

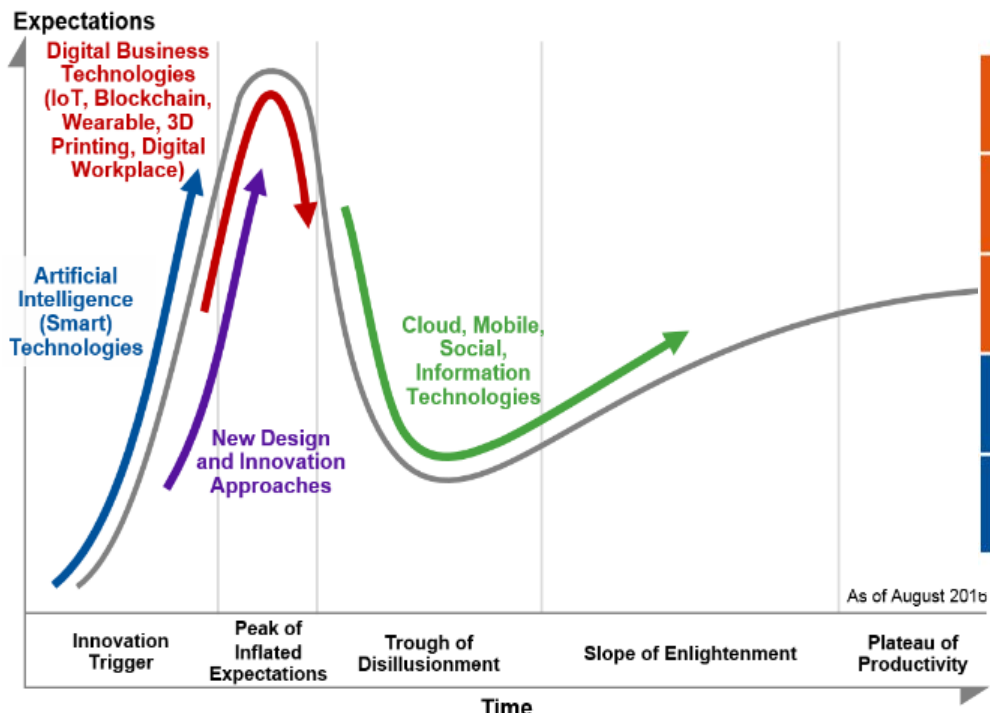
Nathan W. Hartman, Ed.D.

Dauch Family Professor of Advanced Manufacturing

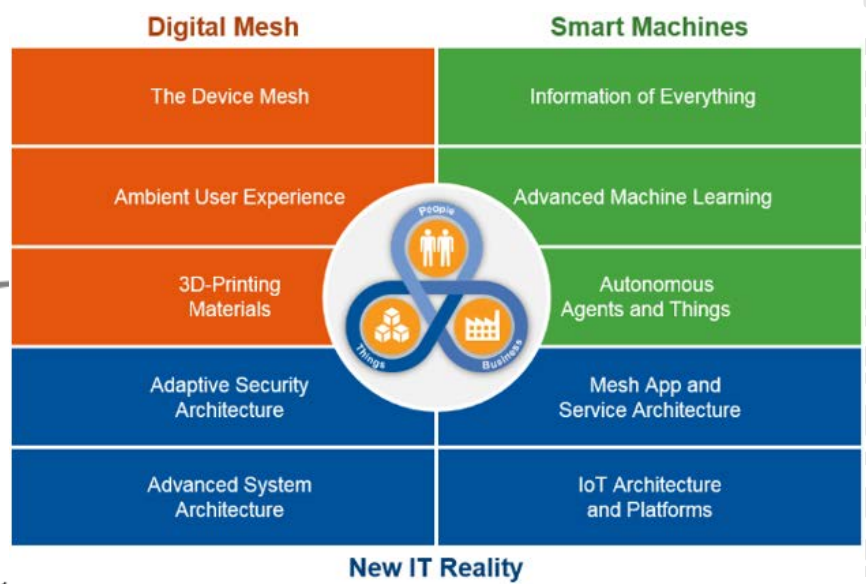
Director, Purdue University PLM Center of Excellence

ESTABLISHING A LEXICON FOR THE MODEL-BASED ENTERPRISE

A new world...



Source : Gartner 2016 Hype Cycles



- By 2018, 20% of all business content will be authored by machines
- By 2018, more than 3 million workers globally will be supervised by a "roboboss"
- By 2020, more than 35 billion things will be connected to the Internet
- The growing range of 3D-printable materials will drive a compound annual growth rate of 64.1% by 2019

Source : Gartner Analysis

Ongoing industrial challenges



Driving product lifecycle data with high fidelity representations

Global competition

Design/make vs. make to print (model)? → supply chain transformation

Increasing product complexity

Product knowledge stored with people or artifacts?

Mobility, Collaboration, and Interfaces → the social psychology of expertise

Securing digital product and process data through the enterprise

Funding priorities for education focus on jobs that are not there

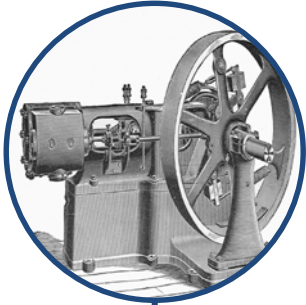
Difficult to hire new workers with requisite knowledge

The next industrial revolution

Mechanization, mass production, automation, digitalization

Four Industrial Revolutions

Industry 1.0



1

End of 18th Century

Use of manual labor, **water and steam power** to run machines and facilities.

Industry 2.0



2

Beginning of 20th Century

Electrical power generation and use of **electricity** to enable longer running machines and mass production.

Industry 3.0



3

Middle of the 20th Century

Use of electronics and basic computing to **automate** production. Menial, repetitive tasks began to be replaced by machines.

Industry 4.0



4

Today and beyond

Use of IT infrastructure to **connect** machines and humans in a **digital** environment. Automated processes with active machine monitoring and analysis.

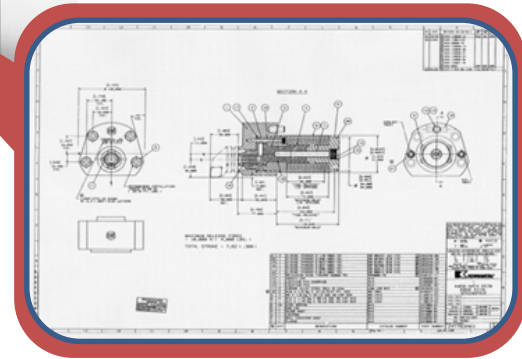
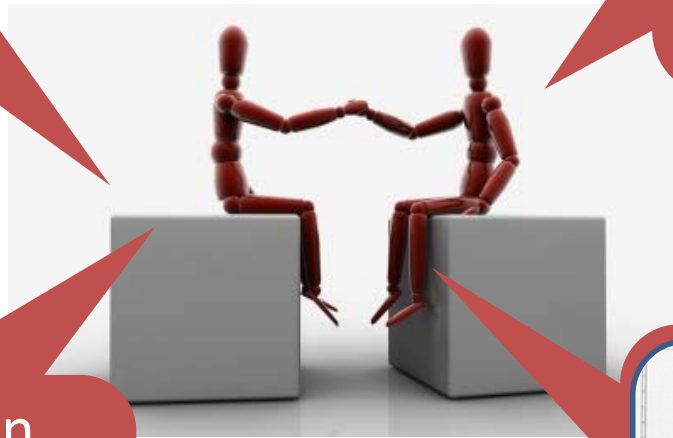
The collaboration journey...

