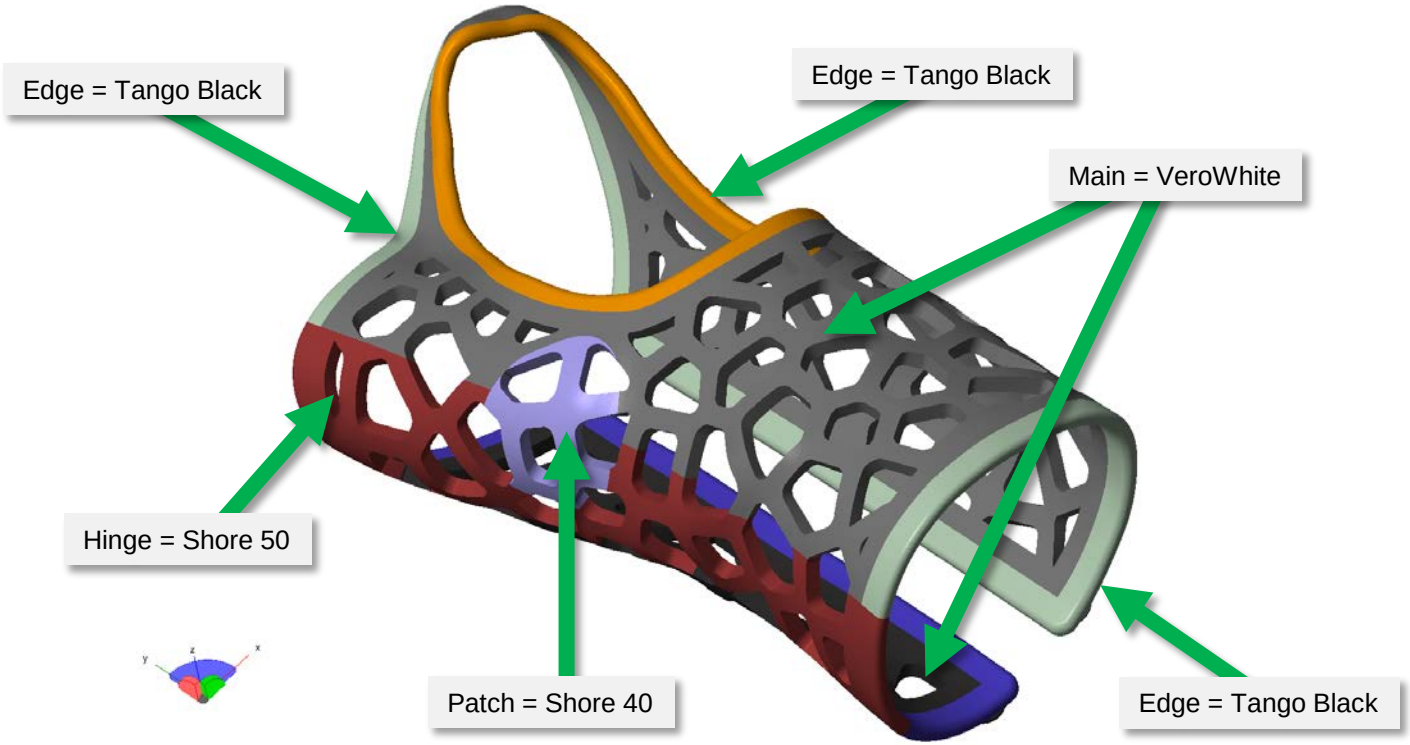
# 2. Design Tools

## **Multiple Materials** – *can be done in CAD but more complex*




Objet Connex Multi-Material Splint Concept © Abby Paterson and Richard Bibb September 2012

