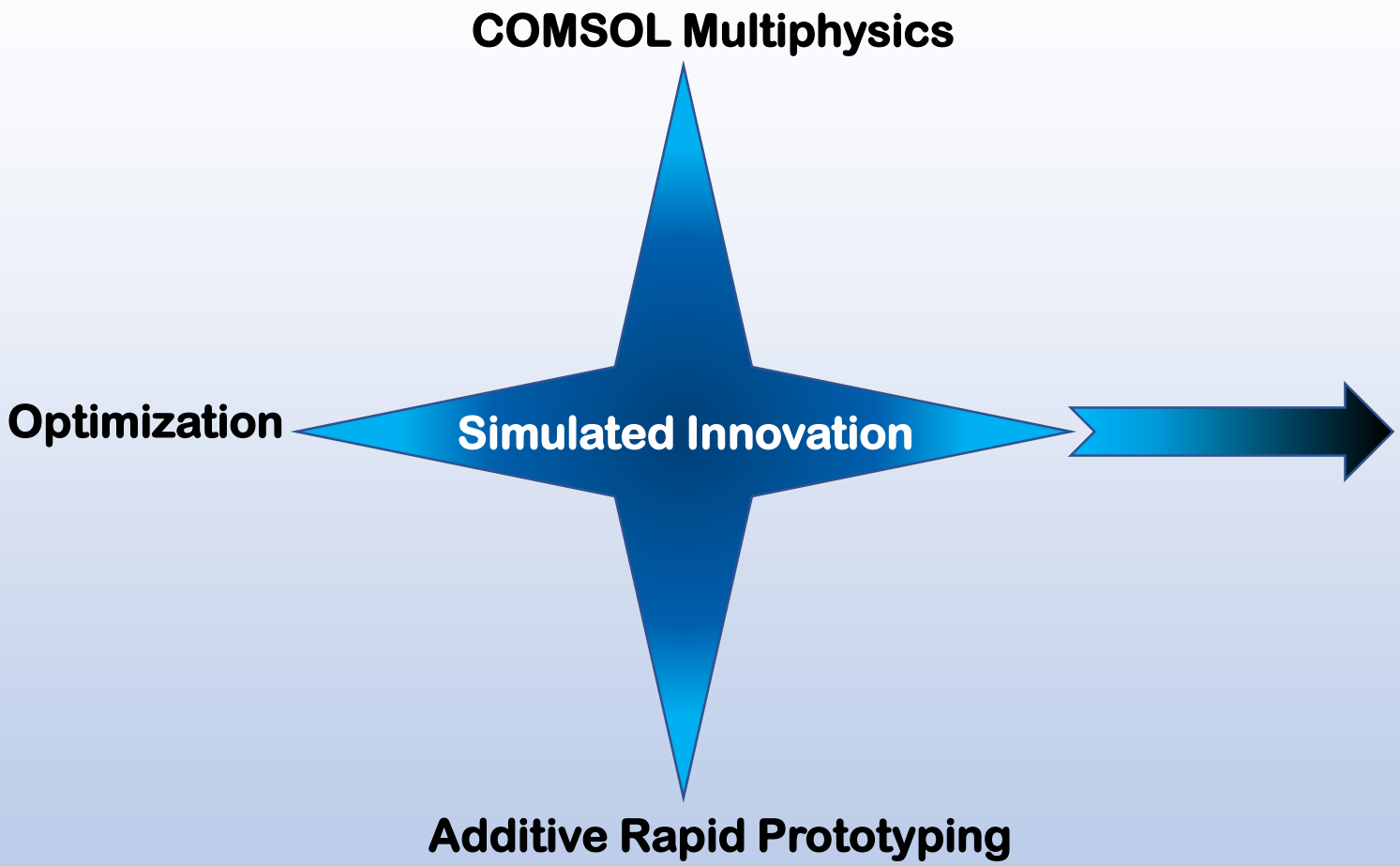
Simulated Innovation – Virtual Product Development



- ✓Low Carbon Footprint
- ✓Low P&E Spend
- ✓Fail Fast
- ✓Distributed Workforce
- ✓Speed to Market

Stephen Farmer PhD

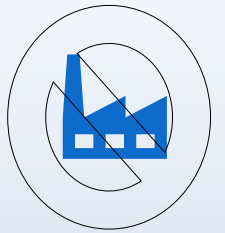
COMSOL Multiphysics is a great tool for in-depth simulation and analysis. The opportunities are only limited by our imagination and skill set.

