THE DIGITAL TWIN THROUGHOUT THE SYSTEM LIFECYCLE

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AGENDA

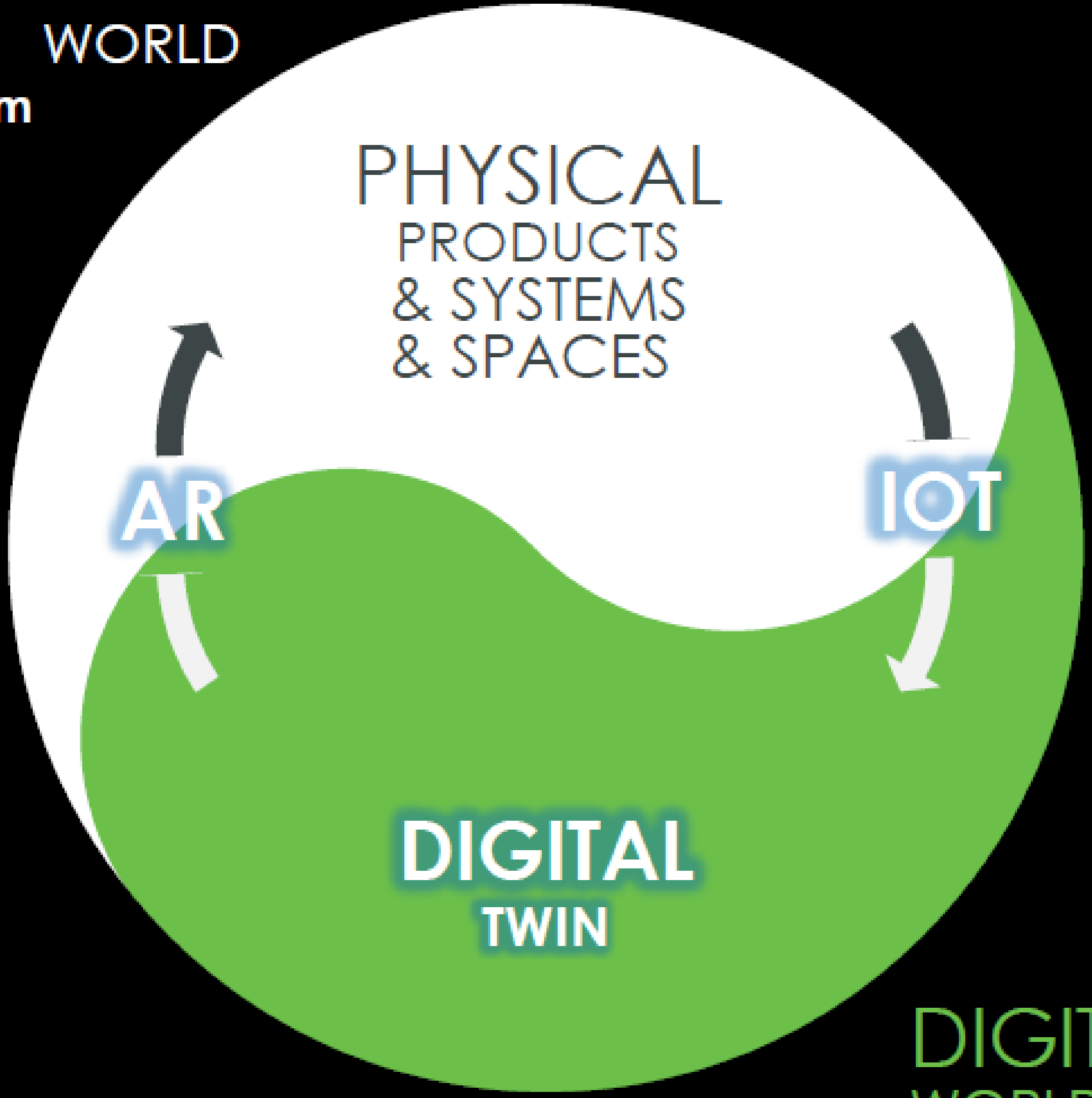
- Introduction
- The Digital Twin
- MBSE and the Digital Twin
- The System Lifecycle
- Conclusions
- Questions and Answers?