## **Functionally Graded Materials (FGM)** – *cannot be done in CAD – needs new tools!*



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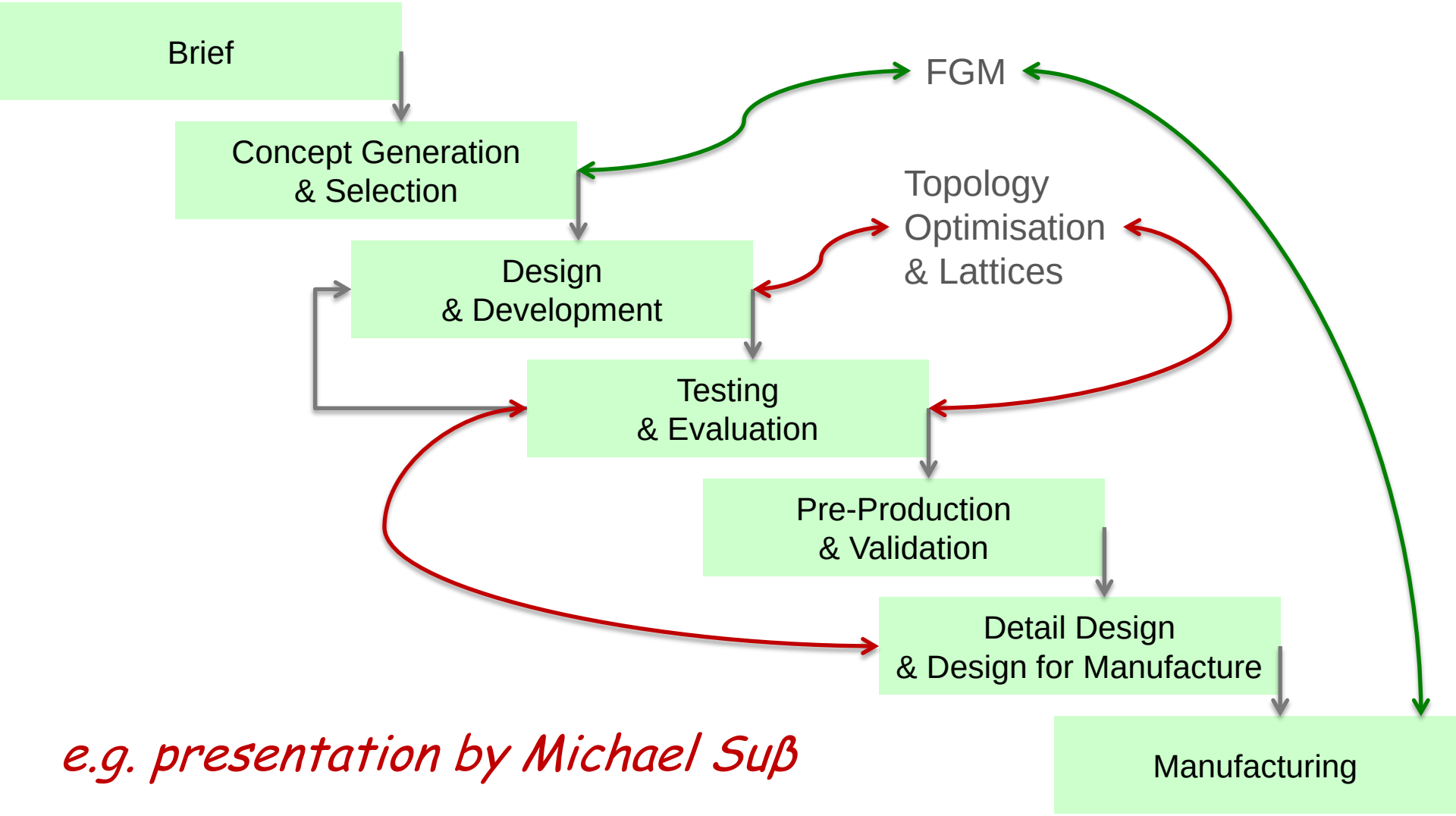
# 2. Design Tools