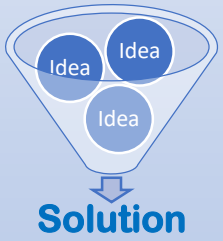
Technology enablers such as Cloud infrastructure, on-demand machine learning, scalable storage, and access to high-performance computing platforms provides an opportunity to embed multiphysics simulation into enterprise scale product development programs.

Simulated Innovation is a proposal to integrate multiphysics into a widely accepted stage-gate, new product development (NPD) process.

The process provides an opportunity to develop new products in a completely virtual path that:

- ✓ Leaves a very low carbon footprint
- ✓ Requires low P&E spend
- ✓ Is available for a distributed workforce
- ✓ Reduces the development cycle for new product speed to market
- ✓ Provides expanded design space to evaluate new ideas, fail fast and quickly iterate revised solutions





Virtual Product Development

Stage-Gate New Product Development Process

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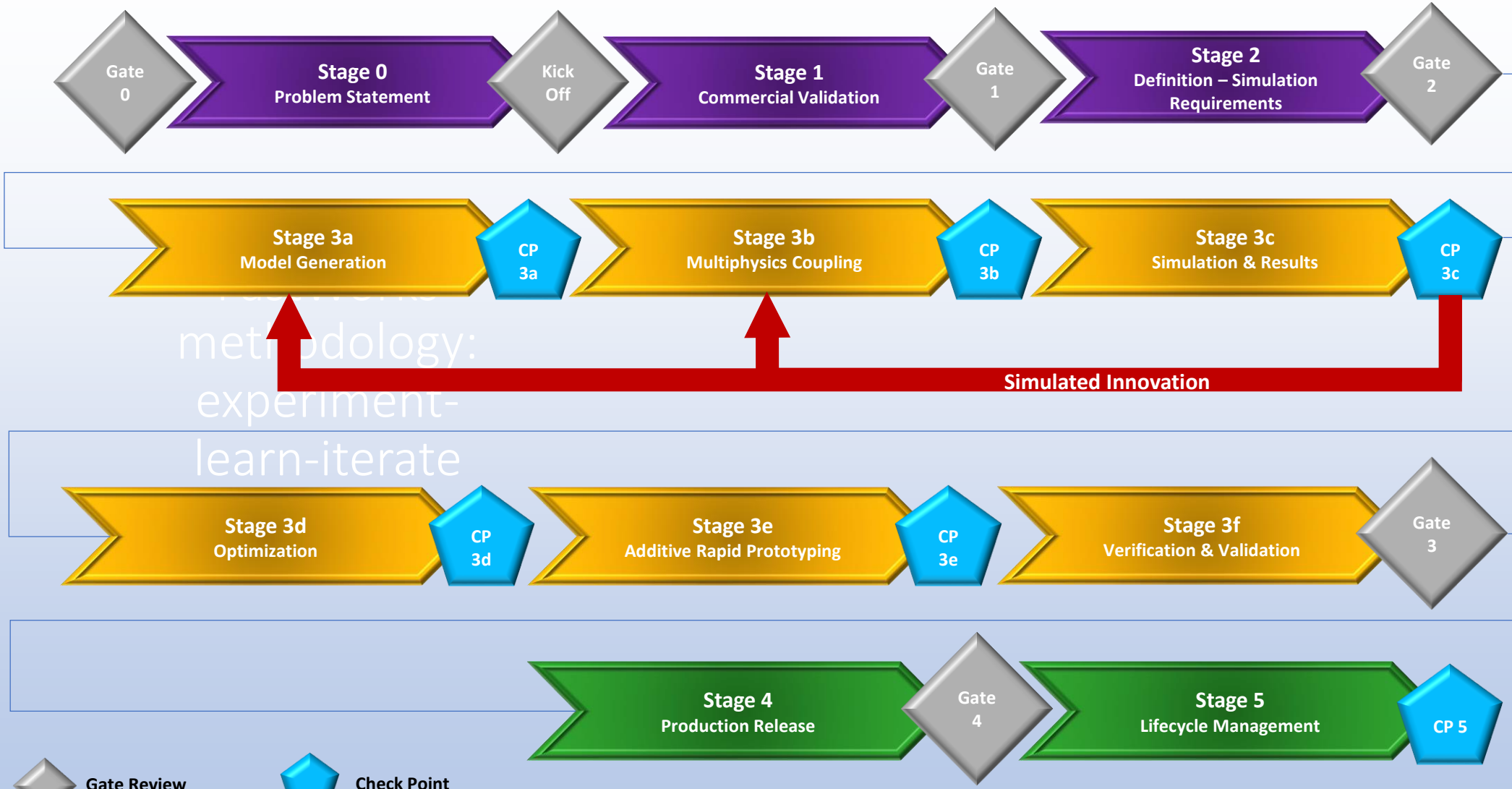