Yesterday

Communications
often in serial
fashion

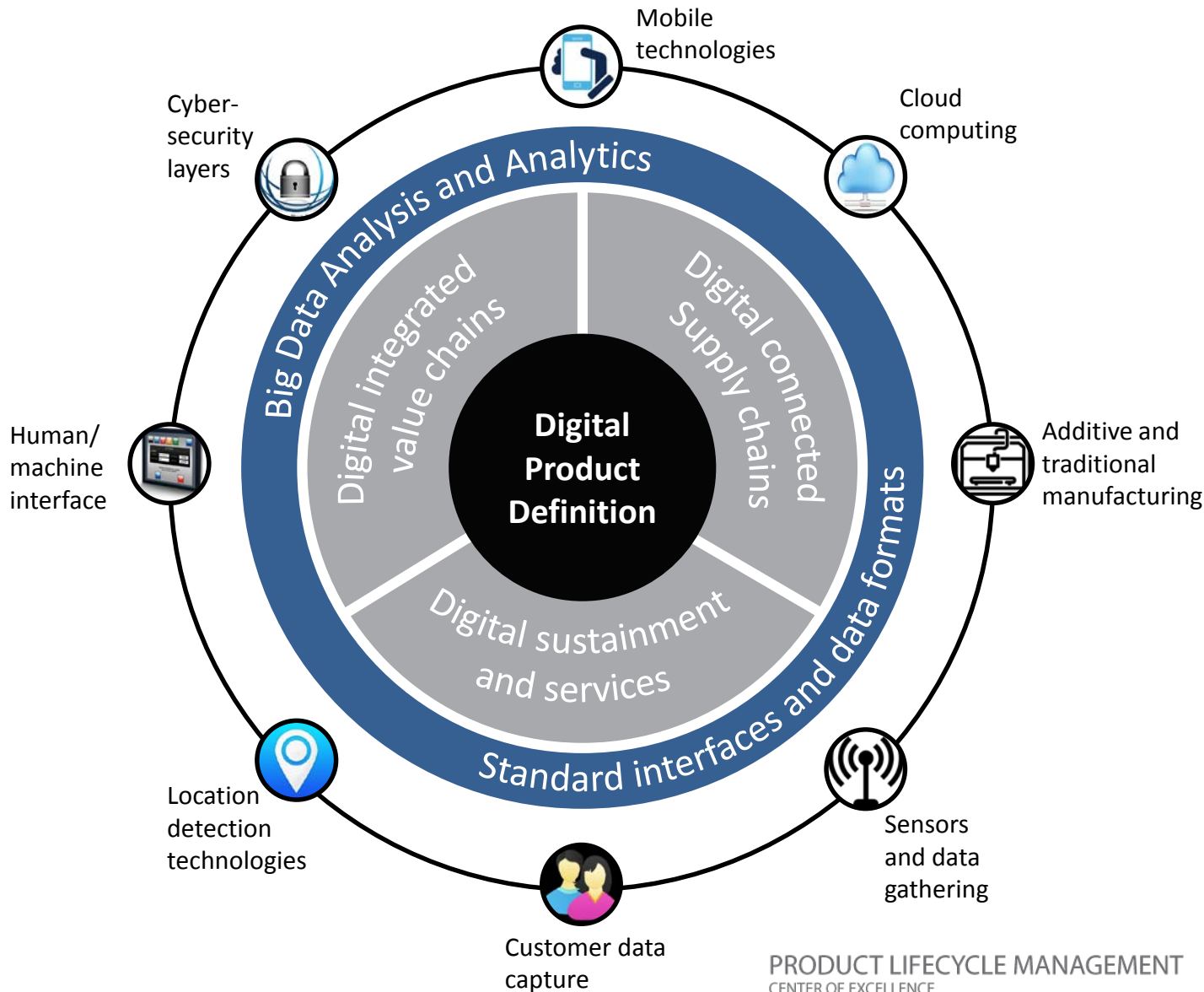
You trusted the
data because you
trusted the person
that generated
the data

Collaboration
meant face-to-
face
communication



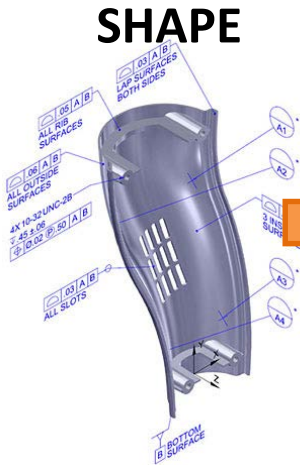
What is a digital enterprise?

A digital enterprise changes the way people work and how they use information



The communications spectrum...

A complete MBD supports lifecycle communication

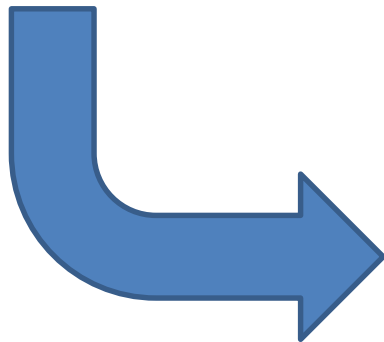
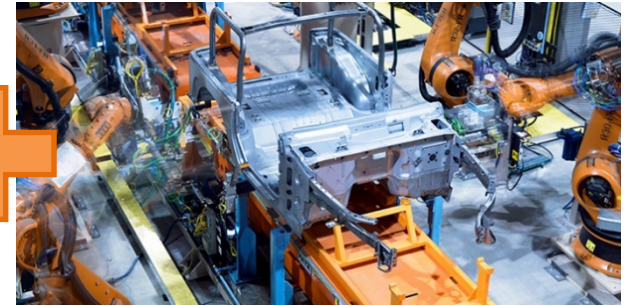


BEHAVIOR

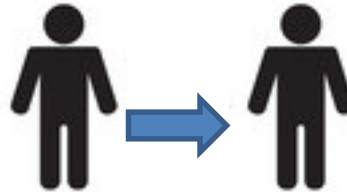
3.

