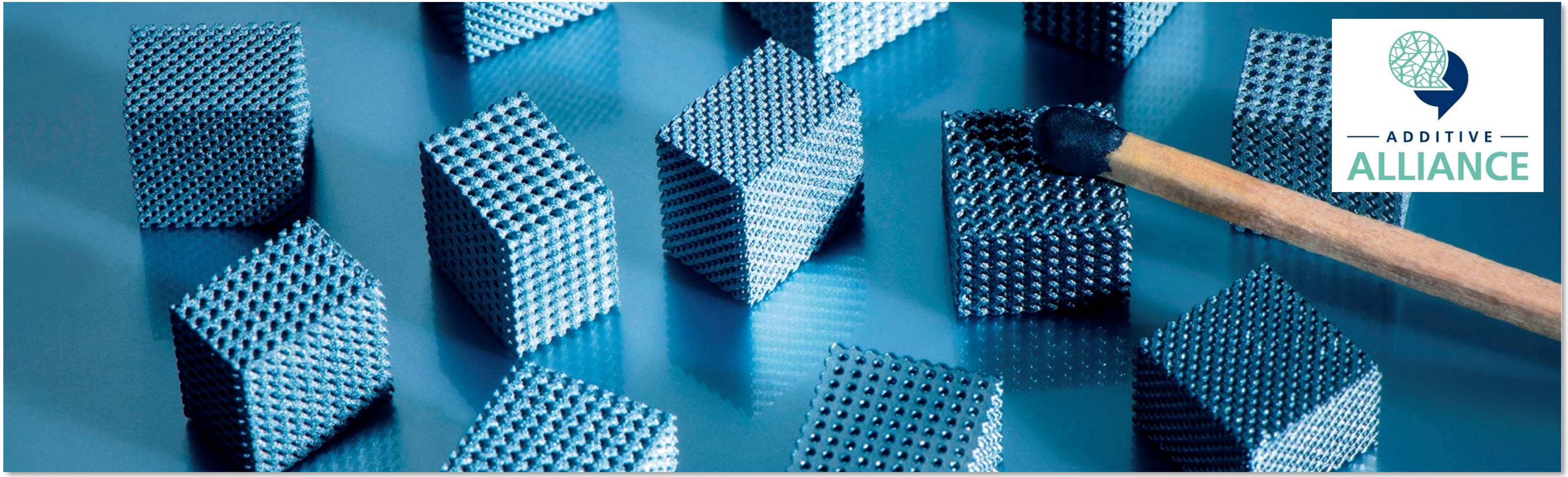
APPLICATION POTENTIAL OF STRUCTURES BASED ON TRIPLY PERIODIC MINIMAL SURFACES (TPMS)

Alliance Deep Dive 2021

EXCLUSIVE



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AGENDA

1. What are TPMS?
2. Motivation & approach
3. Geometric modeling & mechanical properties
4. Potential applications
5. Conclusion

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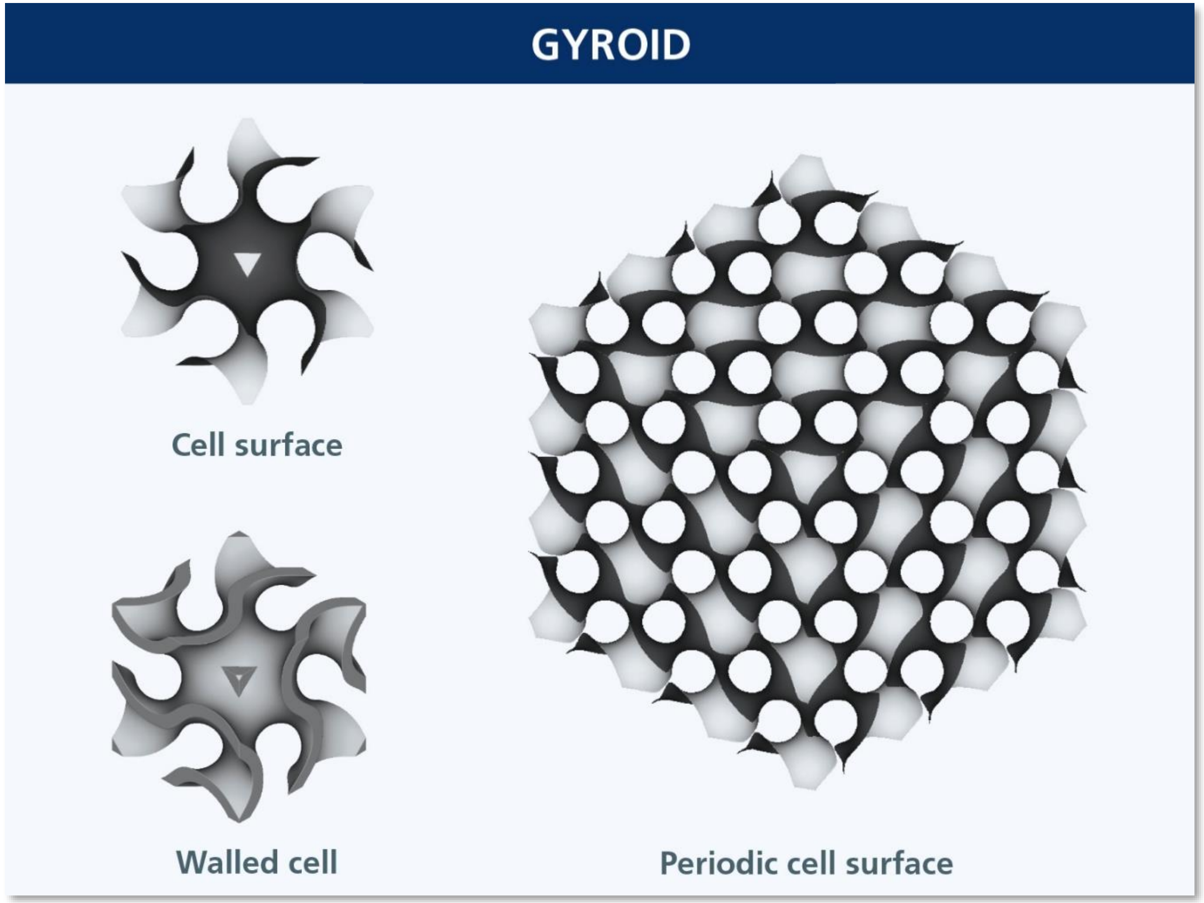
TPMS STRUCTURES

- Periodically arranged unit cells with the following properties:
  - divide space into two nonintersecting, intertwined domains
  - no sharp corners or edges
  - described by one implicit equation

- **Shell:** thickening in both normal directions
- **Solid:** one subdomain solid, other void



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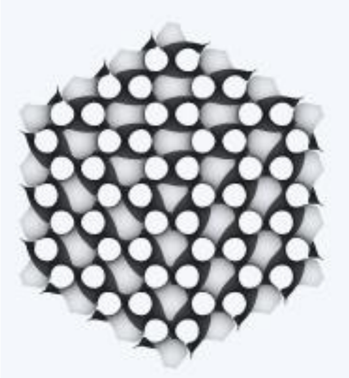
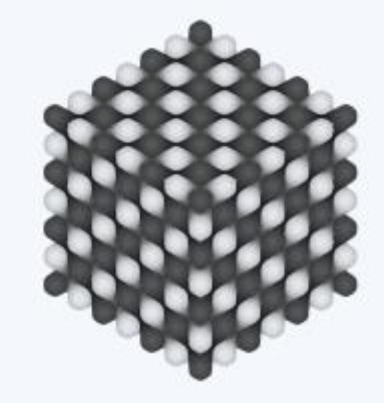
TPMS STRUCTURES

GYROID



DIAMOND



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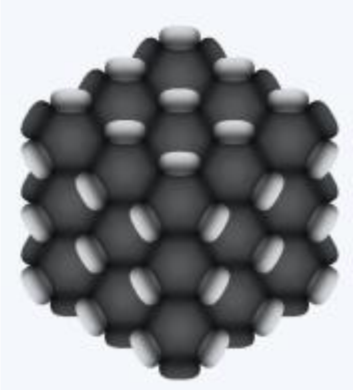
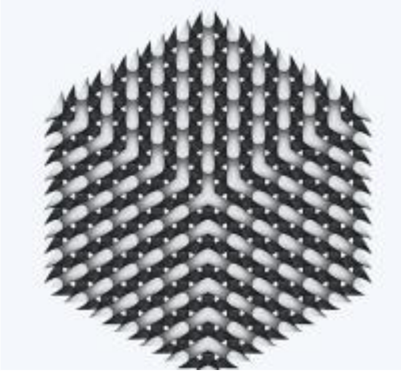
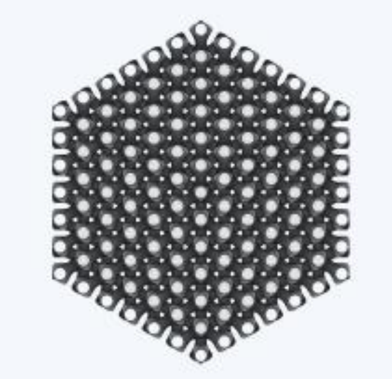


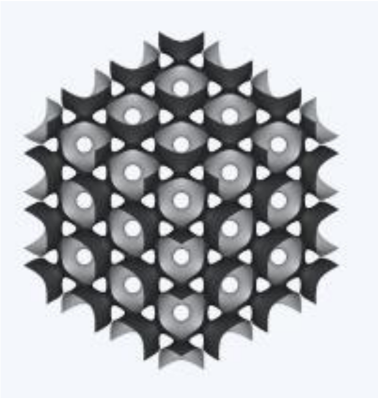
DOUBLE DIAMOND



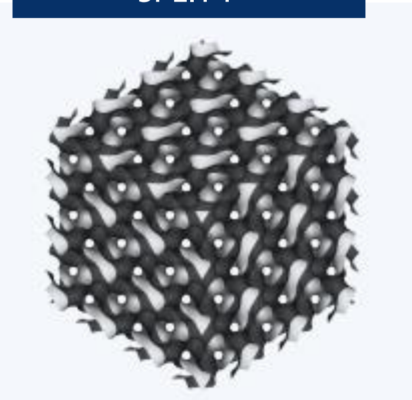
DOUBLE DIAMOND 2



IWP

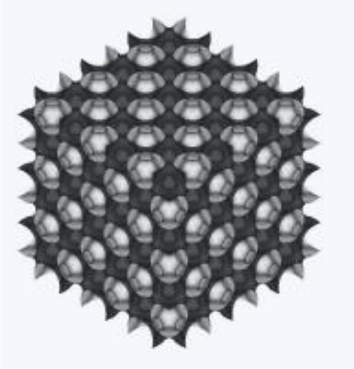


SPLIT P



NEOVIUS

FRD



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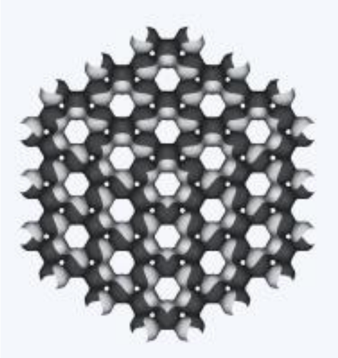