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Simulated Innovation

Definition and Simulation Requirements

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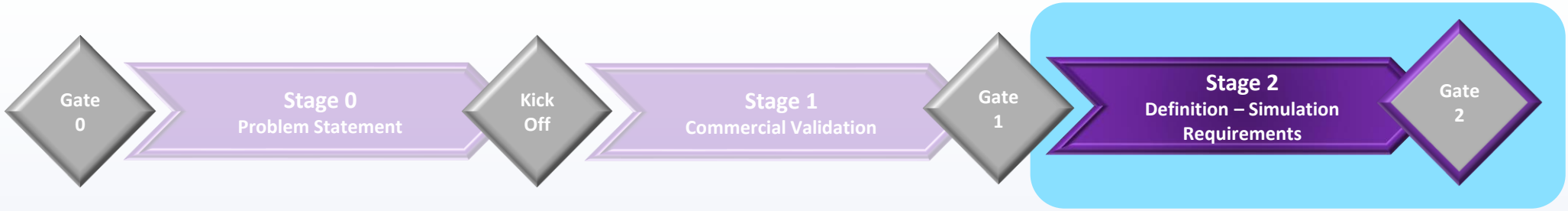

Stage 2

- ✓ Critical activity to transform physical world into virtual environment
- ✓ Requires close collaboration between the physical world subject matter experts and simulation experts
- ✓ Define variables and constraints such as:
  - Material properties
  - Geometry interfaces
  - Boundary conditions
  - Initial and operating conditions
  - Failure modes
  - Meshing strategy
  - Domain-sub-domain strategy

Stage 2

- ✓ Decide on sources for properties:
  - COMSOL materials library or user defined
  - Import CAD geometry, import mesh data, use LiveLink, or draw in COMSOL
- ✓ Conduct a Product Requirement Review (PRR) and Conceptual Design Review (CDR)

Gate Review 2

- ✓ Decide if still a viable project and approval to continue
- ✓ Set project milestones with resource allocation
- ✓ Evaluate gap analysis between requirements and COMSOL capabilities
- ✓ Update Design Review Checklist

Take time to fully understand the physical environment you are modeling

Model Generation

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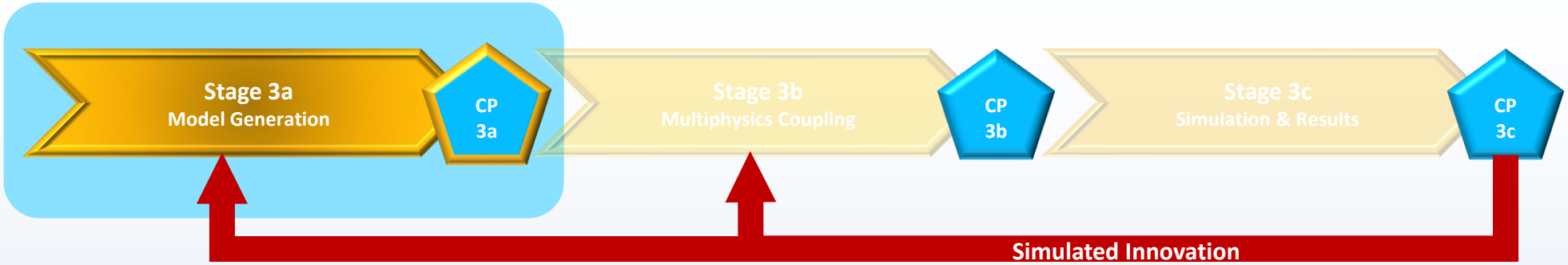