PHYSICAL WORLD

Industrial Innovation Platform

>$100M Revenue
> 50% Bookings Growth FY16
1,200 End Customers
250 OEMs/Resellers
Ecosystem of SI's, partners

IoT & ANALYTICS | thingworx
AUGMENTED REALITY | vuforia
INDUSTRIAL CONNECTIVITY | kepware



PLM Solutions

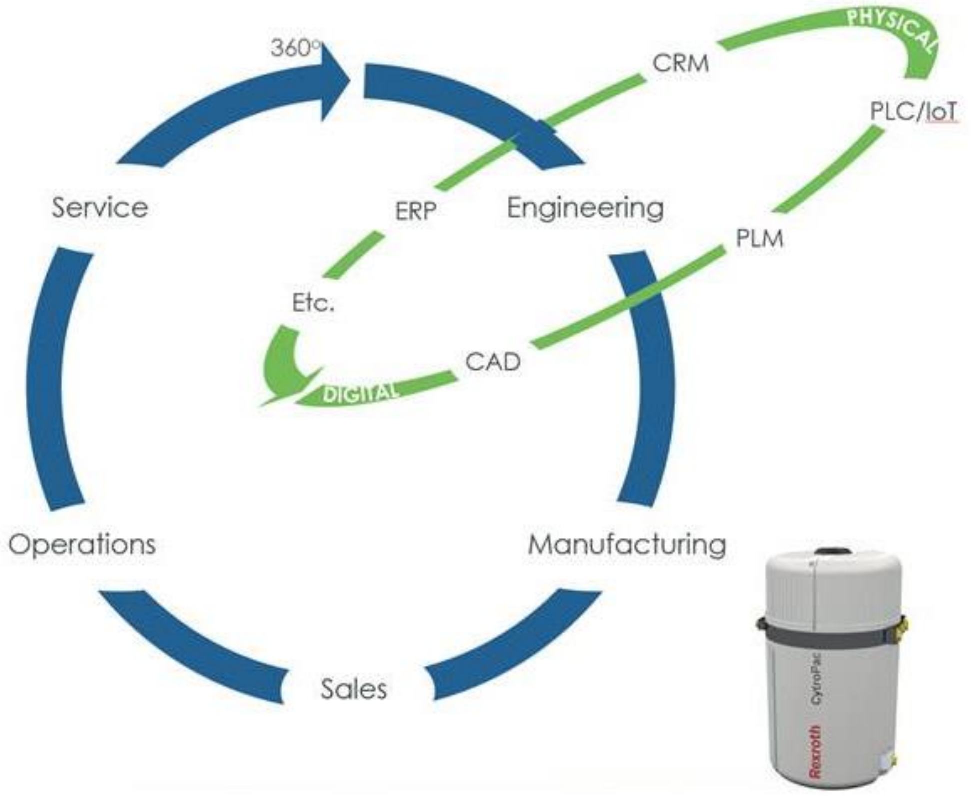
>$1B Revenue
10% Bookings Growth FY16
28,000 End Customers
70% Direct Sales
30% VARs (~400)
Ecosystem of SI's, partners