*e.g. presentation by Michael Suß*



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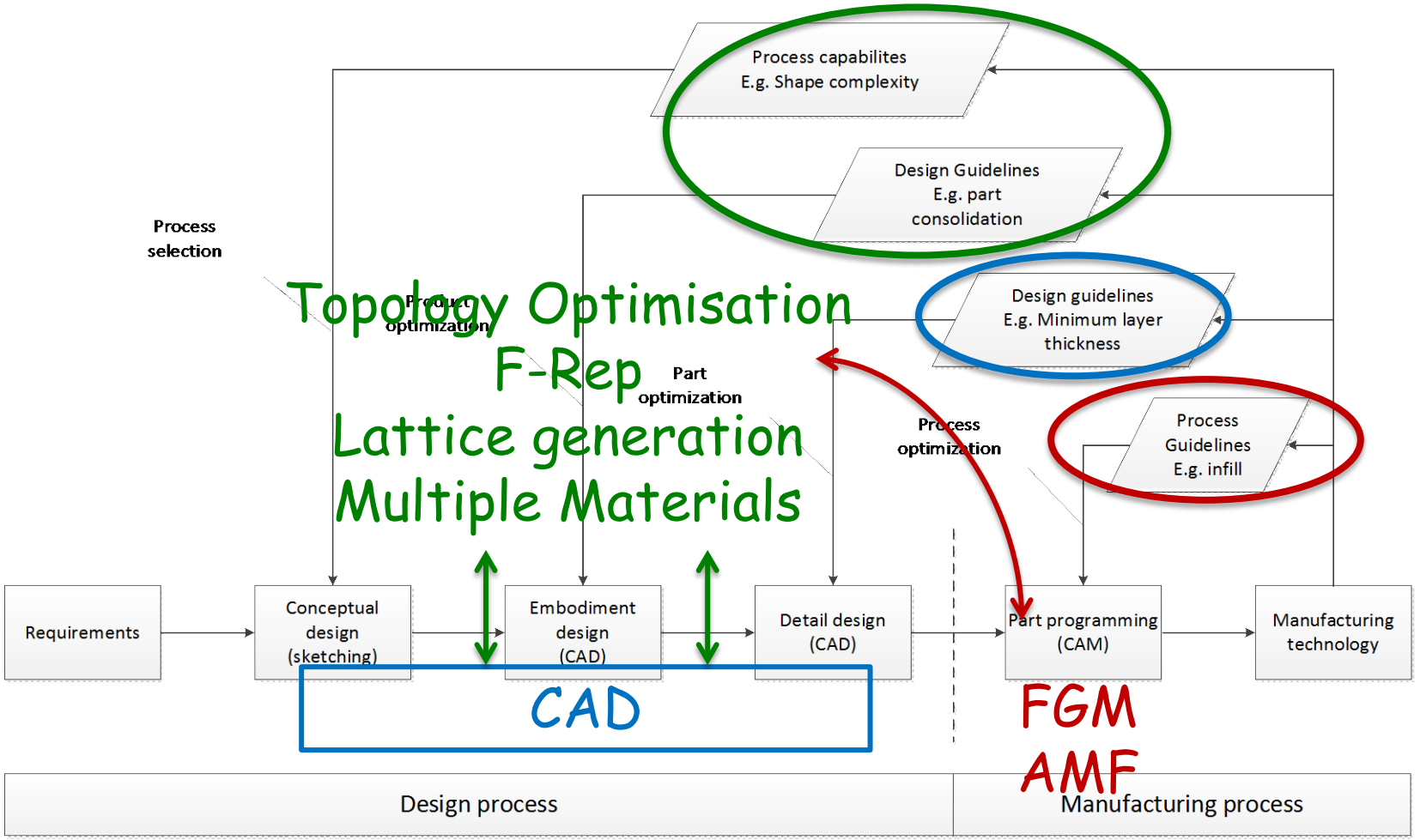
# 2. Design Tools



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# 2. Designing Tools

**This can be achieved but only with new design tools**

- When in the design process – does this change the concept?
- Which tools to use?
- How much do the tools cost?
- How long do they take?
- How many more design stages or iterations?
- How much training and skill is required?
- When in the design process is it applied and by who?

*Is it needed? Is it worth it?*

*Expect lots of development in CAD to come!*



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# 3. Product Development Process

## Advantages (possibilities) of AM

- Customisation
- Personalisation
- Make on demand – no stock holding
- Low cost to change the design – revise design at anytime
- Continual improvement through design changes – revise the design as often as you like