Property	Test Standard DIN/ON EN ISO	corr.to ASTM	Unit	Value	Testing Frequency
Nominal Thickness			mm	78 100 98 196	
			mm	2.0 2.5 3.0 5.0	
			%	+10/-5 +10/-5 +10/-5	every hour
Density (Black)	DIN EN ISO 14632	D 5994	g/cm3	≥ 0.94	per production run 1)
Density (base/coloured)	ISO 1183	D792	g/cm3	≥ 0.931/935	
Melt Flow Rate (190°/5kg)	ISO 1183 Cond T	D 1238 Cond P	g/10 min	≤ 3 ≤ 3 ≤ 3 ≤ 3	per production run 1)
	(190/2, 16kg)	D 1238 Cond E		≤ 1 ≤ 1 ≤ 1 ≤ 1	
Heat Reversion (110°C/1, 5h)	DIN EN ISO 14632	D 1204 modified	%	≤ 3 ≤ 3 ≤ 3 ≤ 2	per production run 1)
Tensile Stress at Yield	DIN EN ISO 527	D 6693	MPa (PSI)	≥ 15 ≥ 15 ≥ 15 ≥ 15 2,200 2,200 2,200 2,200	per production run 1)
Elongated at Yield	DIN EN ISO 527	D 6693	%	≥ 9 ≥ 9 ≥ 9 ≥ 9	per production run 1)
Elongated at Break	DIN EN ISO 527	D 6693	%	≥ 300 ≥ 300 ≥ 300 ≥ 300	per production run 1)
Instrumented Puncture Test (Penetration Test)	ON EN ISO 6603-2	D 4833	N (lbs)	≥ 1500 ≥ 1800 ≥ 2000 ≥ 2500 ≥ 537 ≥ 625 ≥ 750 ≥ 1250	Approval Testing

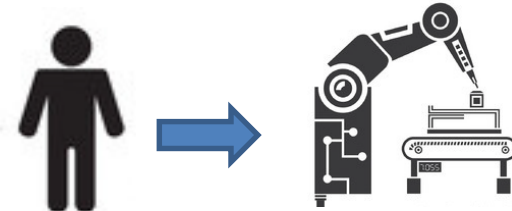
CONTEXT



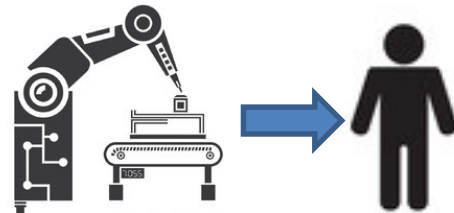
HUMAN TO HUMAN



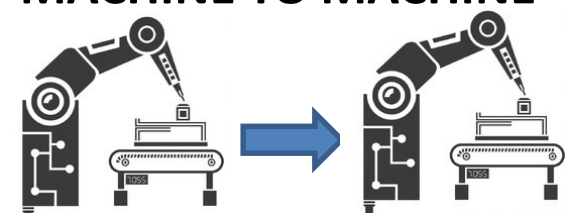
HUMAN TO MACHINE



MACHINE TO HUMAN



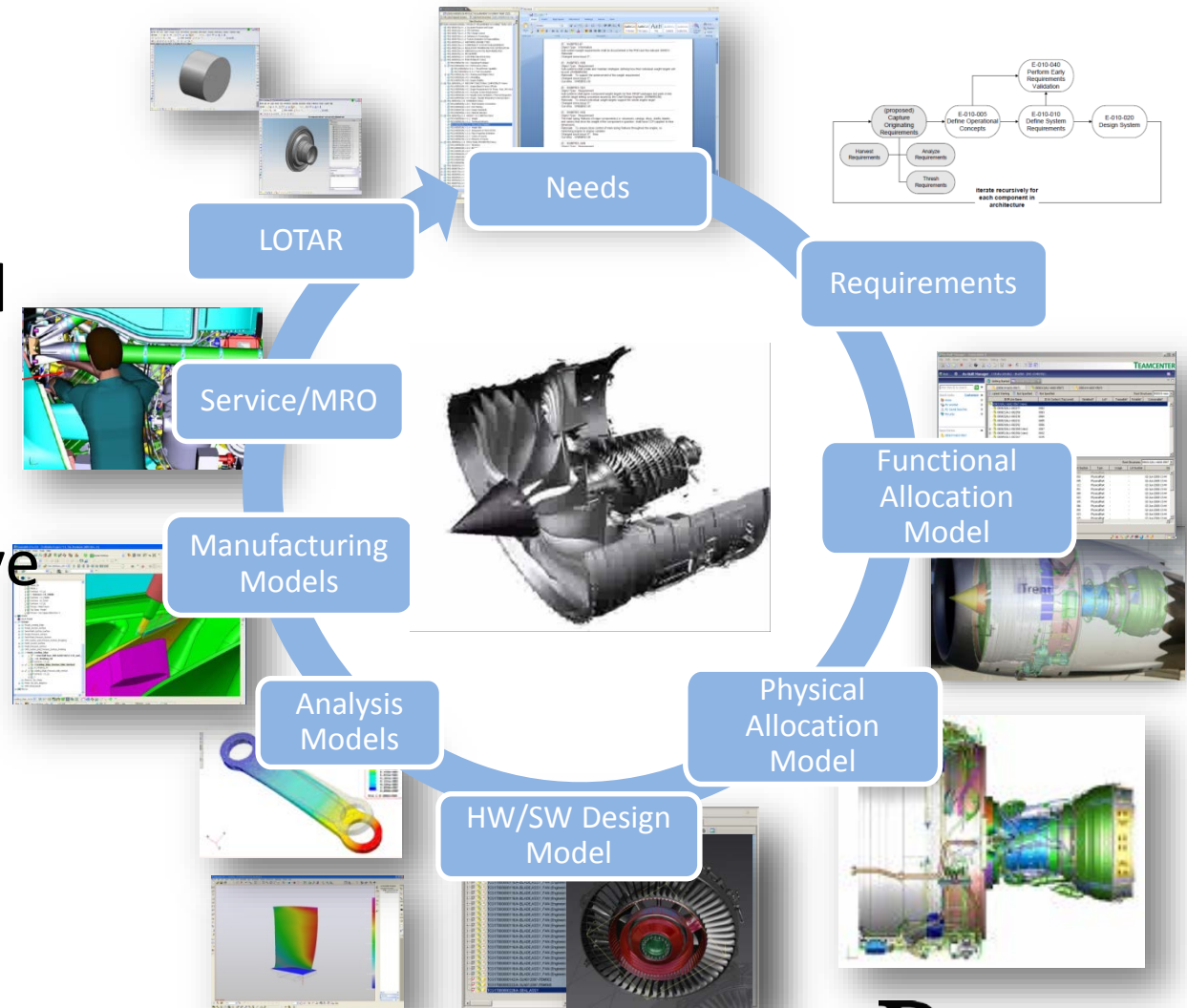
MACHINE TO MACHINE



The product lifecycle and the digital enterprise

The digital product definition forms the core of how product information is moved through this sociotechnical system.