DIGITAL WORLD

CAD | creo
PLM | windchill
ALM | integrity
SLM | servigistics

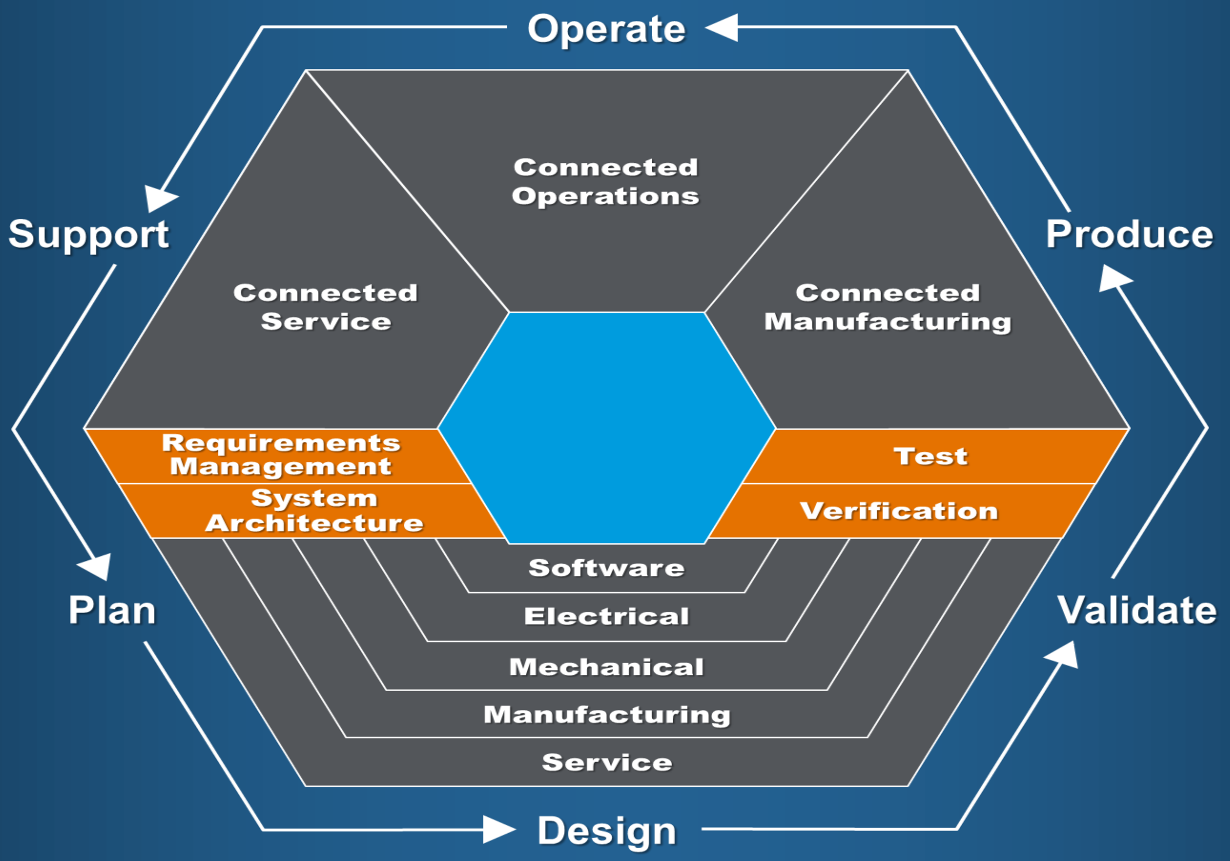
WHAT IS THE DIGITAL TWIN?

- A TRUE Digital Twin needs two components:
  - **The digital definition.** (Universal Access)
  - **The physical experience**. Without the specific physical experience such as environmental data from an operating asset, all you have is a digital sibling but no twin
- The 'Digital Twin' requires a complete digital understanding of the product – the development, history, service records, as-maintained BOM, configurations, CAD analysis, IoT readings, software versions, options and variants, etc.
- With Augmented Reality (AR) 'Digital Twins' you can see a "twin" of your product, factory or office without needing the physical product or to be there in real time



CLOSED LOOP SYSTEMS ENGINEERING

A **holistic**, **multi-disciplinary** and collaborative approach to designing and maintaining **complex** systems throughout the systems lifecycle.



STAKEHOLDERS AND THE DIGITAL TWIN

- Nearly every stakeholder can benefit from the wealth of information generated:
  - Engineering can make better decisions to improve the product
  - Legal and quality assurance can gain complete traceability to ensure security and legal requirements
  - Service technicians can better maintain and repair the product
  - Marketing can determine better ways to position the product in the market
  - Sales can identify future sales and upgrade opportunities
  - Customers can visualize the product in its deployed environment
  - System operators can more closely visualize the system in operational mode
  - Predictive analysis can be performed on the system more effectively
  - Etc.