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MOTIVATION

Advantages

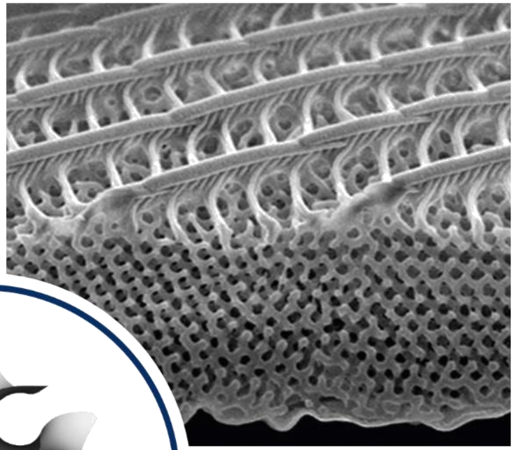
Physical properties superior to other lattice types

Geometry

Topologies with specific mathematical properties

Why AM?

AM and software technology allow for implementation in real products



- Overview of properties of TPMS
- Potential applications in different fields

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APPROACH

Data — Literature review

CAD — Software review

Testing — Own investigations

Providing a methodology for selecting appropriate TPMS-based geometries

Shock:
Why can TPMS structures be beneficial in controlled impact energy absorption?

Vibration:
Which TPMS structure can be used to decouple a vibrating system?

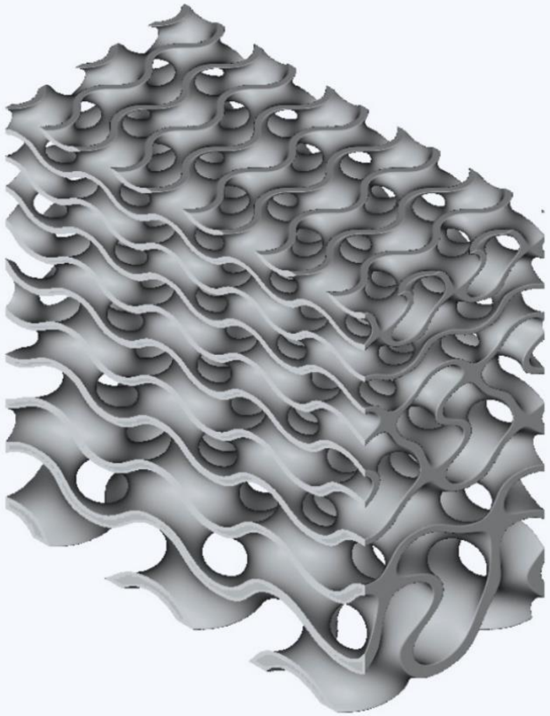
Acoustics:
Which TPMS structure can be used for proper sound absorption?

Heat transfer:
Which TPMS structure can be used to achieve the best possible heat transfer?

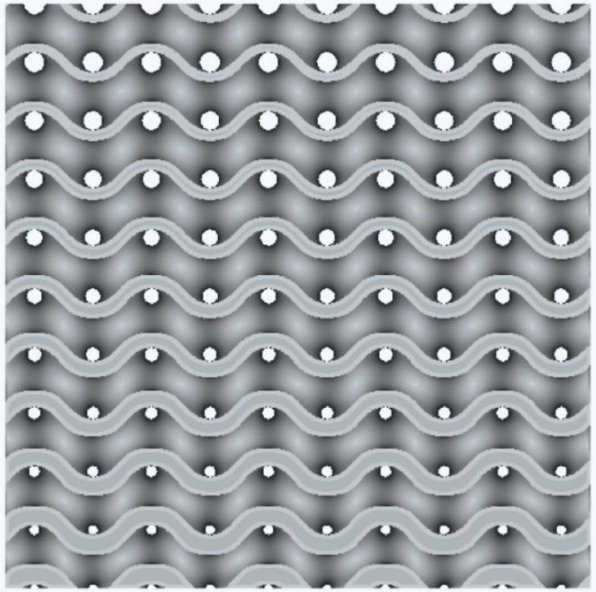
Medical:
Why can TPMS structures be beneficial in bone scaffold and implant design?

POSSIBLE ADAPTATIONS

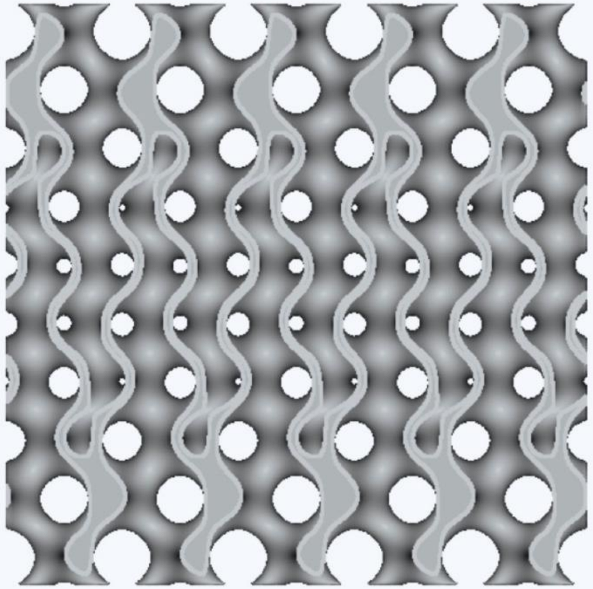
CELL SIZE GRADING



WALL THICKNESS GRADING



BIAS GRADING



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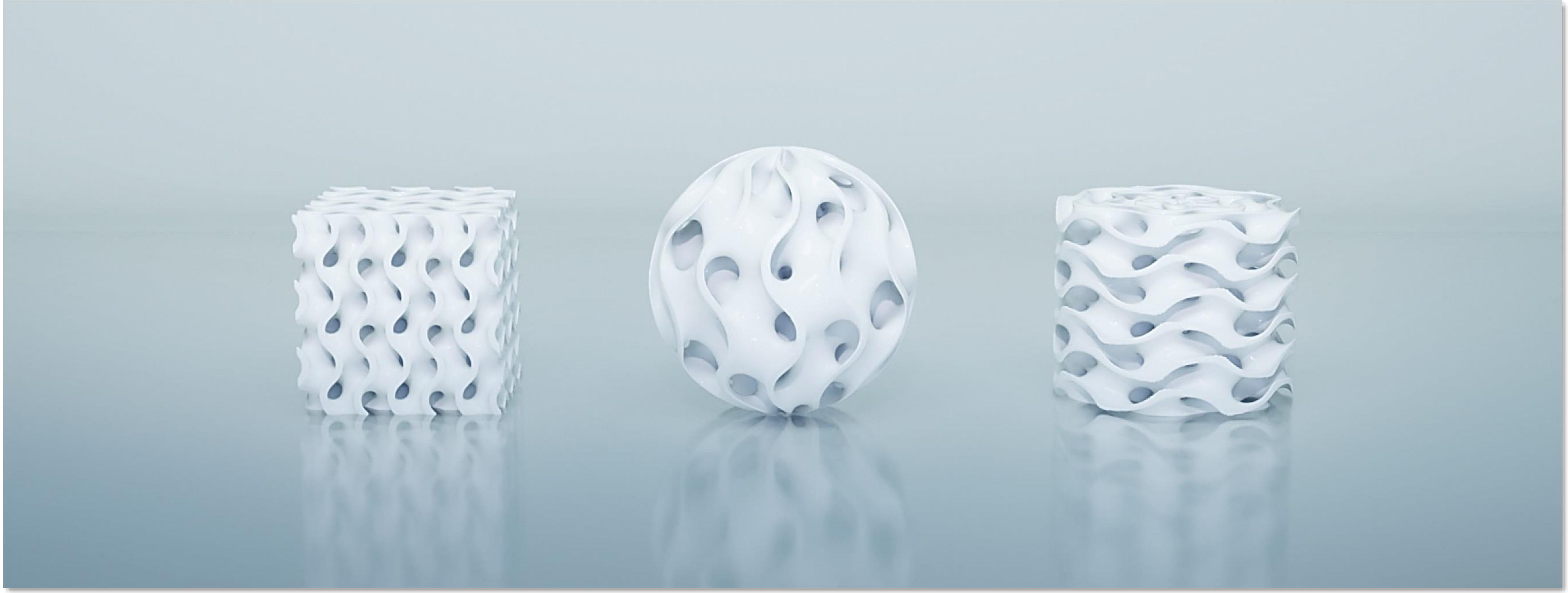
POSSIBLE ADAPTATIONS (CONT.)



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GEOMETRIC MODELING

Company	Software	Mesh-based unit cell	Implicit modeling
CT CoreTechnologie GmbH	4D_Additive	•	
Materialise NV	3-matic / Magics	•	
3D Systems, Inc.	3DXpert	•	•*
Gen3D ltd.	Gen3D	•	•
Siemens Digital Industries Software	Siemens NX	•	•
nTopology, Inc	nTopology		•

* This function is available as of software version V17.