Stage 3a

- ✓ Solve all equations as one fully coupled system
- ✓ Determine physics interfaces:
  - Solid mechanics
  - Acoustics
  - Fluid flow
  - Heat transfer
  - Chemical species transport
  - Electromagnetics
- ✓ Consider using PDE user interface where custom models can be created in mathematical terms
- ✓ Select study types for your model:
  - Time-dependent
  - Stationary

Stage 3a

- ✓ More study types are:
  - Time dependent
  - Time discrete
  - Frequency to time/time to frequency FFT
  - Eingenvalue
  - Eigenfrequency
- Import or draw geometry in COMSOL software using decided method

Control Point 3a

- ✓ Conduct a Preliminary Model Review (PRR) with an extended team of simulation experts and consultants

Goal is to solve all equations as one fully coupled system

Multiphysics Coupling

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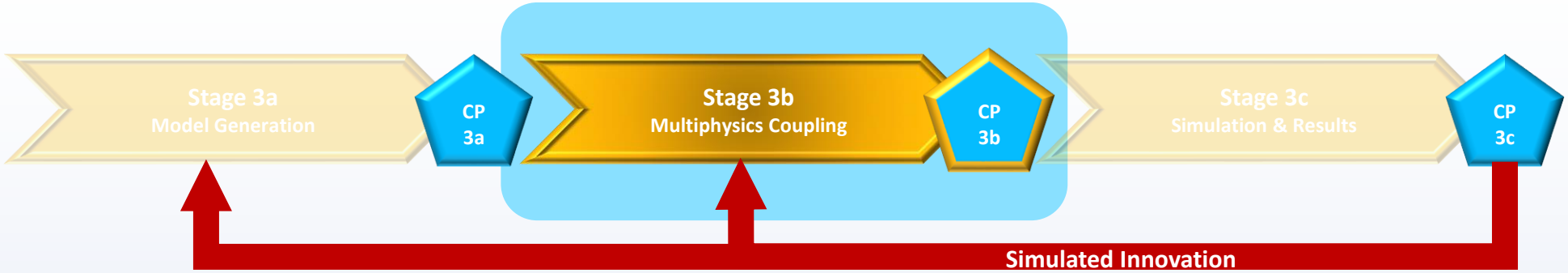

Stage 3b

- ✓ COMSOL physics interfaces typically use the finite element method to solve underlying partial differential equations
- ✓ FEM works by discretizing model domains into small, simplified, domains called elements
- ✓ The solution to these equations approximates the solution to the PDE
- ✓ Estimate the degrees of freedom (DOF): the number of nodes multiplied by the number of dependent variables
- ✓ The number of DOFs is related to the amount of memory a model will need
- ✓ DOF will be reported in the COMSOL GUI

Stage 3b

✓ Several possible approaches to reduce memory requirements:

- Exploit symmetry
- Simplify your problem
- Use submodeling
- Use a different mesh
- Use a lower discretization order
- Use a segregated solver that is not fully coupled

Control Point 3b

✓ Conduct a Detailed Model Review (DMR) with an extended team of simulation experts and consultants