- However, still sequential
- Dynamic model re-purposing still lacking
- MBD must move beyond shape
- Lifecycle loop still not connected



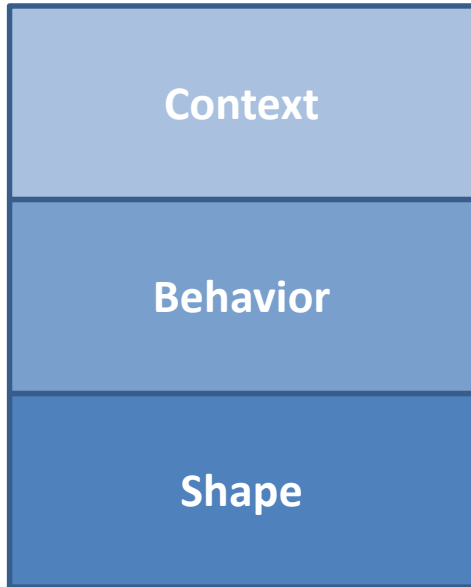
Clearing up some vocabulary...

- A **model-based enterprise** (MBE) is an **environment**. It is an organization that has transformed itself to leverage model-based information in its various activities and decision-making processes. In this environment, the model serves as a dynamic artifact that used by various authors and consumers of information for their respective tasks. The MBE embraces feedback from the various lifecycle stages to improve the model representation for the creation of subsequent products and product iterations. People working within the enterprise have an enlightened view of digital product information that can be leveraged in their daily work.
- **Model-based** _____ (MBx) Model-based engineering, model-based manufacturing (MBm), model-based sustainment (MBs), and any other model-based [fill in the blank] (MBx) are categories of **activity** within the model-based enterprise. Any of these activities (and the people in them) use digital product data to represent shape, behavioral, and contextual information carried by the model-based definition to execute their functional role. Model-based activities are conducted by relying on the predictive and archival capabilities of the model, by replying on its high levels of fidelity to physical object or system.
- A **model-based definition** (MBD) is a **thing**. It is a digital representation (artifact) of an object or system. It is representative of the physical object or system and all of its attributes, and is used to communicate information within various MBx activities in a model-based enterprise. The MBD is rich in information – shape, behavior, and context – and it travels the information architecture within an enterprise (including its extended supply chain and customers), providing input to the various authors and consumers who need it. The model-based definition is analogous to the *digital twin*, although most people today do not think of it in such broad view. And the *digital thread* is the combination of the MBD and the IT architecture that connects the various functional areas of the model-based enterprise.

What is the model-based definition?

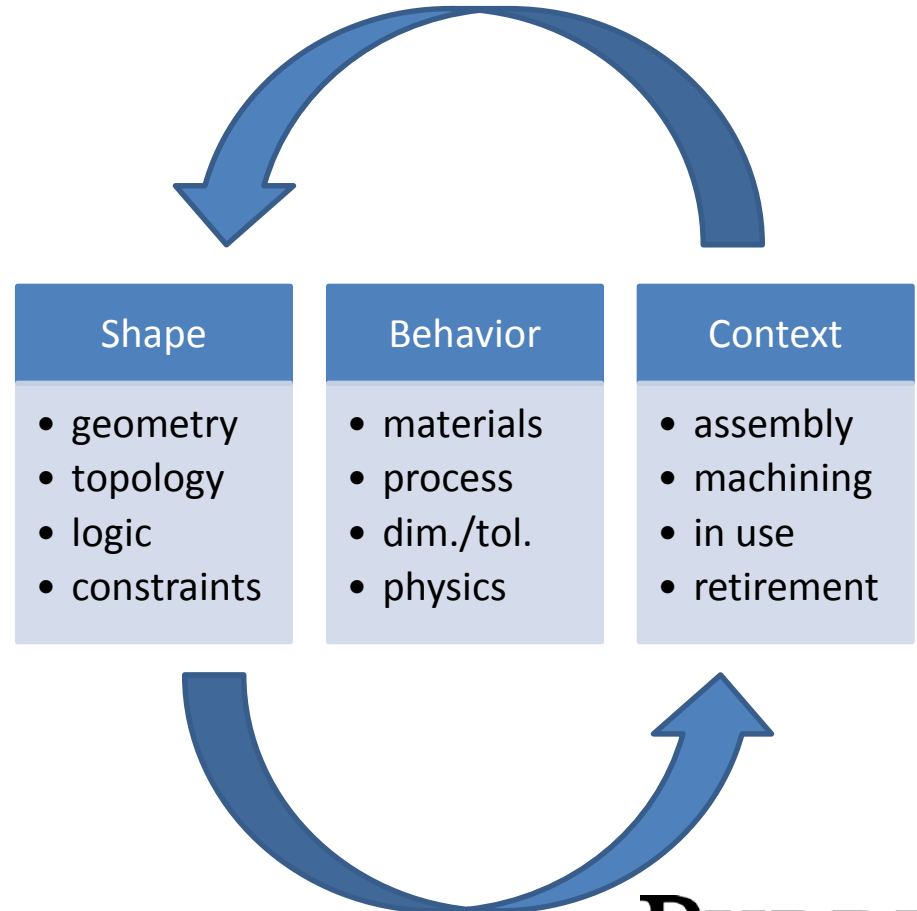
Singular representation vs. multiple, connected representations