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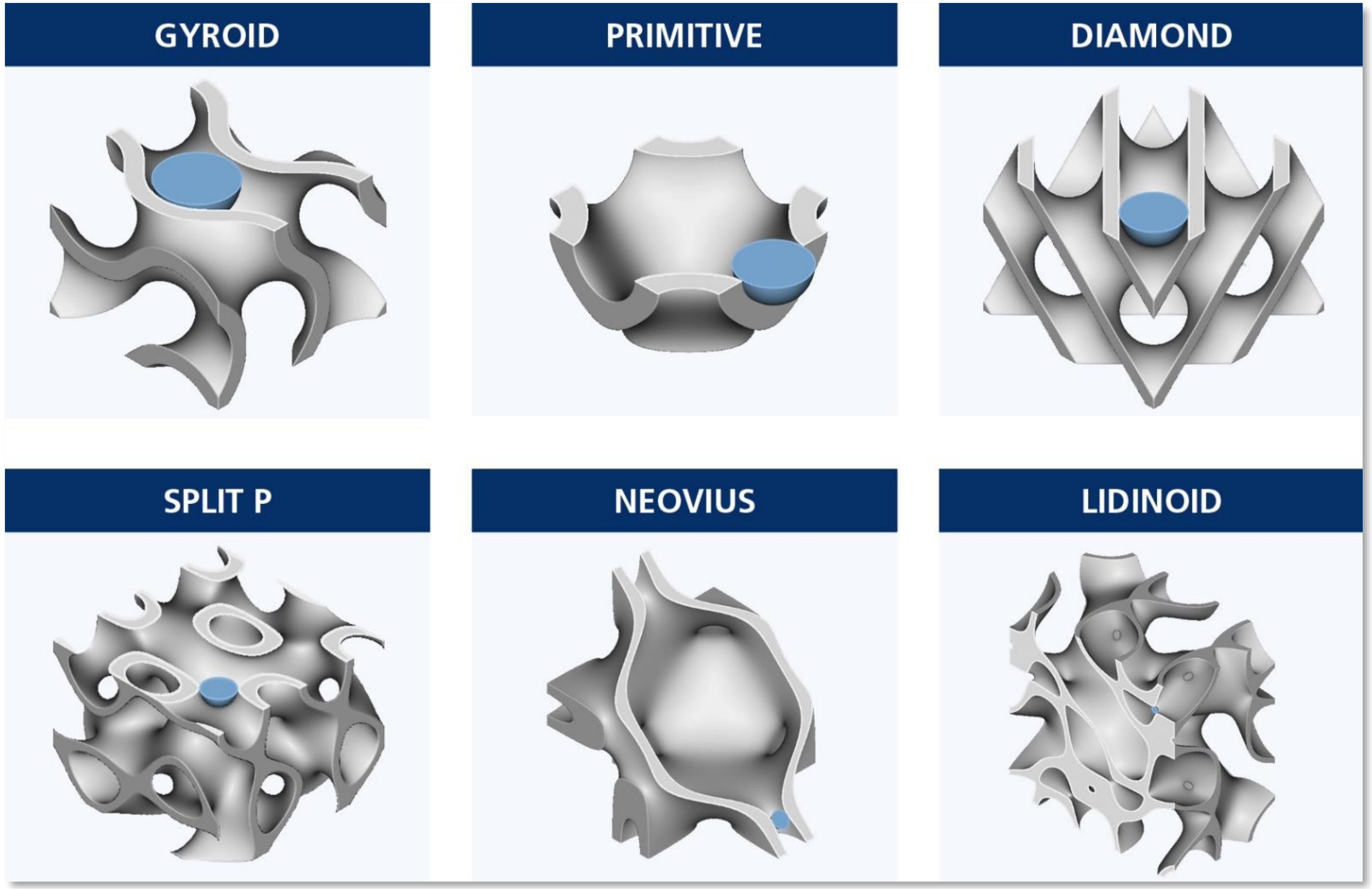
MANUFACTURABILITY

- AM processes very suitable for TPMS
- Information on manufacturable cell sizes cannot be generalized
  - depends on process and material
  - must be determined individually for each combination
- Powder bed processes:
  - cell size not too small regarding powder removal
  - also not too large to counteract potential dross formation
- Important parameter: **Pore size**



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MECHANICAL PROPERTIES

Gibson-Ashby model

- Allows specification of macroscopic effective material parameters
- Function of relative density φ of the TPMS structure
- E.g. Young's modulus of TPMS:

$$E_{\mathrm{TPMS}} = C \cdot \phi^{N} \cdot E_{\mathrm{solid}}$$

E_{solid}: Young's modulus of solid

C, N: material characterization

TPMS STRUCTURE	UNIT CELL (mm)	MATERIAL	*C*	*N*
Gyroid	1.50	Titanium	12.70	1.10
	4.00	Stainless steel	216.60	2.23
	7.00	Maraging steel	18.50	1.23
Diamond	1.50	Titanium	9.90	0.79
	4.00	Stainless steel	81.70	1.42
	7.00	Maraging steel	6.70	0.52

C and *N* are identified experimentally.

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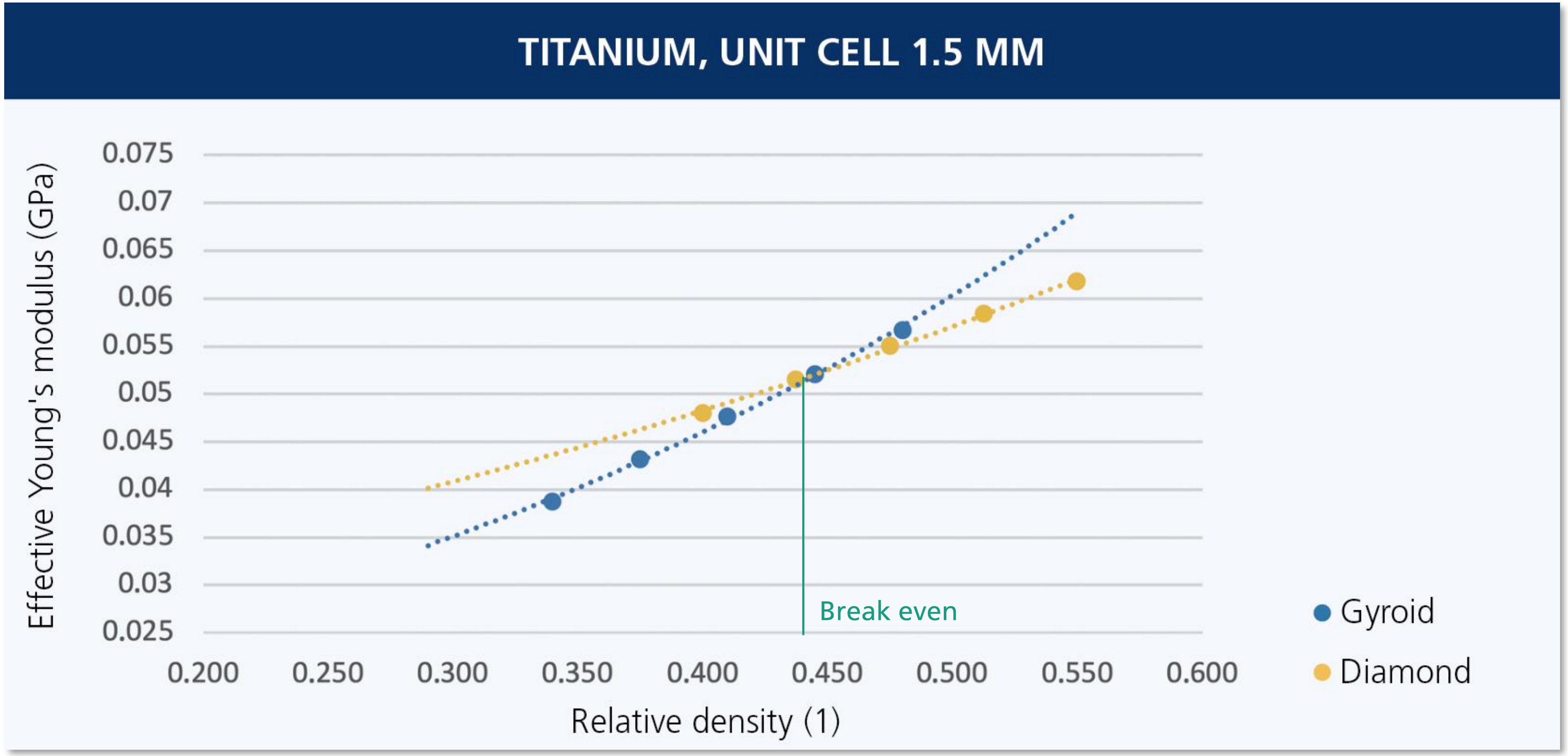
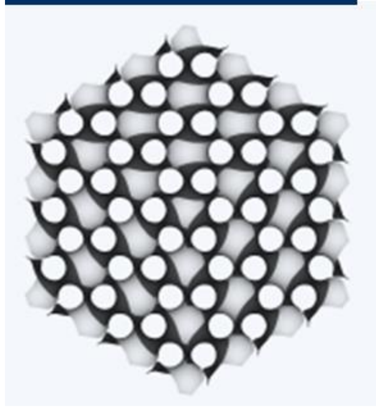
MECHANICAL PROPERTIES (CONT.)



GYROID



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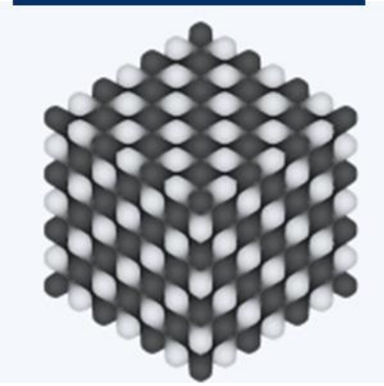

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APPLICATION POTENTIALS OF TPMS

Shock:
Why can TPMS structures be beneficial in controlled impact energy absorption?

Vibration:
Which TPMS structure can be used to decouple a vibrating system?

Acoustics:
Which TPMS structure can be used for proper sound absorption?

Heat transfer:
Which TPMS structure can be used to achieve the best possible heat transfer?

Medical:
Why can TPMS structures be beneficial in bone scaffold and implant design?