Focus on how to minimize memory usage

Simulation and Results

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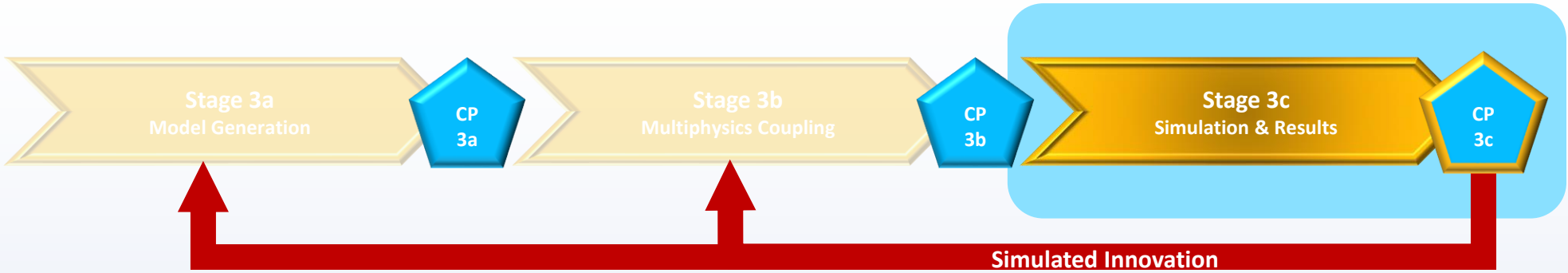

Stage 3c

- ✓ Confirm that the appropriate solvers are selected for the study steps
- ✓ Run the simulation and focus on any error messages or warnings
- ✓ Convergence errors (common) may require a repeat of Stage 3b
- ✓ Evaluate results:
  - Datasets
  - Derived values
  - Evaluation groups
  - Plot groups
  - Tables
- ✓ Use COMSOL's great report generation feature

Control Point 3c

- ✓ Conduct Preliminary Design Review (PDR) to ensure compliance with product requirements
- ✓ Create and review Product Design FMEA (DFMEA) to be reviewed and updated during subsequent steps
- ✓ CP3c is a decision point where development moves into Stage 3d (Optimization) or reverts to Stage 3b (Multiphysics Coupling)/Stage 3a (Model Generation)
- ✓ The point where you move back depends on how the results vary from expected results and requirements
- ✓ Include the physical experts (product and applications Engineers) in the decision to move forward or back in the process

Make decision to move into Optimization or rework the simulation

Optimization

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Stage 3d

- ✓ Optimization is a type of solver that typically requires the COMSOL Optimization Module
- ✓ Dimensional optimization involves defining design variables that can be directly translated to manufacturability
  - Examples include hole sizes, length, width and height of structural members
  - Derivative free methods such as bound optimization and constraint optimization are typically used
- ✓ Shape optimization is a more free-form alteration of the object without over-constraining design
  - Gradient based methods are preferred

Stage 3d

- ✓ Topology optimization treats the distribution of material as a design variable and inserts or removes structures to improve function
  - Gradient based optimization is practical due to the high number of design variables
- ✓ Steps include identifying the objective function that defines the system and defining a set of constraints, bounds and operating conditions

Control Point 3d

- ✓ Conduct a Detailed Design Review (DDR) of product design and related simulations to ensure compliance to product requirements

Optimize by changing variables while still satisfying constraints

Additive Rapid Prototyping

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Stage 3e

- ✓ Export the 3D model of the optimized simulation into a CAD software
- ✓ LiveLink will automatically update the CAD model
- ✓ Build the model from plastic using a common modality such as stereolithography (SLA) to confirm fit and form
- ✓ Continue with rapid prototyping at scale in the qualified metallic material
- ✓ Develop a plan to move from rapid prototyping to digital thread manufacturing
- ✓ Consider 3D model optimization using MBD and MBE methodologies

Control Point 3e

- ✓ Conduct an Additive Manufacturing Review (ADMR) to evaluate dimensional tolerances, critical to quality (CTQ) attributes such as hardness, yield/tensile strength, run-out and surface finishes.
- ✓ Consider sub-scale component testing to validate any sub-scale models
- ✓ Review any additive material test reports from 3rd party labs

Additive Manufacturing offers an expanded design space

Verification and Validation

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Stage 3f

- ✓ Create a plan and complete testing to ensure performance CTQs are achieved
- ✓ Conduct a Design Verification Review (DVR) to evaluate prototype/pilot unit test results, verify the product design complies with product requirements, and release designs for full production
- ✓ Complete any additional tests including performance, hydro, material, and lifecycle
- ✓ Identify customer test installations where products can be monitored in a controlled application

Gate Review 3

- ✓ Complete installation and service validation and documentation
- ✓ Collect Engineering and Supply Chain feedback for design for manufacturability options
- ✓ Evaluate customer feedback (VoC)
- ✓ Update application guidelines and quoting limits
- ✓ Initiate internal and external communications/training campaigns
- ✓ Conduct Approval to Quote (ATQ) authorizing Application Engineering, Marketing and Sales to begin the market introduction process
- ✓ Close program and move to lifecycle management (Stage 4-5)