Singular Representation



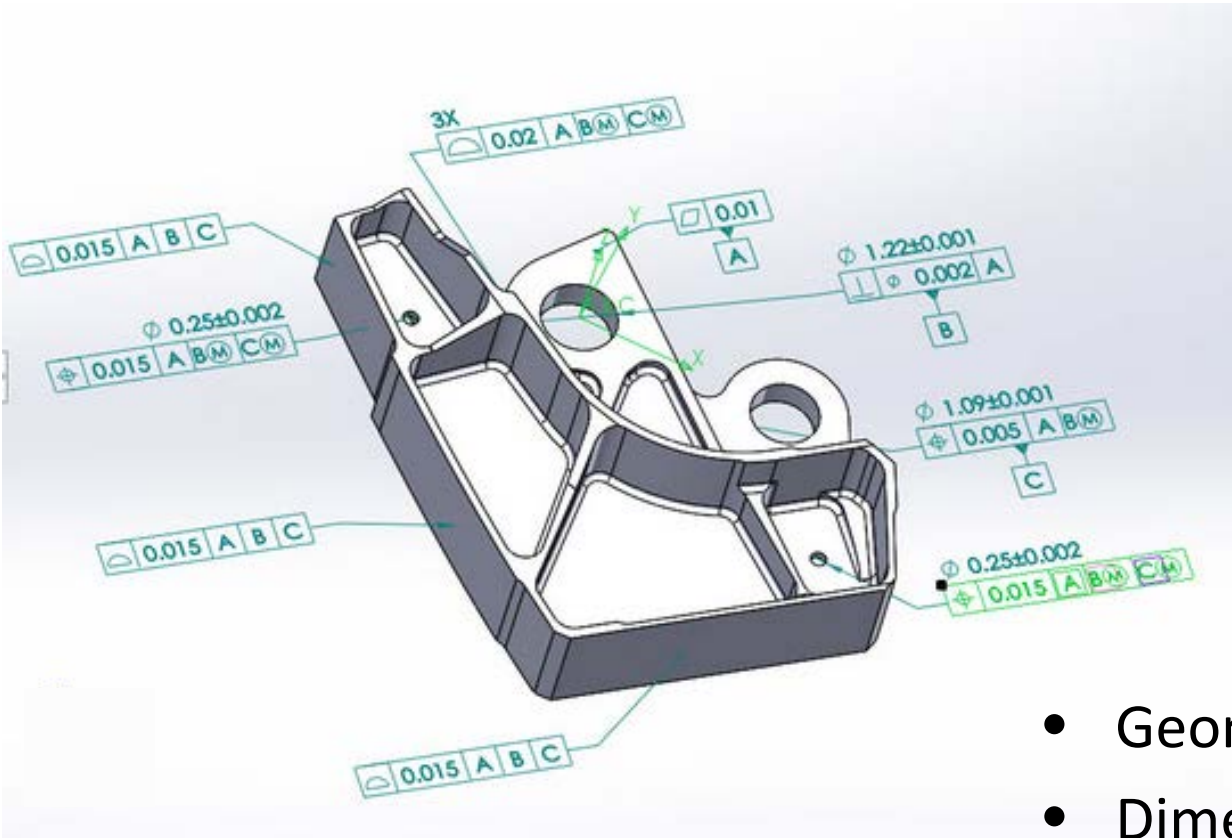
Multiple Connected Representations

OR



Shape definition and visual clarity

Many people simply use annotated CAD models as a proxy for a drawing

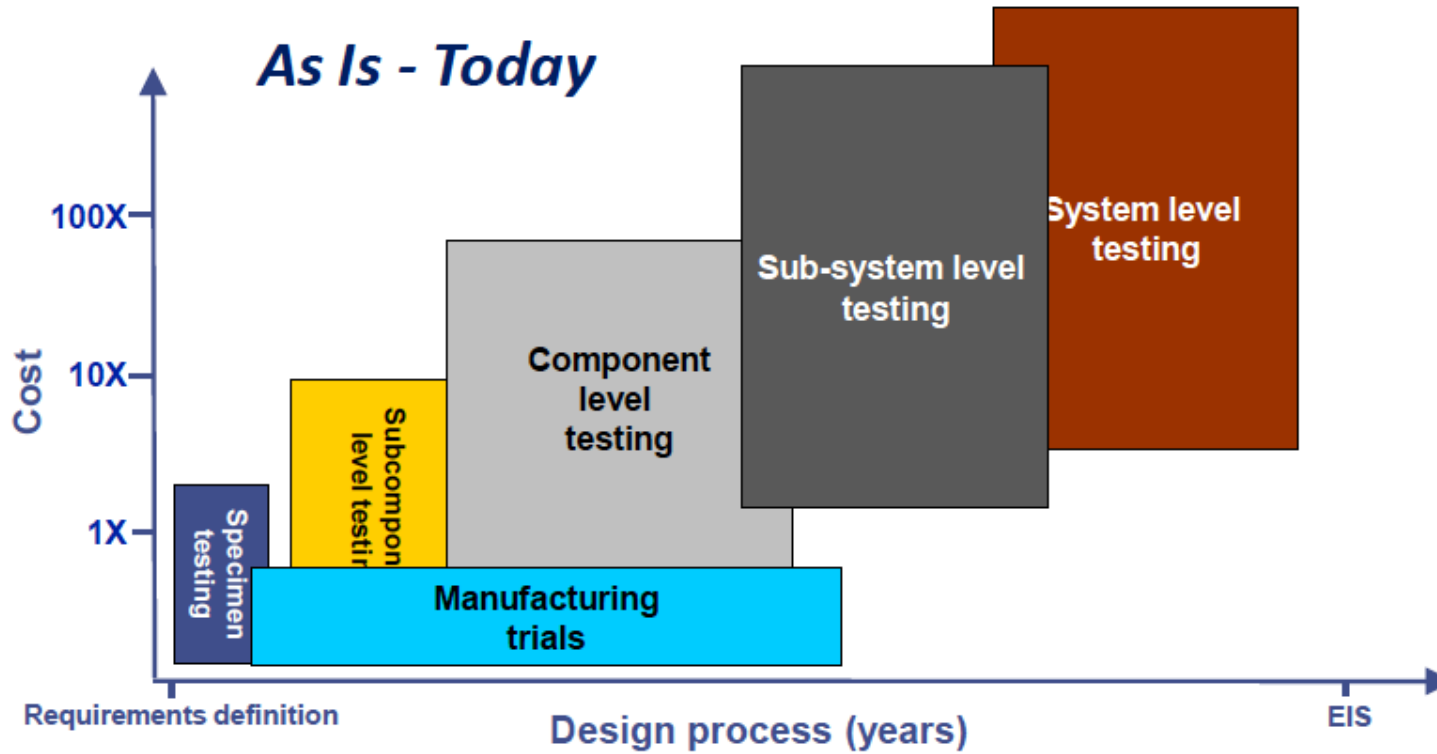


- Geometry definition
- Dimensional information
- Design intent clarity

Behavior and MBD

Reduce the need for trial-and-error approaches