SYSTEMS ENGINEERING AND THE DIGITAL TWIN

- The digital twin does not spring into life fully formed straight from the CAD model. It requires an informed systems engineering approach to ensure that the integration between physical and digital is fit for purpose.
  - The form and function of the digital and physical form a synergy
  - The right measurements are captured and made available
  - The right amount of data is captured
  - The communications infrastructure is sufficient to support this data
  - Security controls are in place to deter unwanted capture of data or worse control of the physical asset
  - The operational and maintenance data of the asset support the operational and maintenance needs of the system of systems
  - Sufficient computing power is made available for predictive analysis
  - The digital and physical assets can evolve to meet the changing needs of the system of systems.
  - Etc.

MBSE AND THE DIGITAL TWIN

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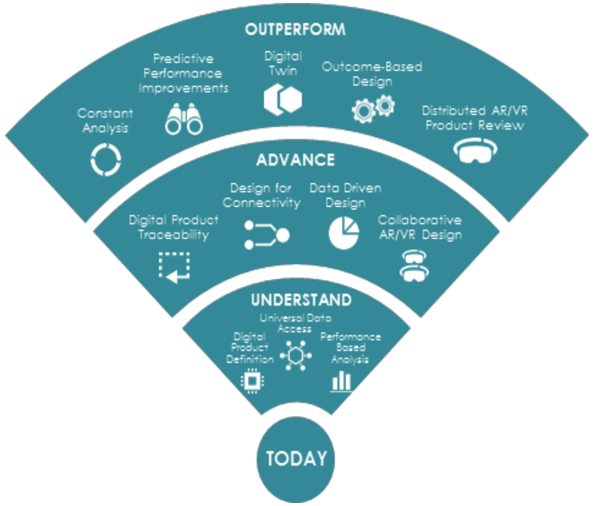
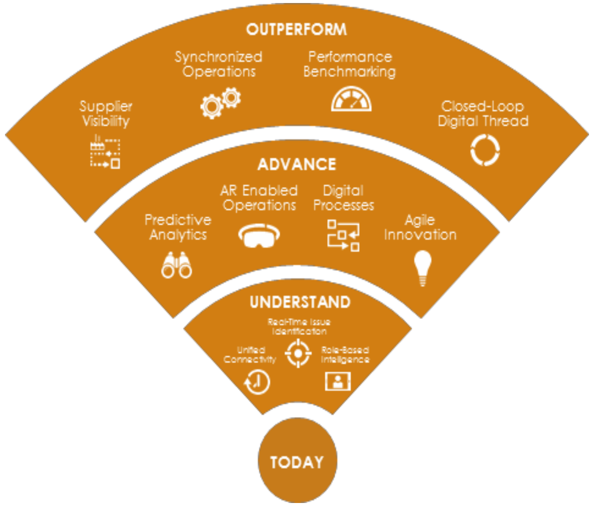
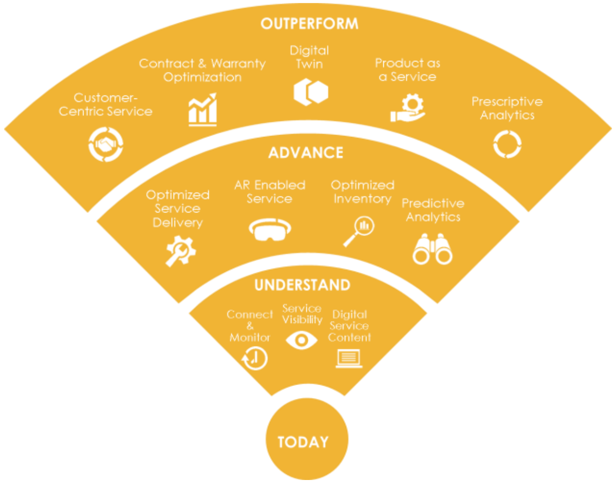
- The NDIA defines Model-Based Systems Engineering (MBSE) as "an approach to engineering that uses models as an integral part of the technical baseline that includes the requirements, analysis, design, implementation, and verification of a capability, system, and/or product throughout the acquisition life cycle."
- With the addition of simulation, the Internet of Things (IoT) and connected models, MBSE also provides value in the operations and maintenance phases.
- The digital twin is an enabling technology that used in conjunction with MBSE will help achieve the goals of these initiatives.