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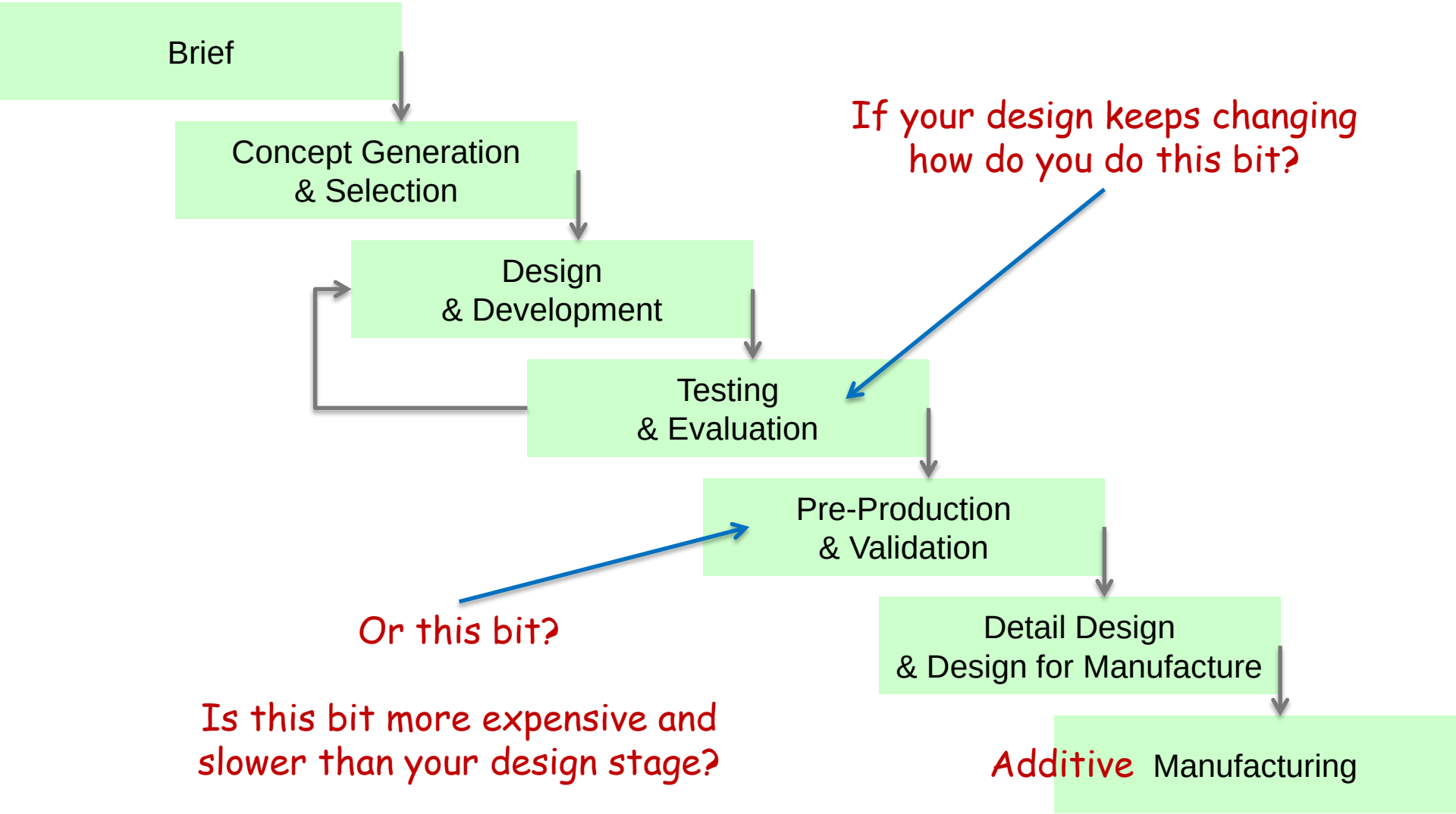
# 3. Product Development Process



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# 3. Product Development Process

**Consequences of design decisions**

- When is your design finished?
- When is your design approved and how?
- How do you do quality control when making on demand?
- If you can keep changing the design how many designers can you afford? Are they busy doing tiny revisions the whole time?
- How do you validate your designs?
- How do you adhere to standards and legislation?
- What happens to version control and specification?


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# 3. Product Development Process

## Consequences of AM

- Where is your cost?
- Is it in part manufacture?
- Is it in assembly?
- Is it in validation, qualification, certification or quality assurance?
- Is it in service and maintenance?
- Is it in accuracy and service life?

- *All of these have an impact on the design process*


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# 4. Separating designing from making

- Custom made devices
    - Designing is making, it is concurrent – it is the same craft-based activity
- AM
    - Necessitates CAD, and the separation of designing from making – what does this do to the design process?