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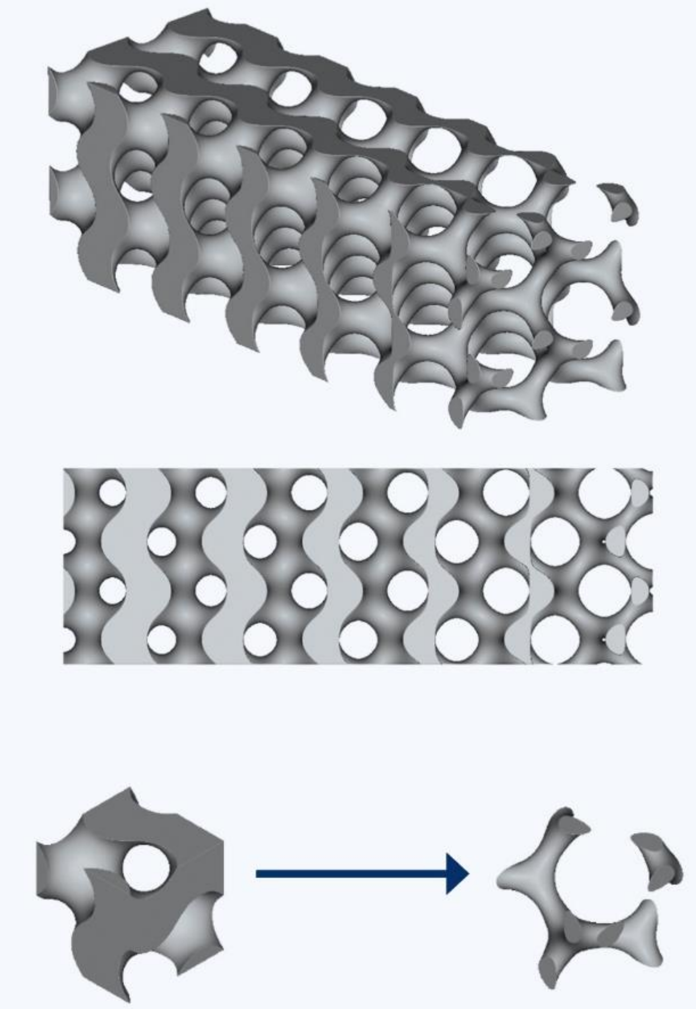
APPLICATIONS – SHOCK

Key question:

Why can TPMS structures be beneficial in controlled impact energy absorption?

- Good prediction of effective mechanical properties
- Tunable material properties by functionally grading the relative density
- Examples:
  - defined crash behavior
  - improved energy absorption

LINEARLY GRADED GYROID STRUCTURE



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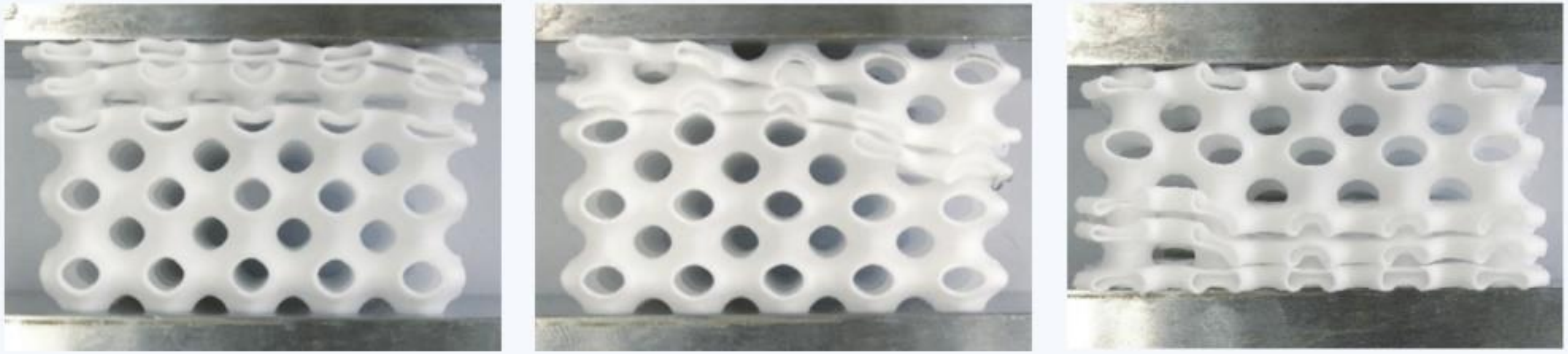
APPLICATIONS – SHOCK (CONT.)

RANDOM FAILURE OF THE LAYERS

Uniform primitive



Sample 1, compression 17.2 mm

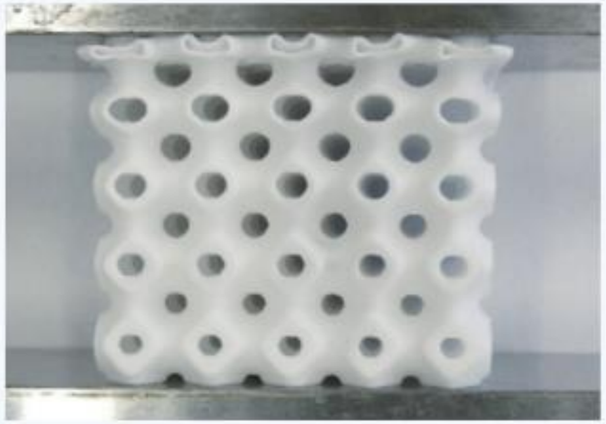
Sample 2, compression 17.8 mm

Sample 3, compression 24.7 mm

APPLICATIONS – SHOCK (CONT.)

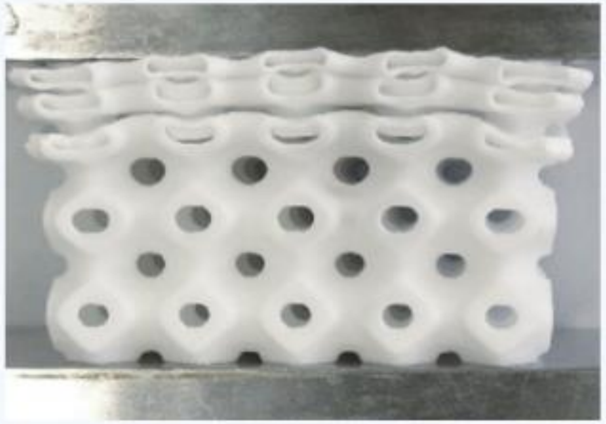
SEQUENTIAL FAILURE OF THE LAYERS

Graded primitive



Compression
6.9 mm

Compression
12.8 mm



Compression
20.0 mm

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APPLICATIONS – SHOCK (CONT.)

Use TMPS structures where a specific and predictable damage behavior is needed.

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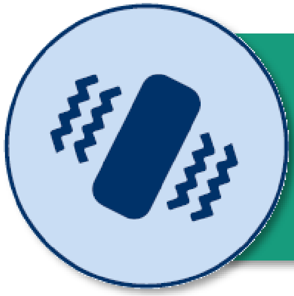
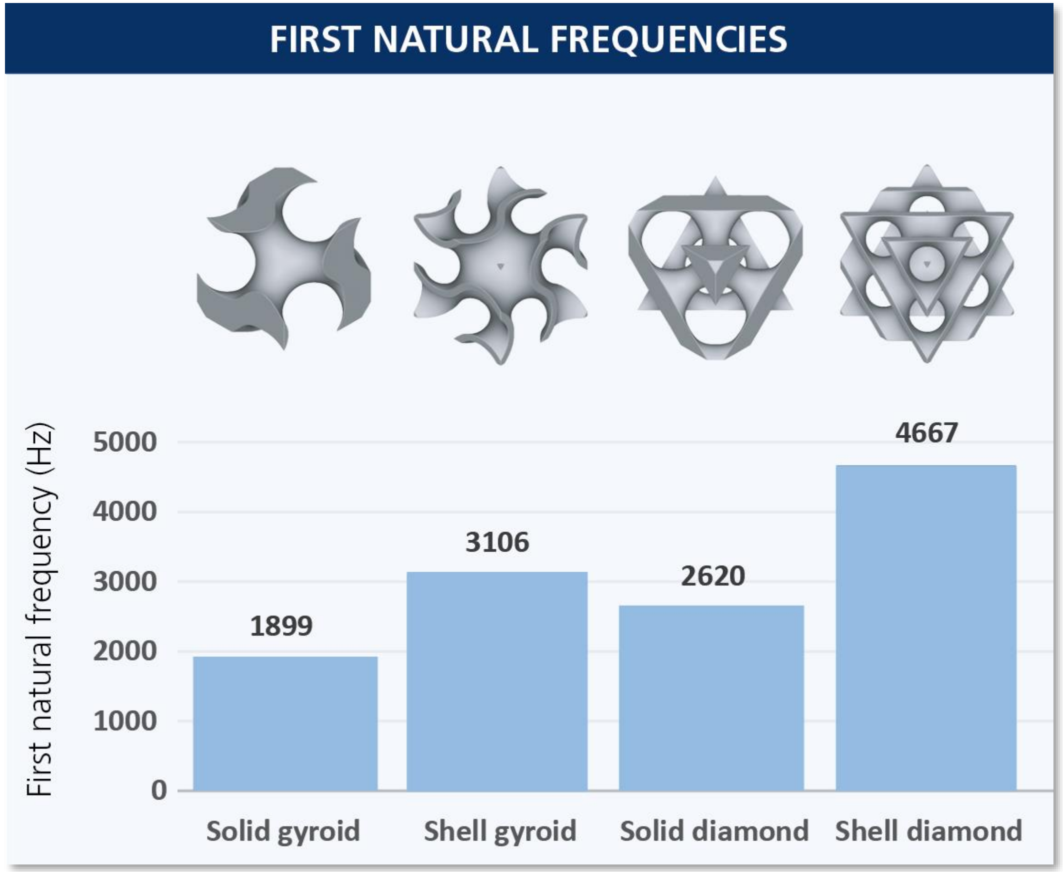
APPLICATIONS – VIBRATION



Key question:

Which TPMS structure can be used to decouple a vibrating system?