PAVING THE WAY – JOURNEYS OF TRANSFORMATION



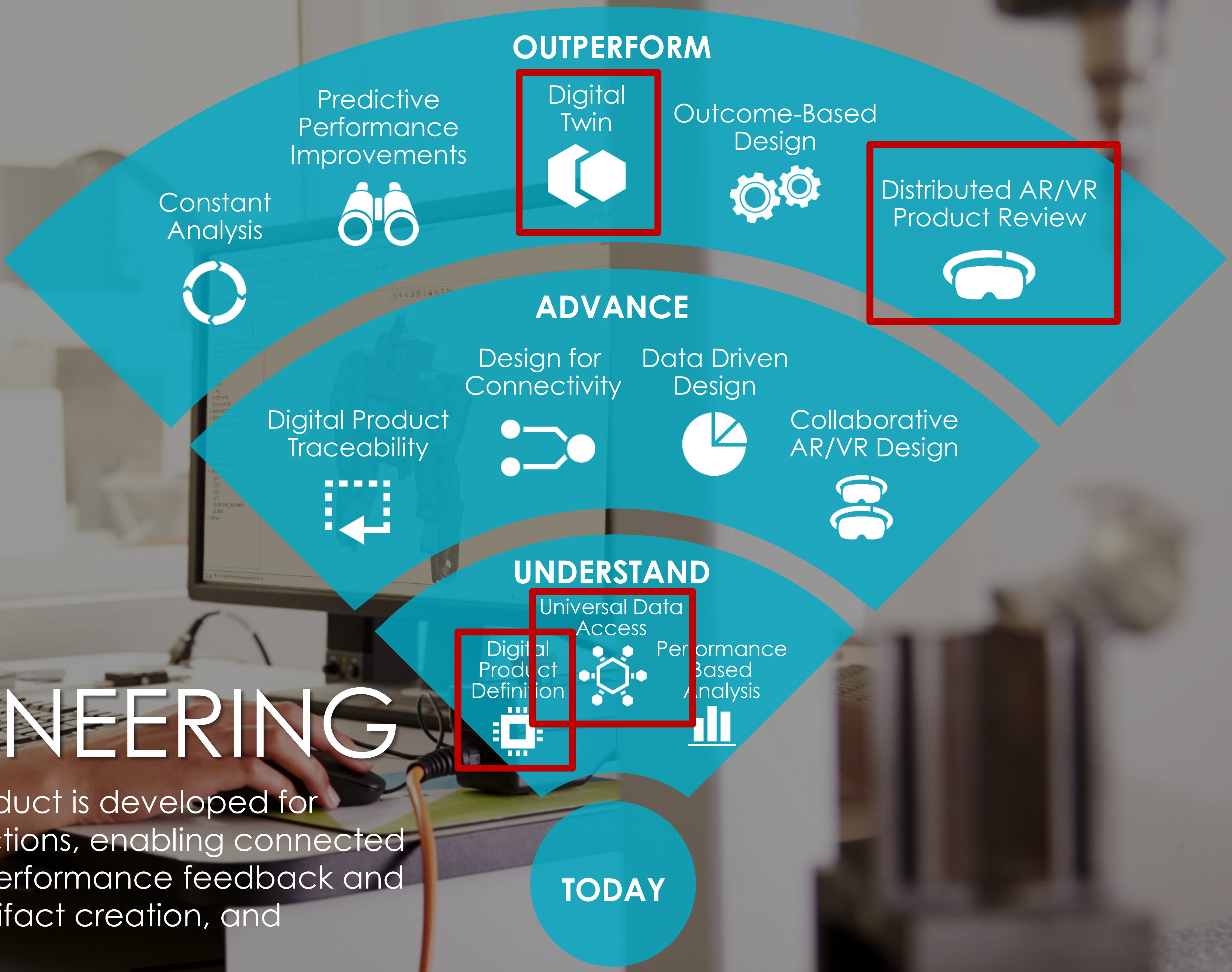




Digital Engineering

Manufacturing

Service



DIGITAL ENGINEERING

A fully digital representation of the product is developed for connectivity and is used across all functions, enabling connected manufacturing and service, product performance