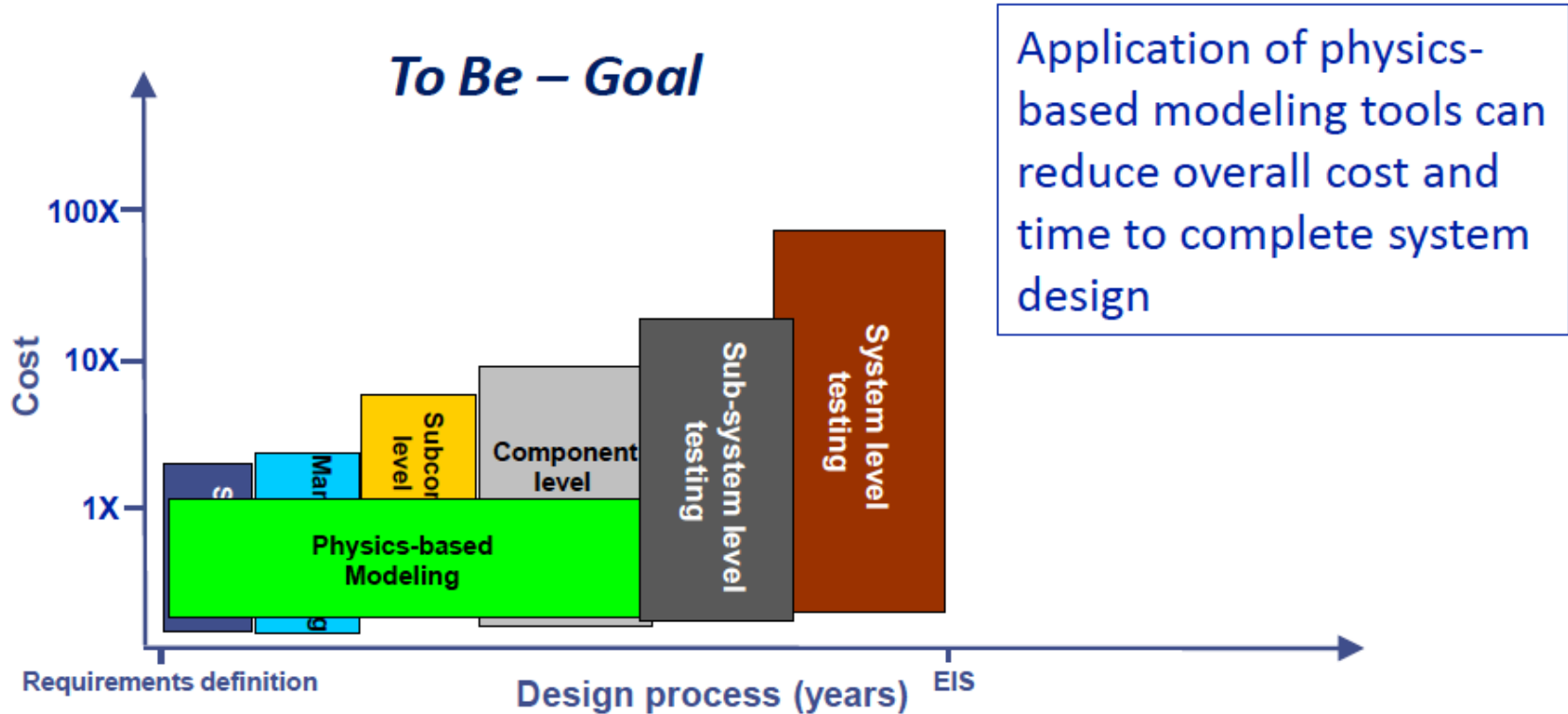
Models and analysis replace costly experimental iterations to optimize the manufacturing process and component performance



Behavior and MBD

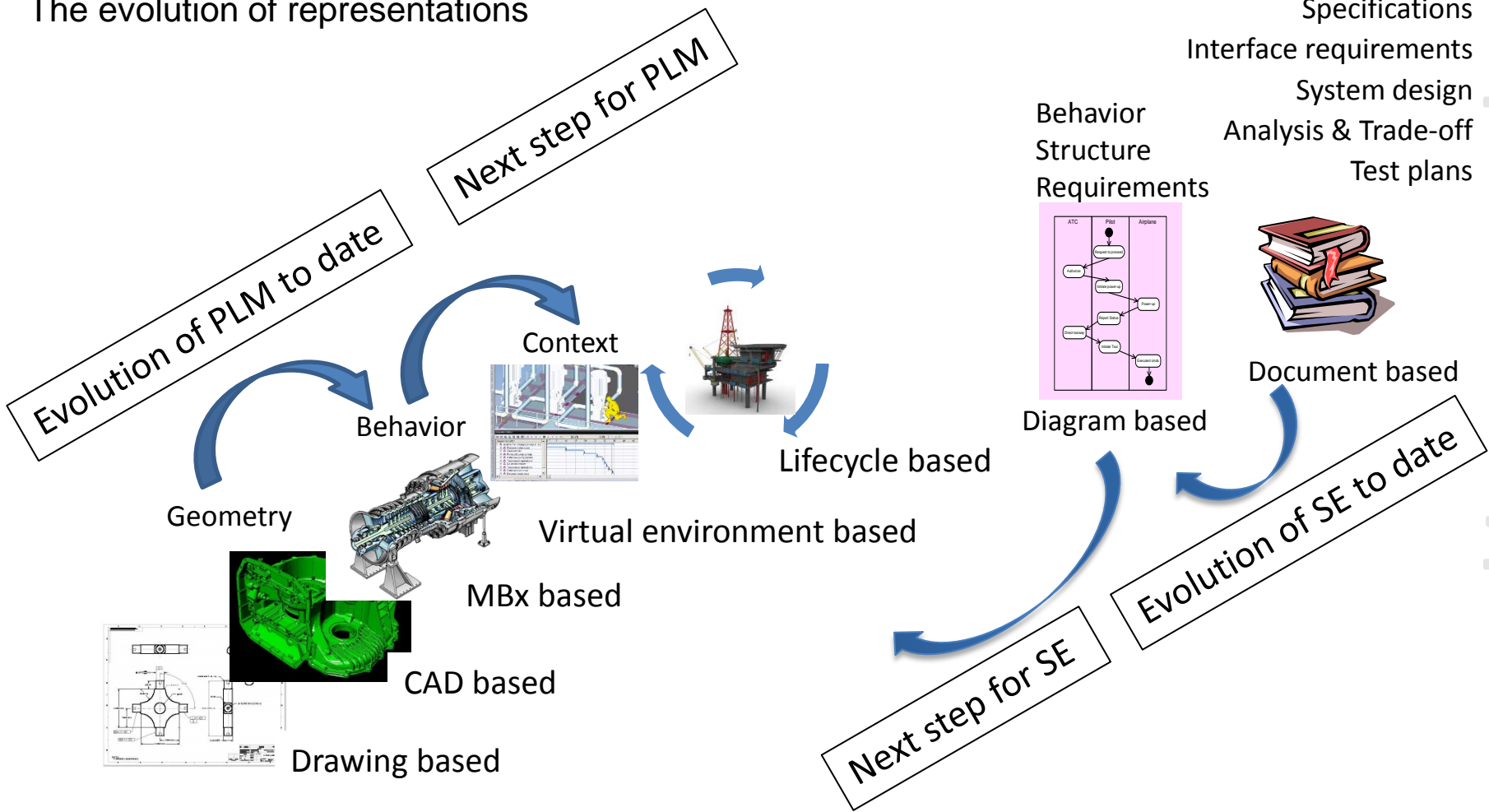
Reduce the need for trial-and-error approaches

Models and analysis replace costly experimental iterations to optimize the manufacturing process and component performance