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Patient arrives

↓

Create splint outline

↓

Heat up plastic

↓

Form shape on patient

↓

Adjust fit

↓

Roll edges

↓

Add fasteners

↓

Adjust fit

↓

Final splint adjustments

←

Repeat whole process



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Import patient scan data

↓

Create splint outline

↓

Adjust outline

↓

Integrate ‘clinical’ design features

↓

Select material and thickness

↓

Patient choice → Apply lattice pattern

↓

Final splint adjustments

↓

Fillet edges (automatic)

↓

Export STL file for fabrication → 3D Print as many as you like



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# 4. Separating designing from making

***Firstly – what doesn't change!***

- The design principles of splinting
- The anatomical landmarks and references
- The nature, location and support provided by the splint
- The knowledge, skills and expertise of the clinician
- The clinical effectiveness of the splint


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# 4. Separating designing from making

***So what is the impact on the design process?***

- Separation of designing from making – designing can be done remotely, in batches, the patient doesn't have to be present ✓
- Manufacturing can be done remotely, repeatedly, locally ✓
- New features can be added, lattice patterns, multiple materials etc. ✓
- Totally different tools – 3D scanning and CAD ✗
- Totally different skills needed ✗
- Patient involvement – they can exercise choice in pattern, colours, etc. ✓


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# 4. Separating designing from making

*Fundamental design principles are not changed but the practice and process of design are radically changed*

- Who does the designing? – do we train clinicians in CAD and Scanning?
- Does it de-skill clinicians? Does it make them redundant?
- How do we empower them – *give them the tools*
- How do we get sufficient trained people quickly?
- Who pays for the investment in equipment?

*This could destroy or empower a profession! How do you manage that?*



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# Impact

**Designers and Engineers need education, process knowledge and training in key skills and tools**

- Industrial designers need to be taught about design for additive manufacturing to a comparable level to other processes
- Design engineers need to be taught about process specific parameters and given access to detailed design guidance
- Manufacturing engineers need to be liaise with designers and help to produce design guidance and be clear about what is and is not within the designers control


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# Designer Knowledge

**Industrial Designer – needs Design Rules for AM**

Requires a knowledge of the fundamental characteristics of AM to inform

- Design opportunities for concept generation; such as part complexity, part consolidation, size, shape, etc.

Requires a working knowledge of basic AM processes to inform

- Which processes and materials will be suitable
- Awareness of size, accuracy and cost constraints
- Ability to compare AM to alternatives

*"A new sense of engineering beauty"*
*Tomasso Ghidini*


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# Designer Knowledge

**Design Engineer – needs 3D Printing Rules**

Requires a detailed knowledge of specific AM material / process characteristics of AM and manufacturing parameters to inform

- Detail design – minimum wall thicknesses, minimum gaps, minimum feature sizes, etc.
- Adjustment of dimensions and feature sizes to ensure appropriate stiffness, strength, fatigue, etc.
- Adjustment of features to assist post-processing (e.g. powder or support removal)


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# Designer Knowledge

**Designers and Engineers – need 3D Printing Specifications**

Requires a very deep and detailed knowledge of specific AM material / process characteristics and manufacturing parameters

- Who is specifying the manufacturing parameters? It could be the designer, engineer or manufacturer?
- Is orientation a design decision or a manufacturing decision?
- Is in-fill a design decision or a manufacturing decision?

*Some of this may be invisible to the designer – should it be?*


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# Impact on the Design Process

- **Design Process –** may have to radically change – can you control the process?
- **Design Tools** – might need new (expensive) tools to realise the advantages
- **Skills** – might need new design skills or even new people – different levels for different design stages
- **Knowledge** – will need to improve education and training which takes years, experience will come

*All of these have an impact on the design process*


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# Strategies

- Build AM process selection into your NPD process
- Use “real” AM data not ideal or manufacturer claims
- Qualify and invest in new Design Tools
- Allocate design tasks and train staff accordingly – make sure all your designers have the appropriate knowledge
- Decide how, when and how often you “fix” validated designs and match design revisions to quality control procedures
- Automate or semi-automate design tasks and procedures
- Look for new opportunities – e.g. customer engagement


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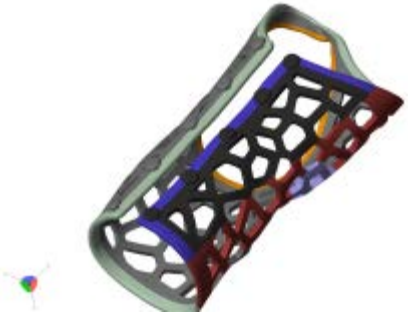

EPSRC
Engineering and Physical Sciences Research Council

D4AM
Design for Additive Manufacturing



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