- Mechanical bandgap behavior: complete elimination of oscillations in the corresponding frequencies
- Initial frequencies and widths of bandgaps can be directly influenced by suitable selection of cell size and relative density



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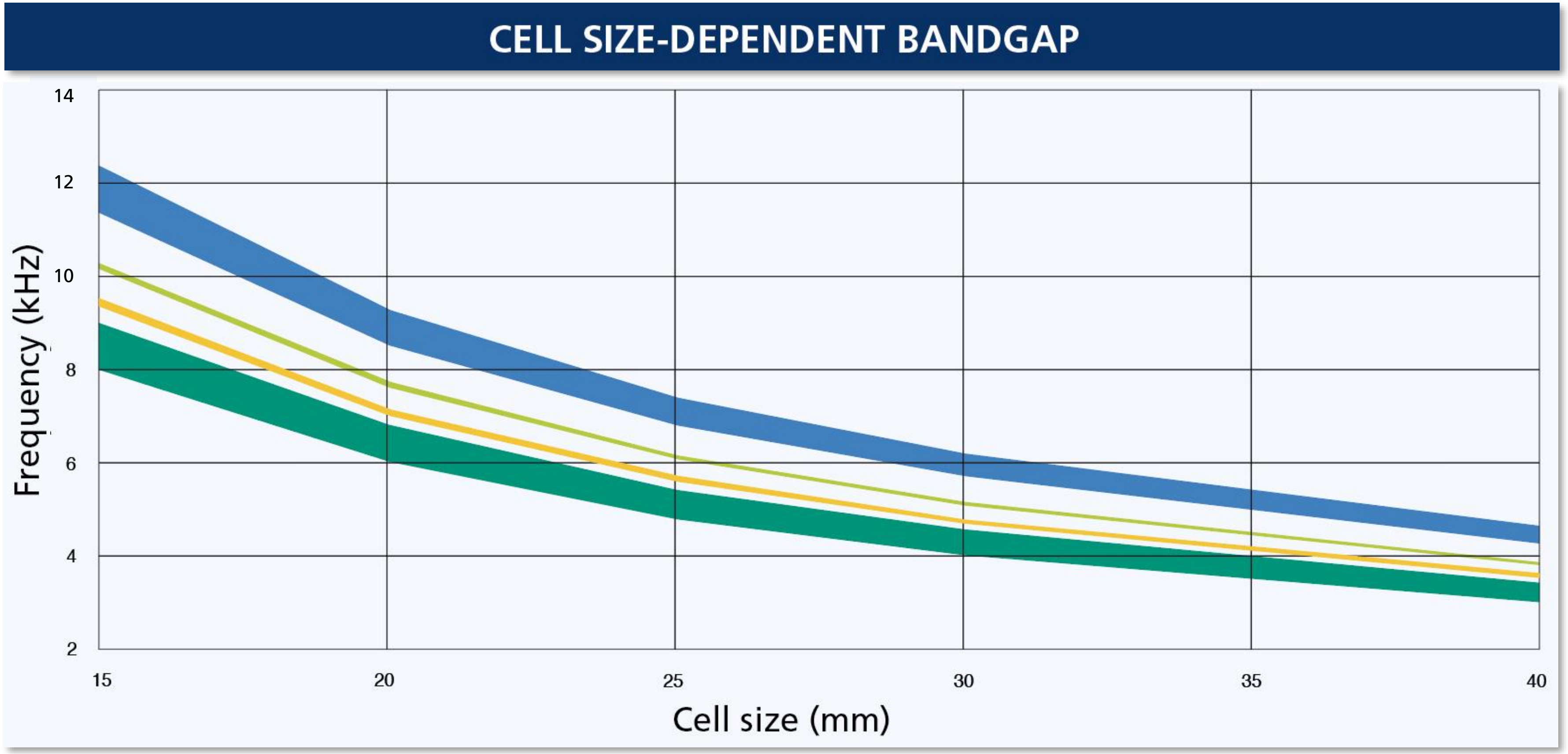
APPLICATIONS – VIBRATION (CONT.)



Solid Gyroid
Relative density: 20 %

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APPLICATIONS – VIBRATION (CONT.)

Use TMPS structures where oscillation of a component within a specific frequency range should be avoided.

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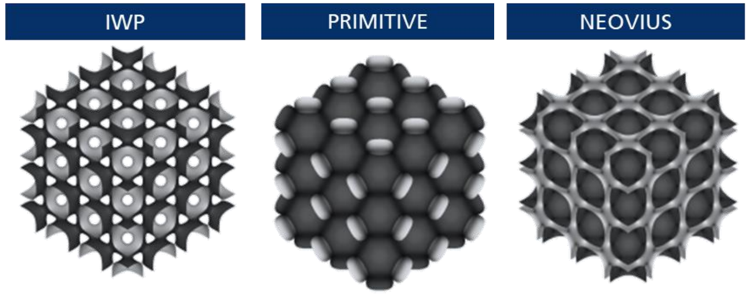
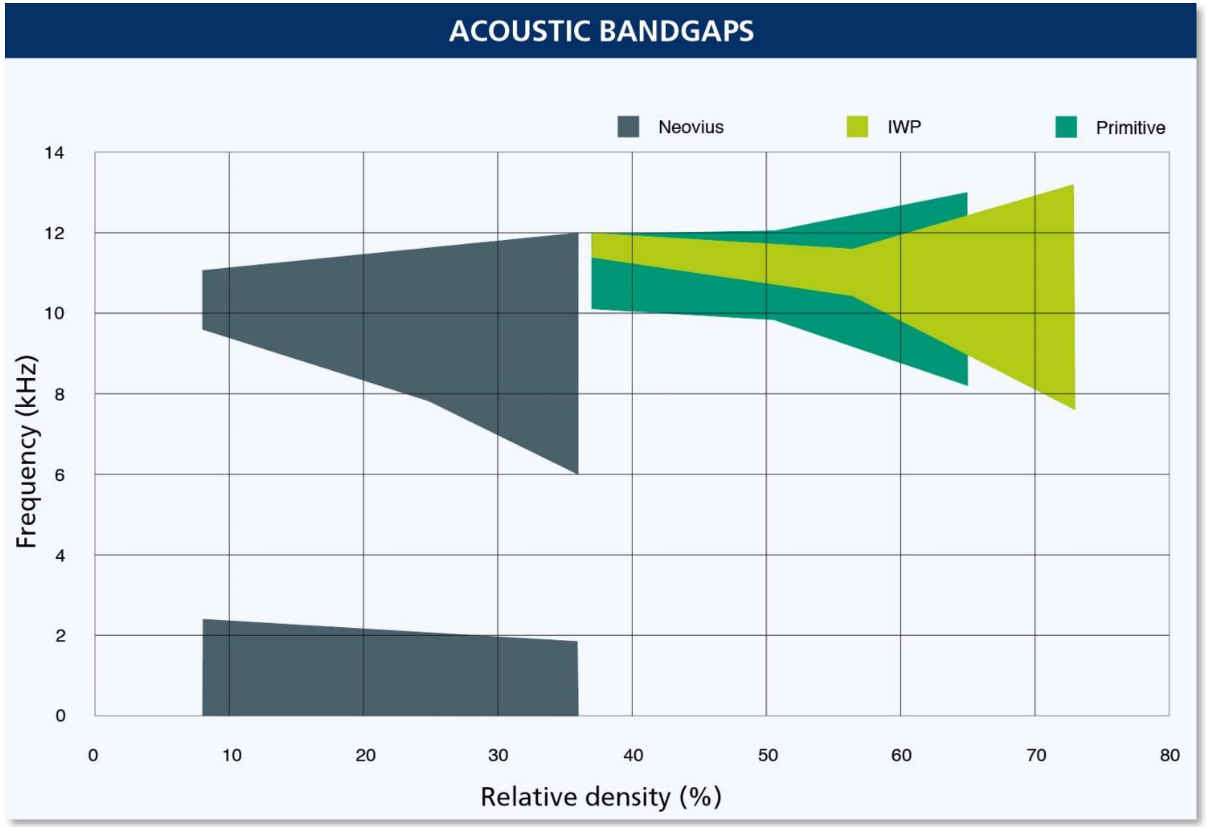
APPLICATIONS – ACOUSTICS

Key question:

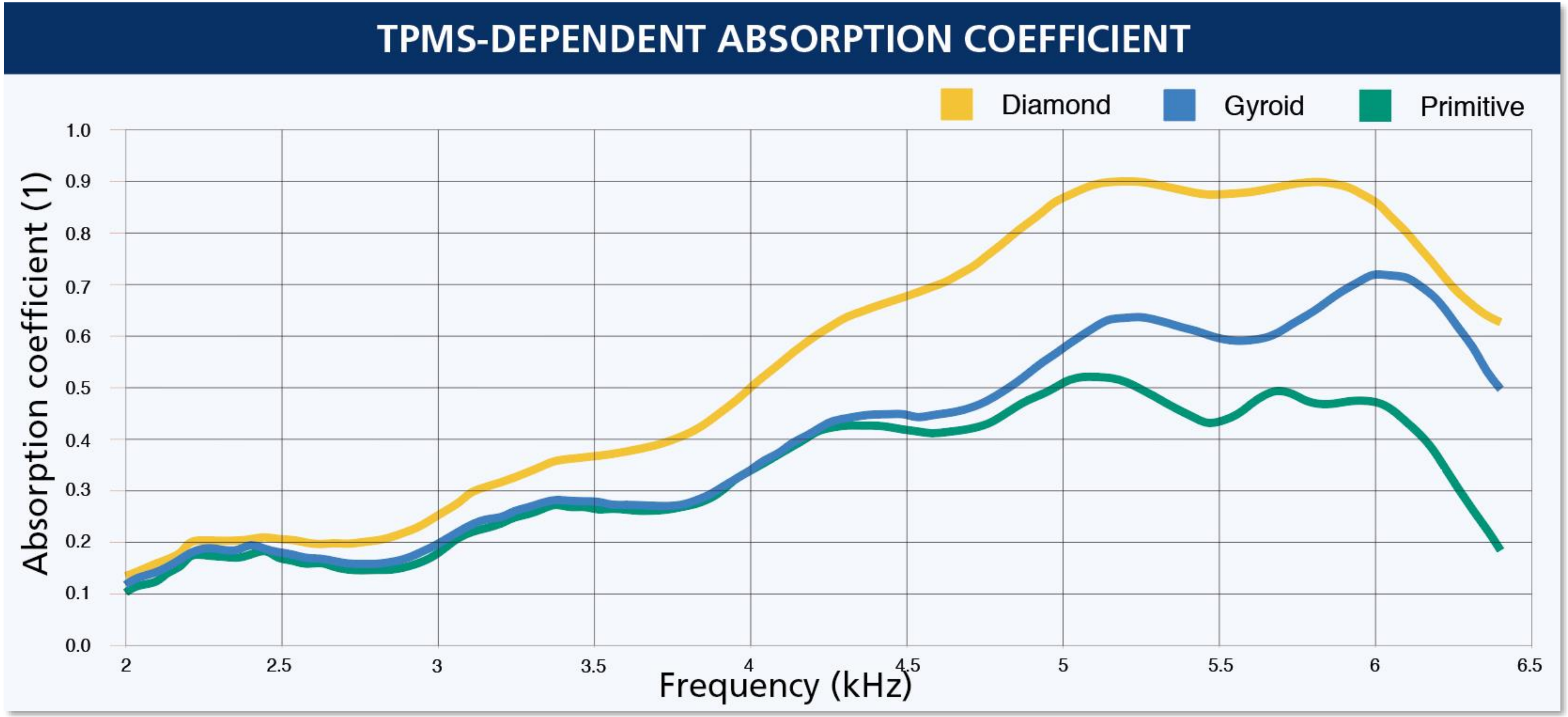
Which TPMS structure can be used for proper sound absorption?