Complete V&V testing and begin commercial engagement

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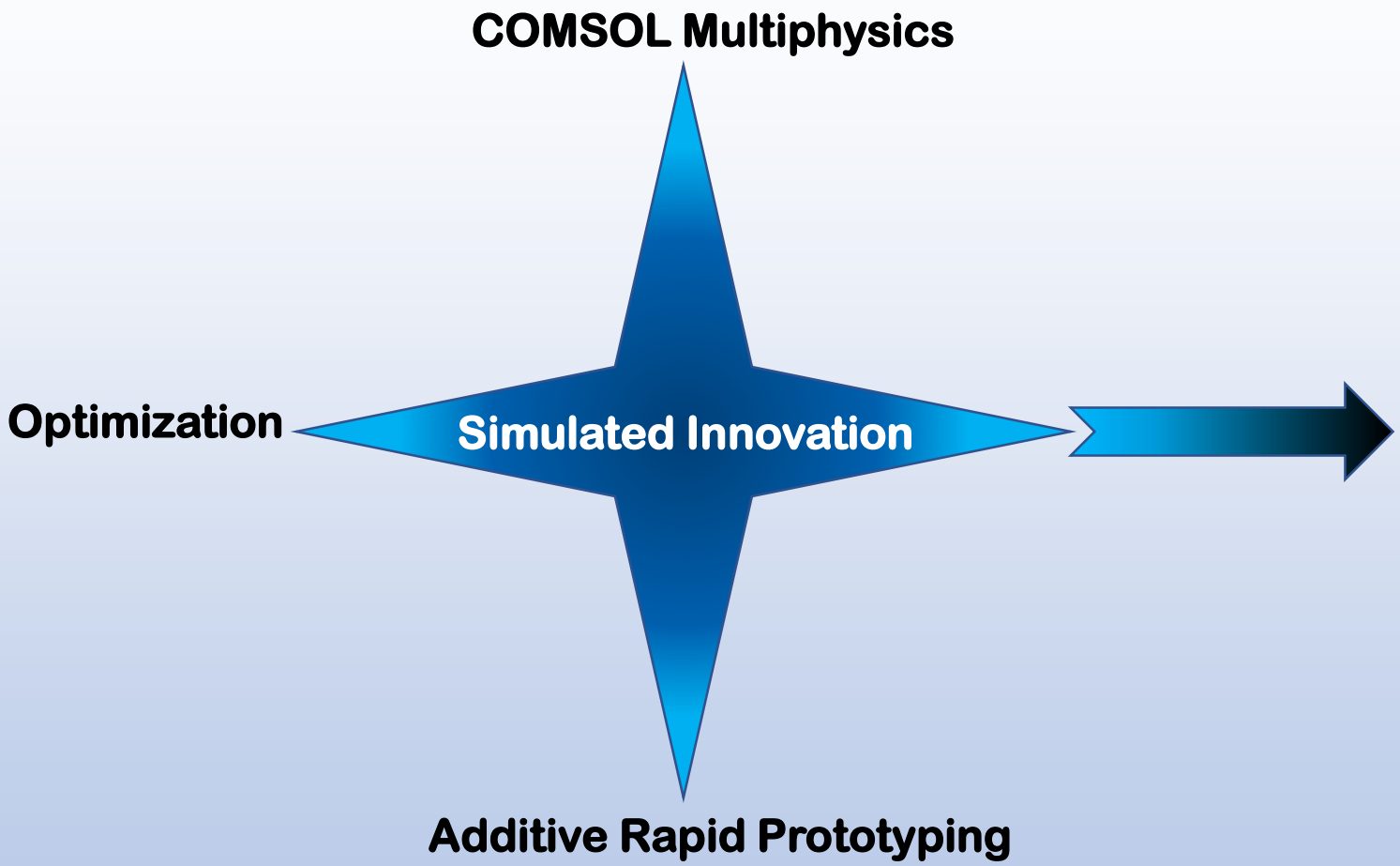

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