Context and MBD

The evolution of representations



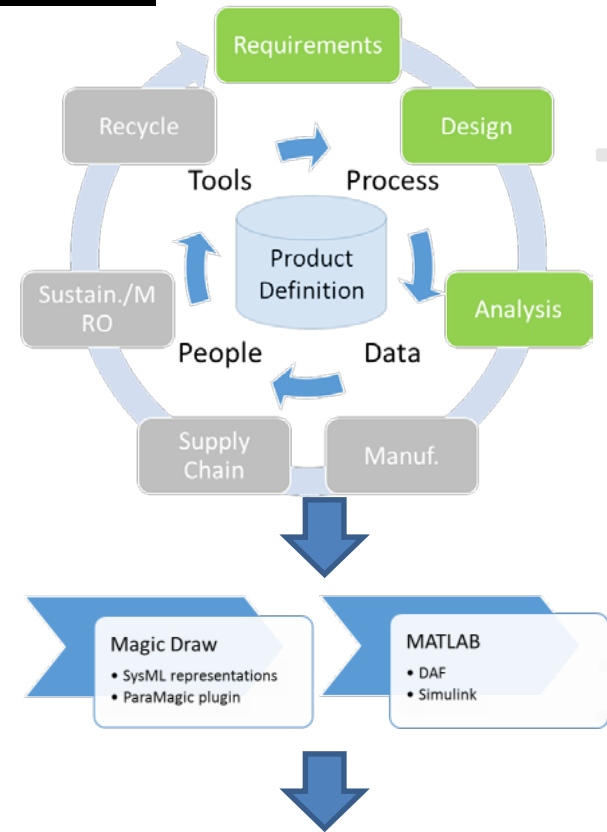
Context and MBD

MBD, Systems engineering, and big data decision making

- Big Data and Data Analytics
 - State-of-art methods to help make sense of generated data
 - In line with INCOSE SE Vision 2025* vision of “Leveraging Technology for SE Tools”
 - Current parametric solvers limited in scope and application** to potential bigger SE picture
- Can we exploit state-of-art in analytics to aid in turning large volume of MBSE outputs into useful information?

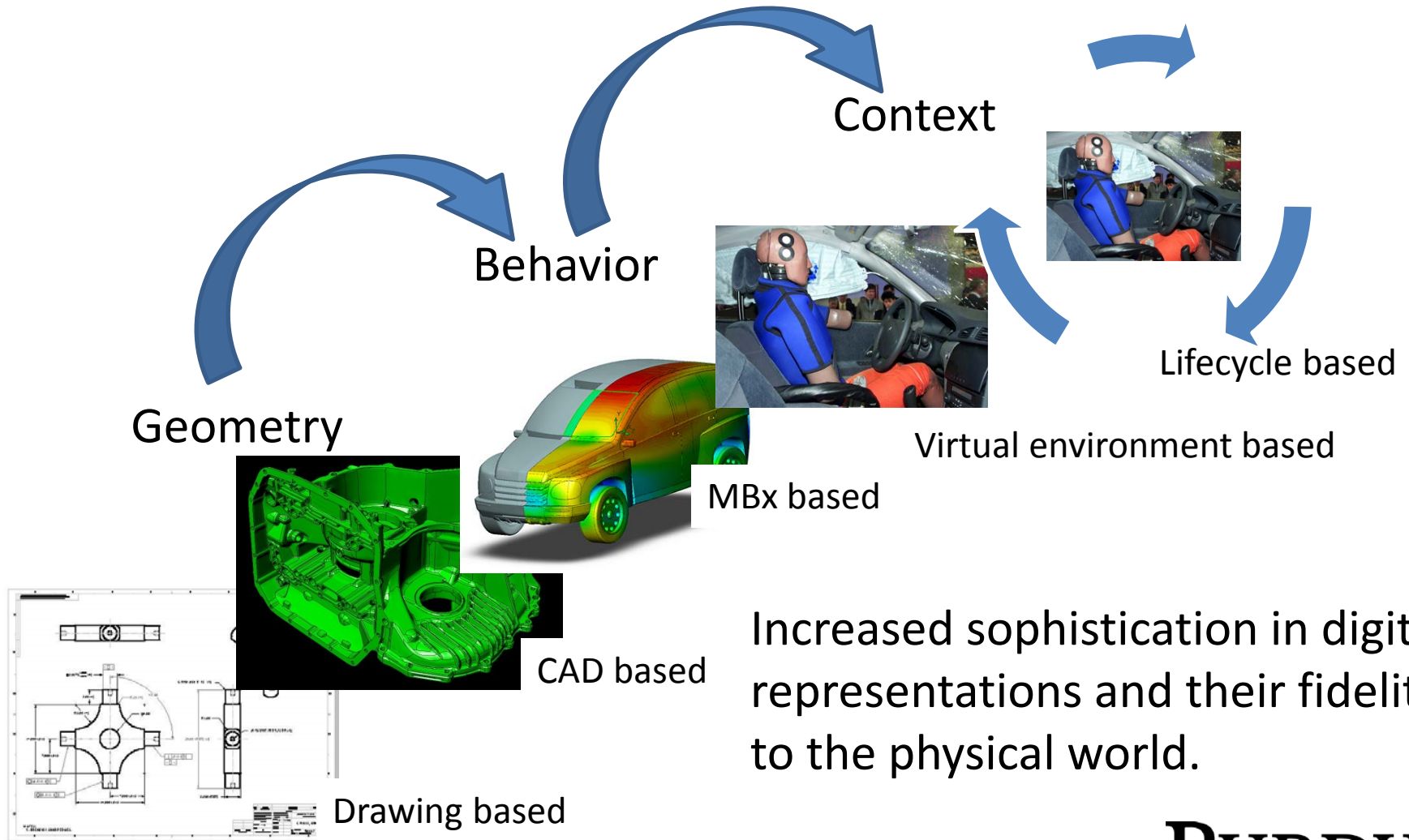
*INCOSE Systems Engineering Vision 2025 June 2014

**Approximation Analytics for Model-Based Systems Engineering – Vitech Corporation 2014
Insight Webinar



Evolution of a model-based product representation

MBD relevance is often a matter of whether you are an **author** or a **consumer**.



Increased sophistication in digital representations and their fidelity to the physical world.

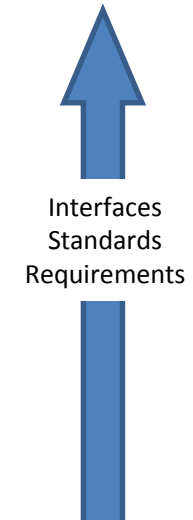
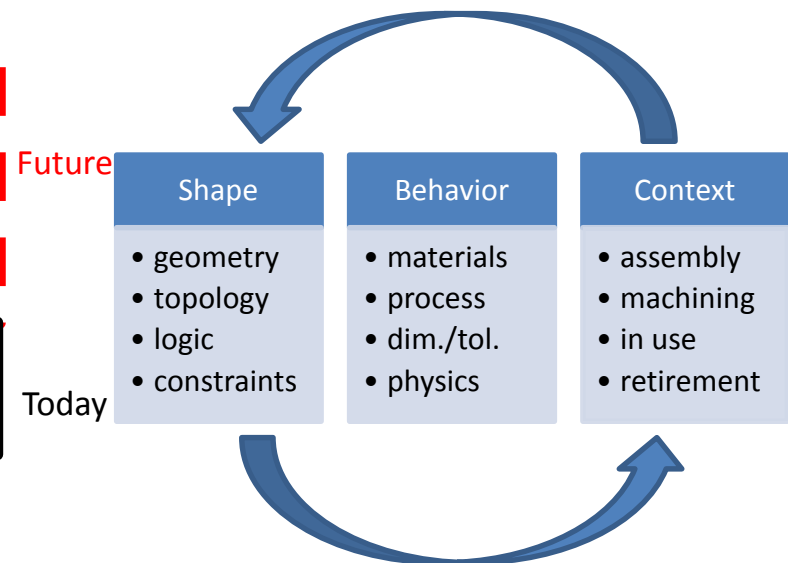
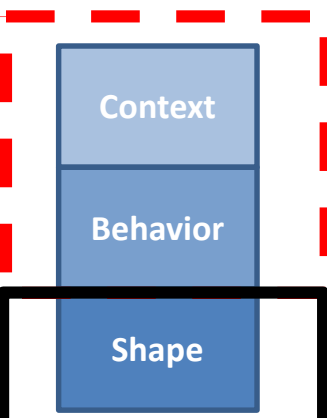
MBD and the Digital Twin