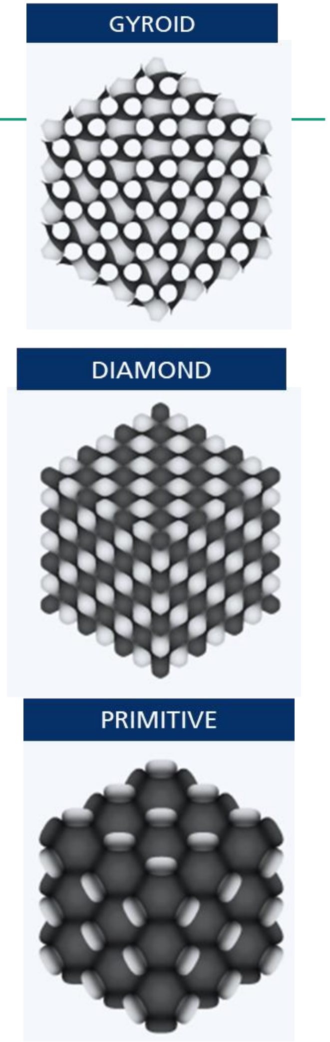
- Similar to mechanical vibrations, TPMS can also exhibit acoustic bandgaps.
- Higher relative densities lead to wider acoustic bandgaps.





APPLICATIONS – ACOUSTICS (CONT.)





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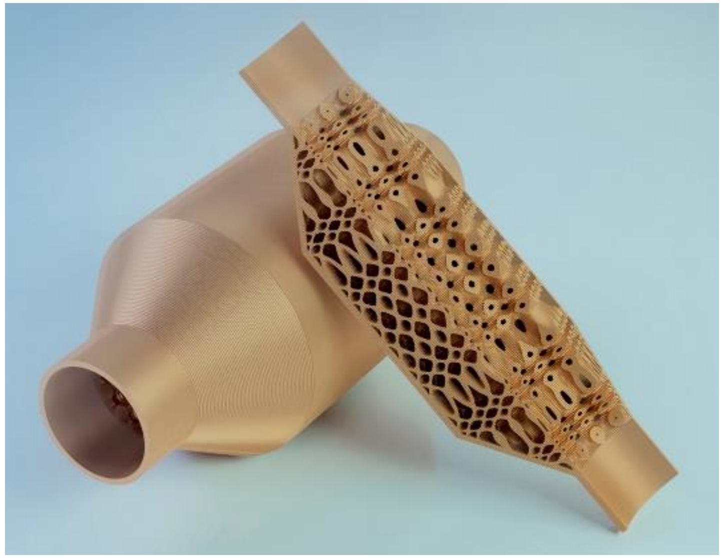
APPLICATIONS – ACOUSTICS (CONT.)



Use TMPS structures for acoustic design or damping of components.

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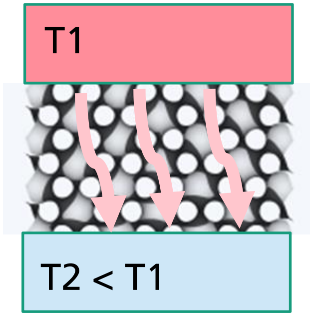
APPLICATIONS – HEAT TRANSFER

Key question:

Which TPMS structure can be used to realize a desired heat transfer or heat exchange?

low heat transfer

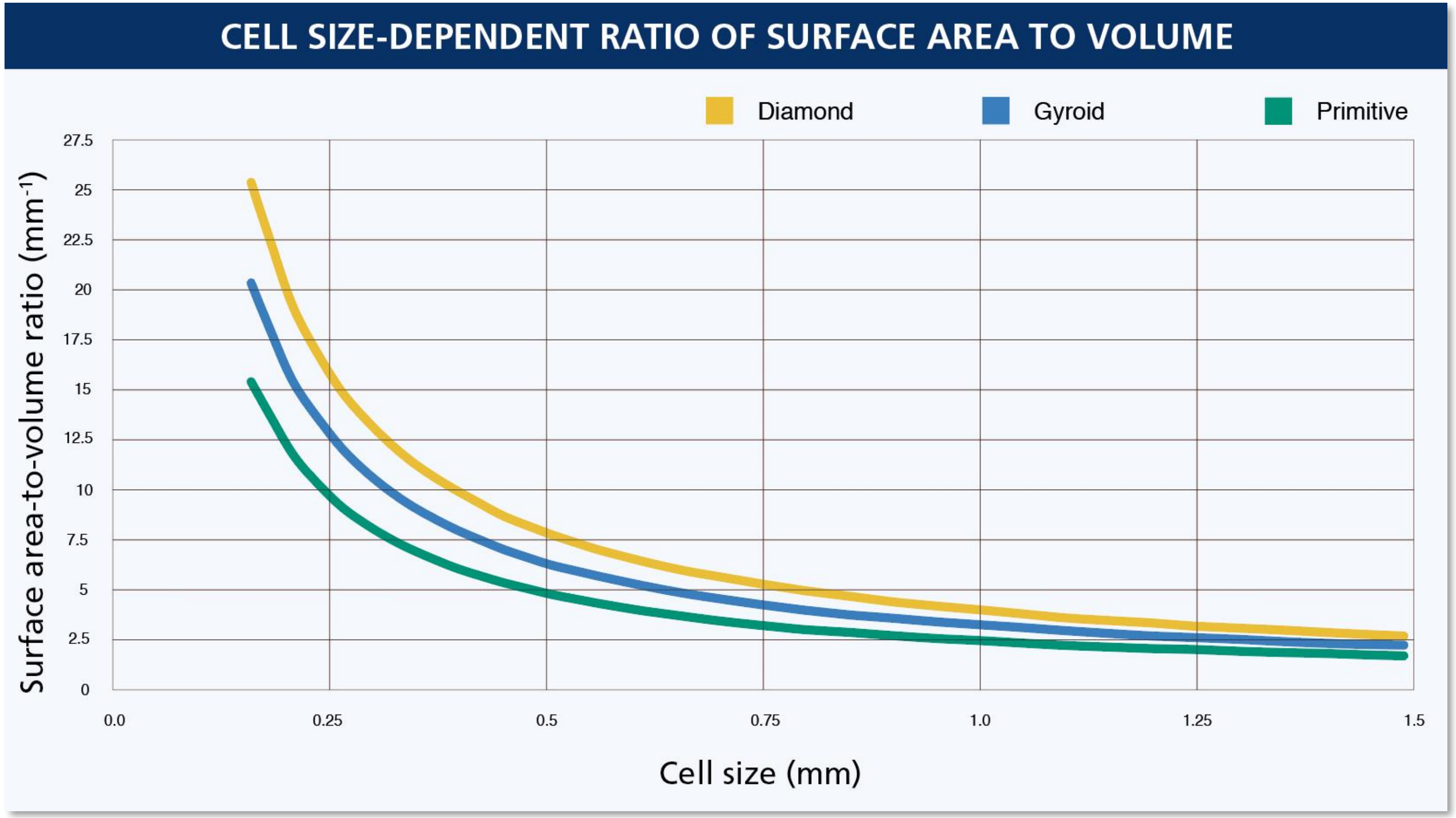


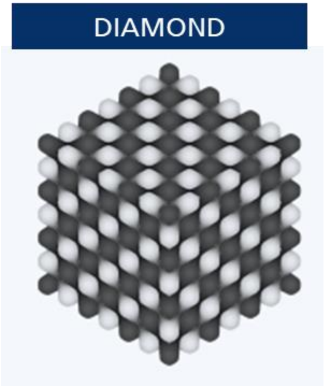
TPMS structures have a very high surface to volume ratio:

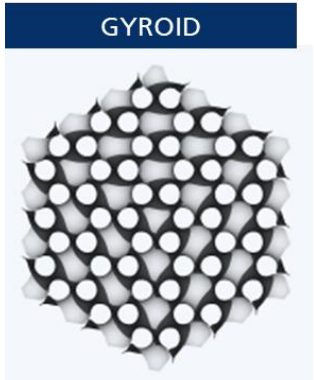
- Heat transfer → TPMS structures can be used to reduce heat transfer between two components.
- Heat exchange → TPMS structures can be used to increase heat exchange between two media flowing through the structure.

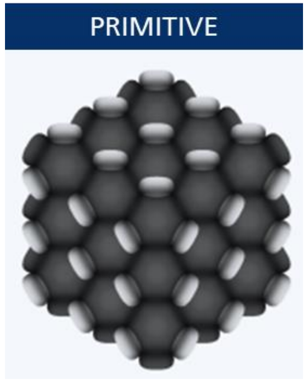
high heat exchange

APPLICATIONS – HEAT TRANSFER (CONT.)