MODEL-BASED DEFINITION

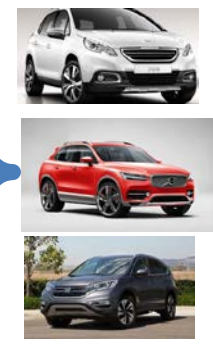
Multiple Connected Representations



DIGITAL TWIN



- Product Line
- Model 1
Model 2
Model N
- Subsystem
- Component



Temporal, lifecycle-based levels of a model-based definition

DIGITAL THREAD

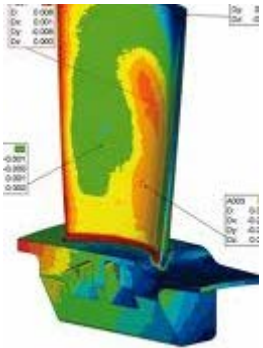
MBD + IT architecture + Connectivity



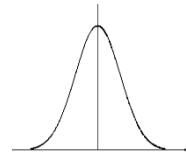
Enabling a digital twin

By comparing digital product data to the physical performance of the object, variation can be tracked and used to inform design of next-generation products or to develop predictive modeling and validation schemes for existing products.

As Designed

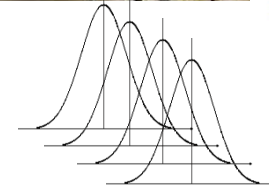
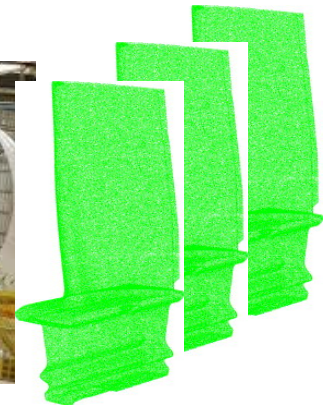


As Manufactured



Variability between
As Designed and As
Manufactured

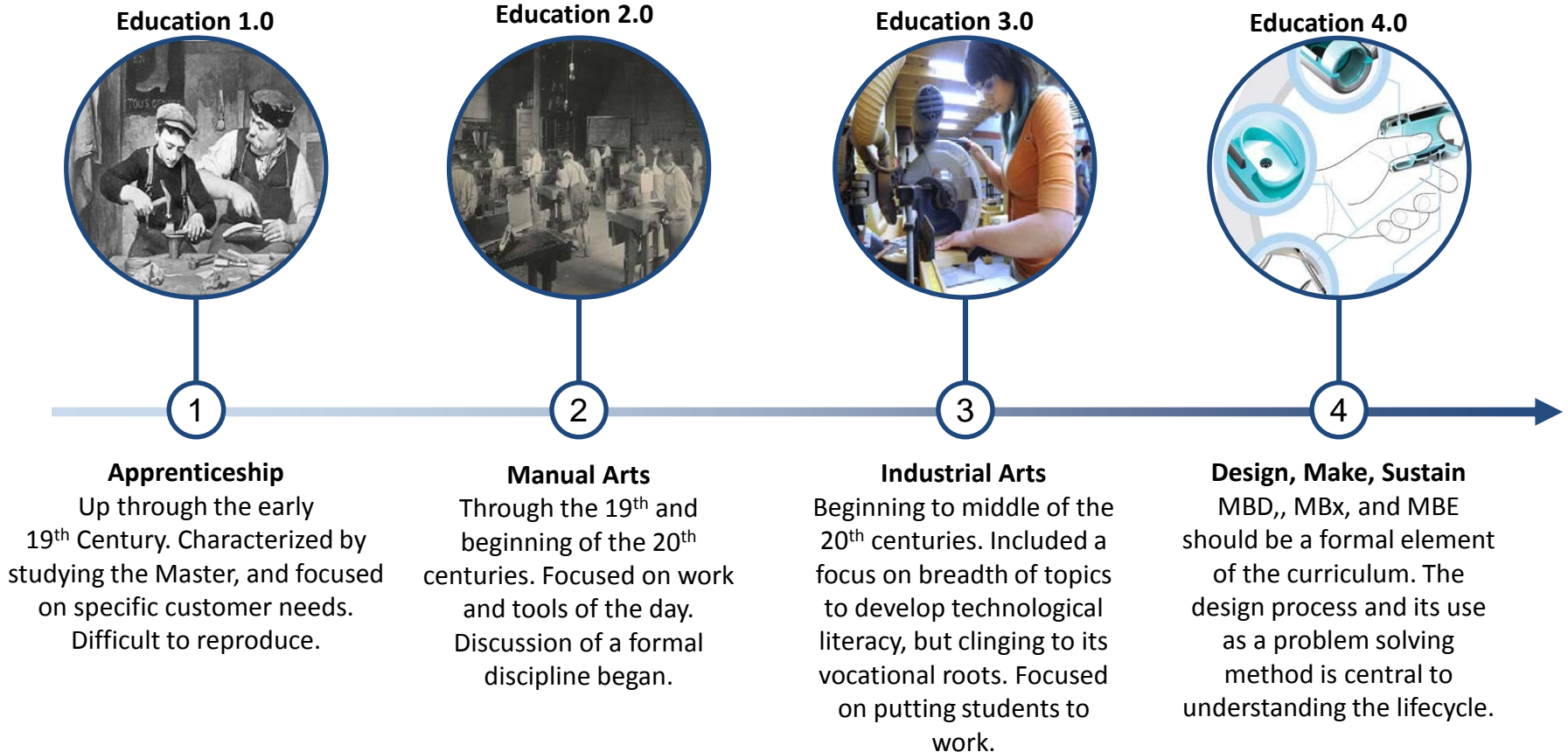
As Used



Variability between
As Manufactured
and As Used

... and the accompanying educational revolution

Craft, tools, practice, and design



Regardless of the era, the educational revolution connected to manufacturing has always had a focus on the tools and techniques of the day, and on the making of something. However, the incumbent workforce was left unattended in this model.

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