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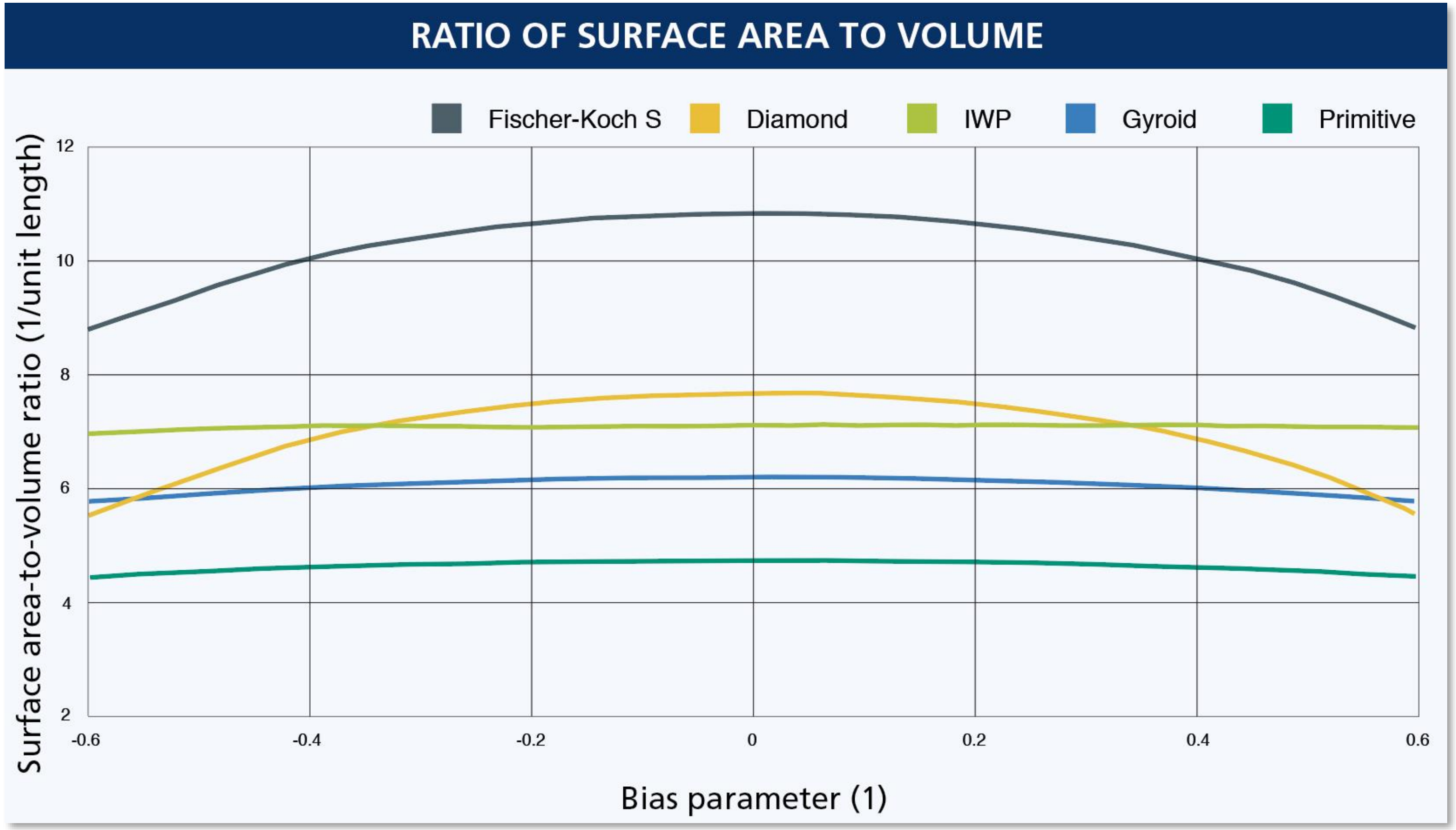
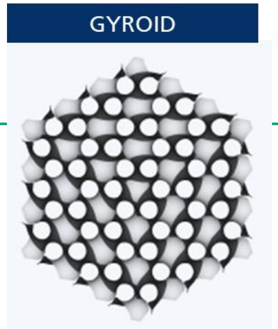
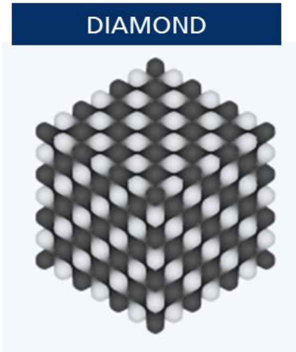
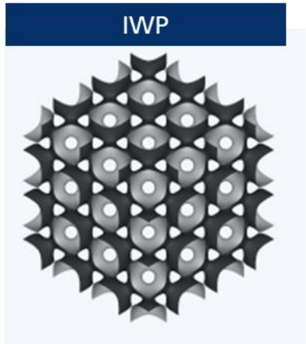
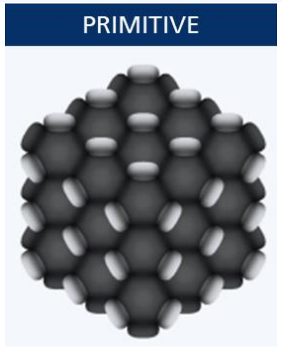
APPLICATIONS – HEAT TRANSFER (CONT.)











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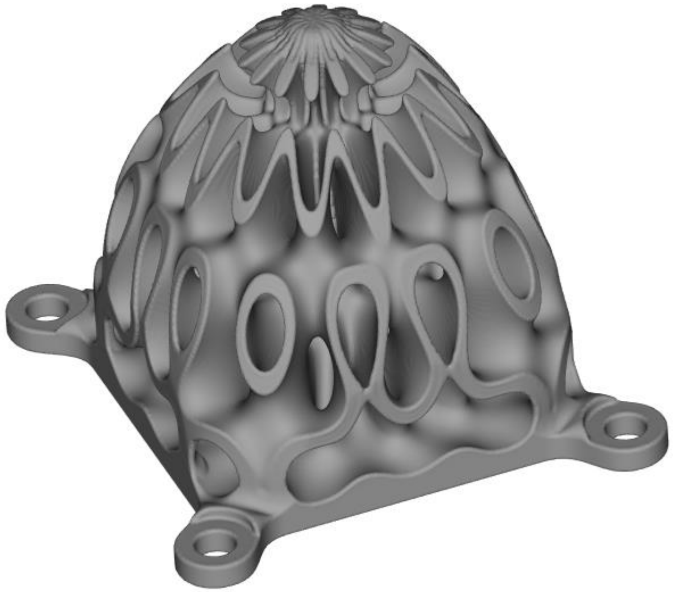
APPLICATIONS – HEAT TRANSFER (CONT.)



Use TMPS structures for highly efficient heat exchangers.

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APPLICATIONS – MEDICAL

Key question:

Why can TPMS structures be beneficial in bone scaffold and implant design?

- Medical requirements, technical requirements and properties of TPMS match very well
- Grading of TPMS allows specific adoption of structure to requirements of an implant / bone

Löw & Seibel (2021)

		Technical requirements						
		Large surface area	High permeability	Small curvature radii	Uniform load transfer	Matched stiffness	No stress peaks	Load-conform design
Medical requirements	High osseointegration	X	X	X				
	Avoidance of "stress shielding"				X	X		
	Sufficient strength						X	X
Requirements for mesostructure	High porosity	X	X			X		
	(Mathematical) smoothness			X			X	
	Functional grading		X		X	X		X

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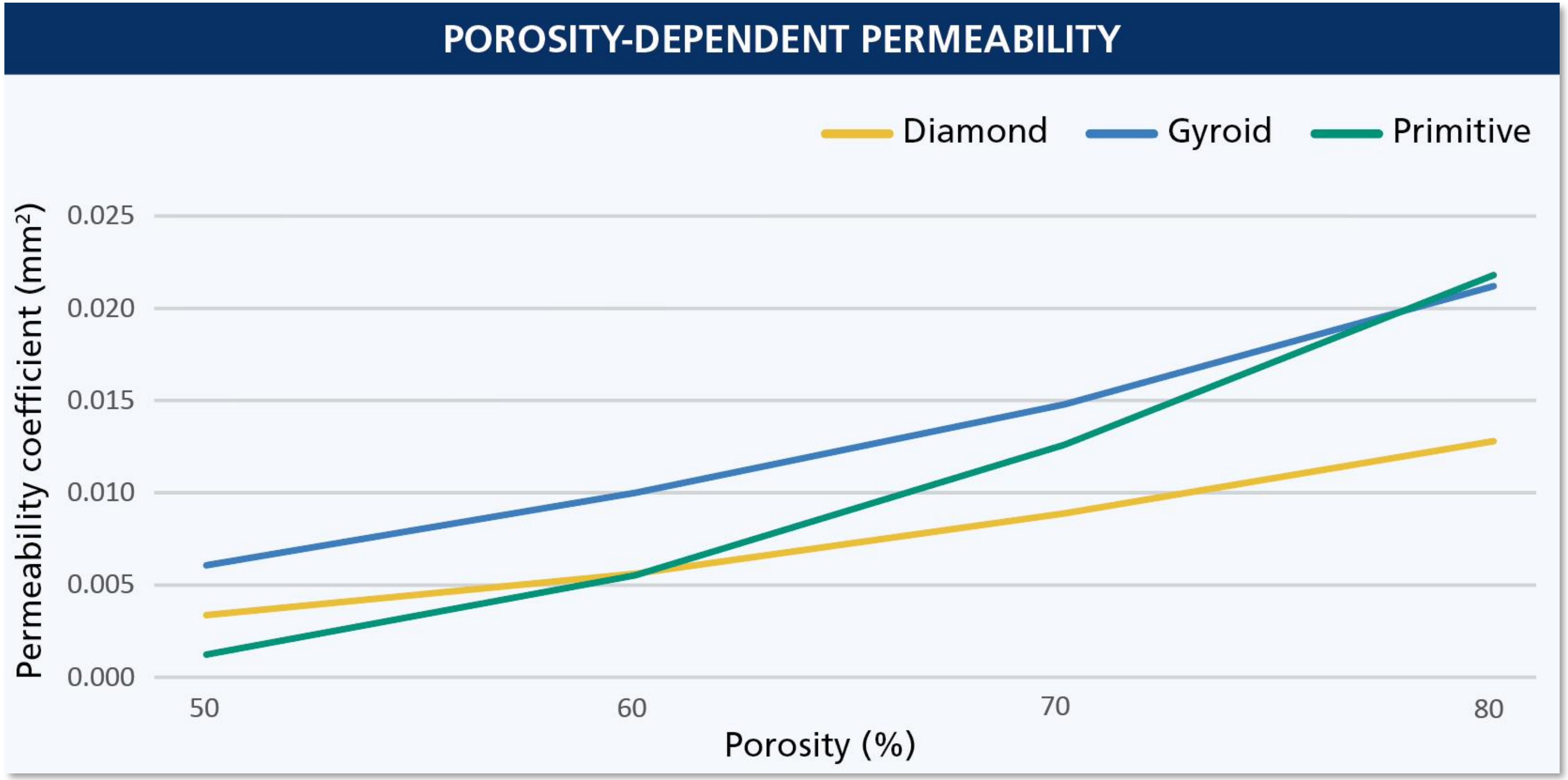
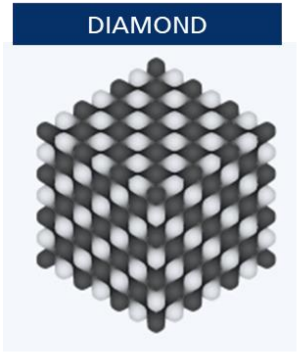
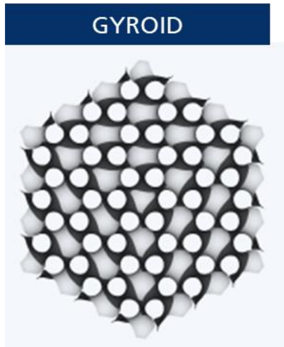
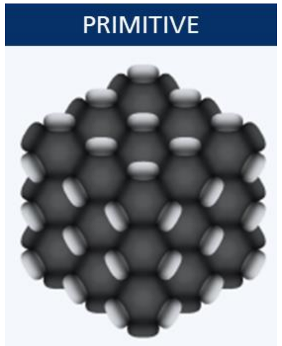
APPLICATIONS – MEDICAL (CONT.)









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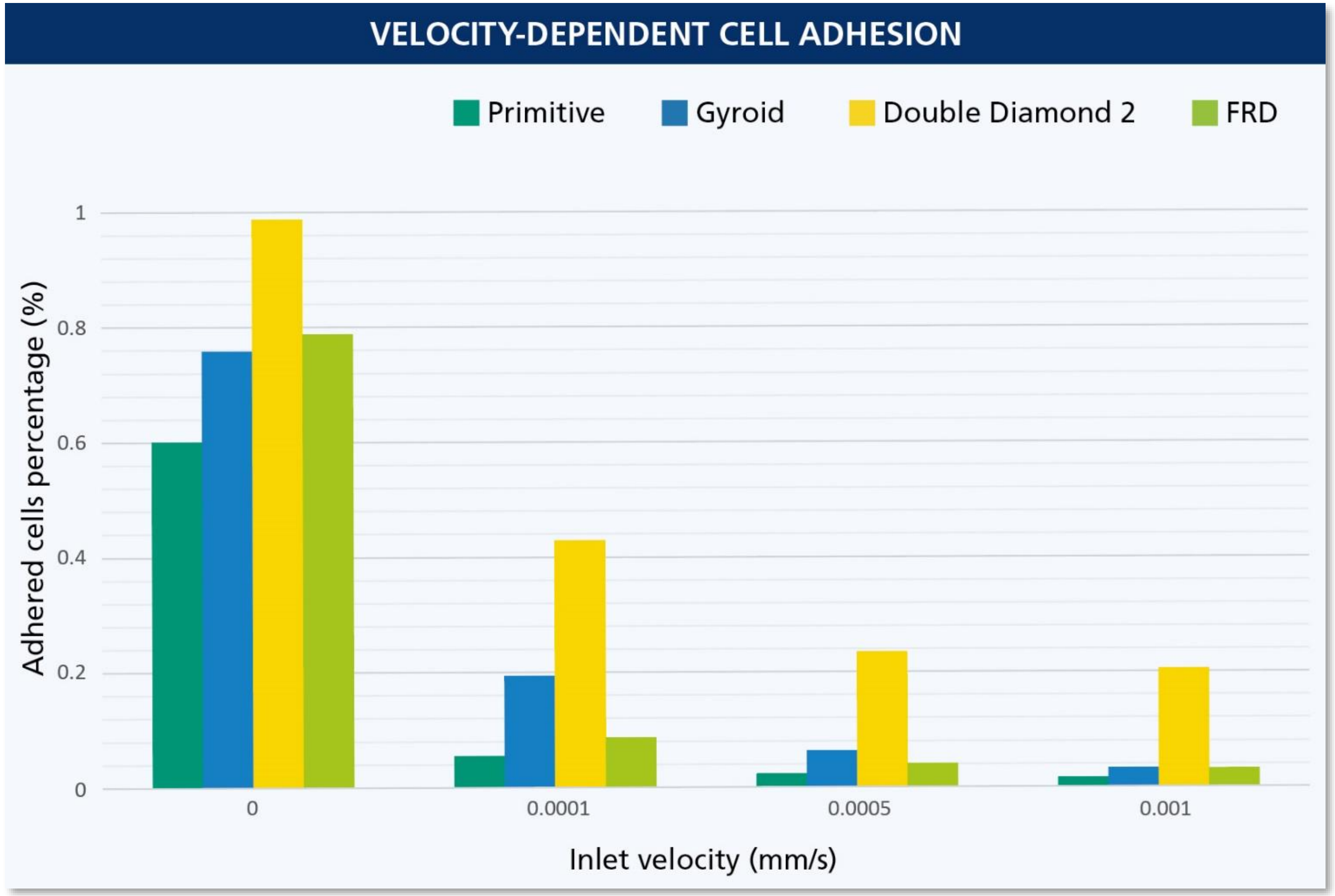
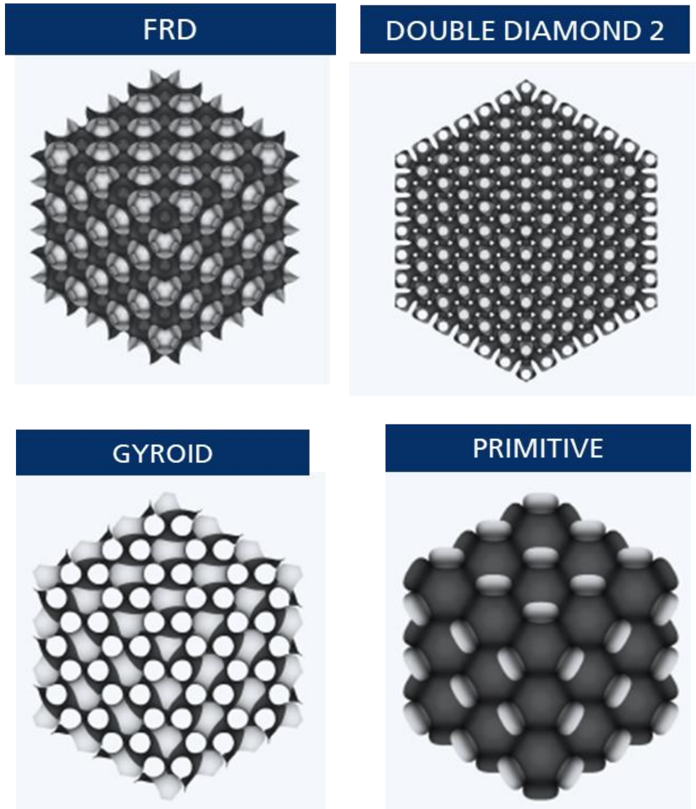
APPLICATIONS – MEDICAL (CONT.)





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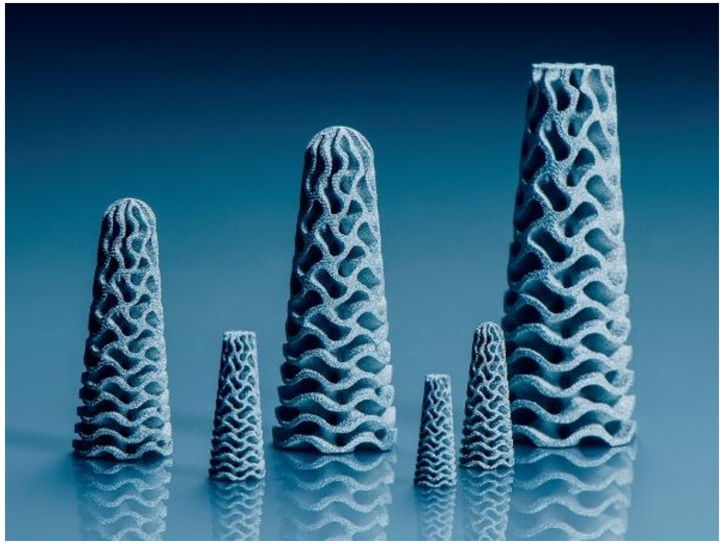
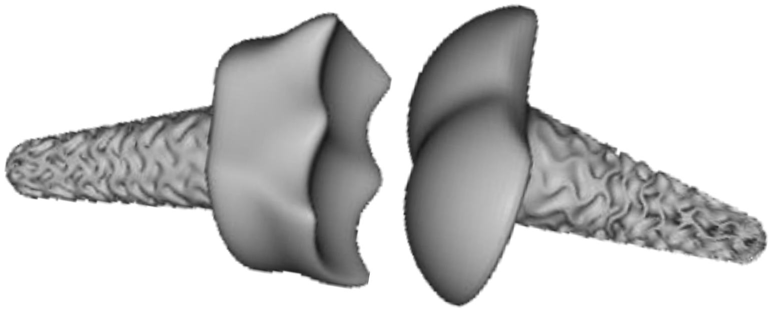
APPLICATIONS – MEDICAL (CONT.)





Use TMPS structures for implants (bone ingrowth).

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CONCLUSION

- Insight into structures based on TPMS
- Outstanding properties with regard to wide range of functions
- Additive manufacturing and modern modeling tools allow taking advantage of these properties.
- Individual applications need to undergo further investigations for creating functionally optimized products.

THANK YOU FOR YOUR ATTENTION!

QUESTIONS???