feedback and traceability, automation simulation, artifact creation, and collaboration

SYSTEMS ENGINEERING AT THE CORE OF DIGITAL ENGINEERING

Digital Twin

Performance Based Analysis & Data Driven Design

Design for Connectivity

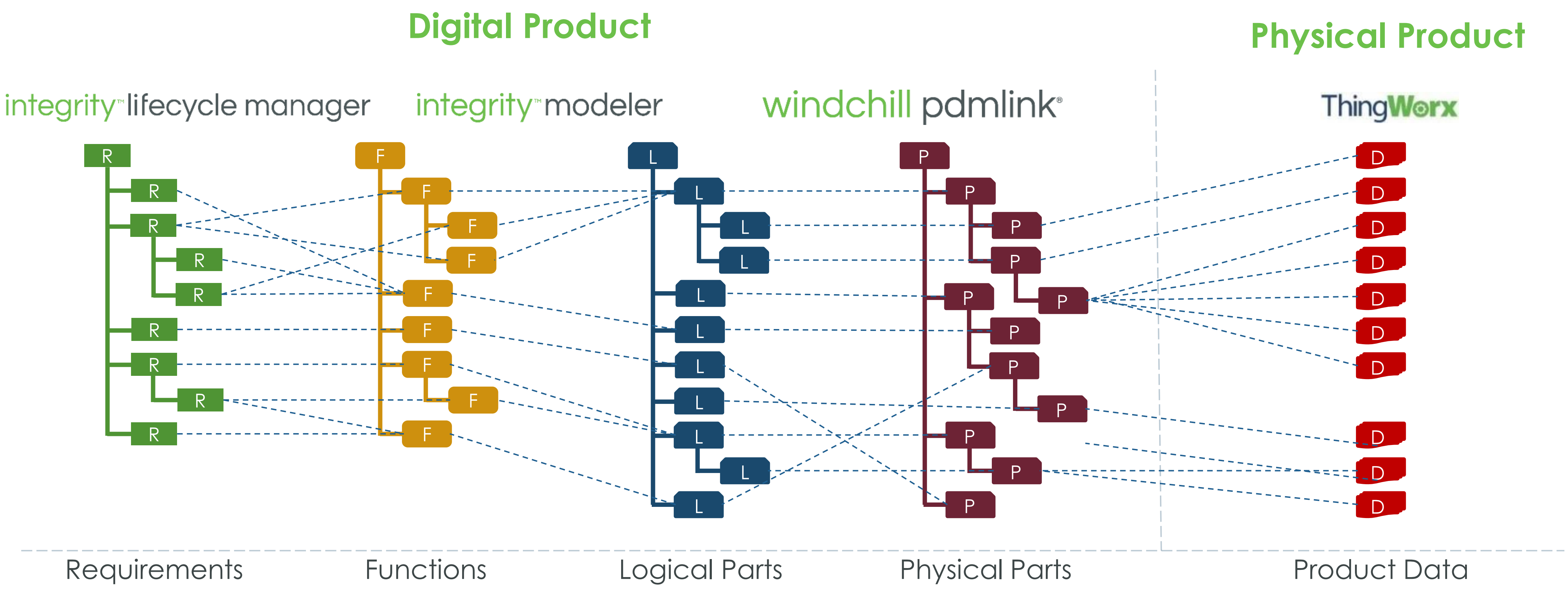
Digital Product Traceability

Universal Data Access

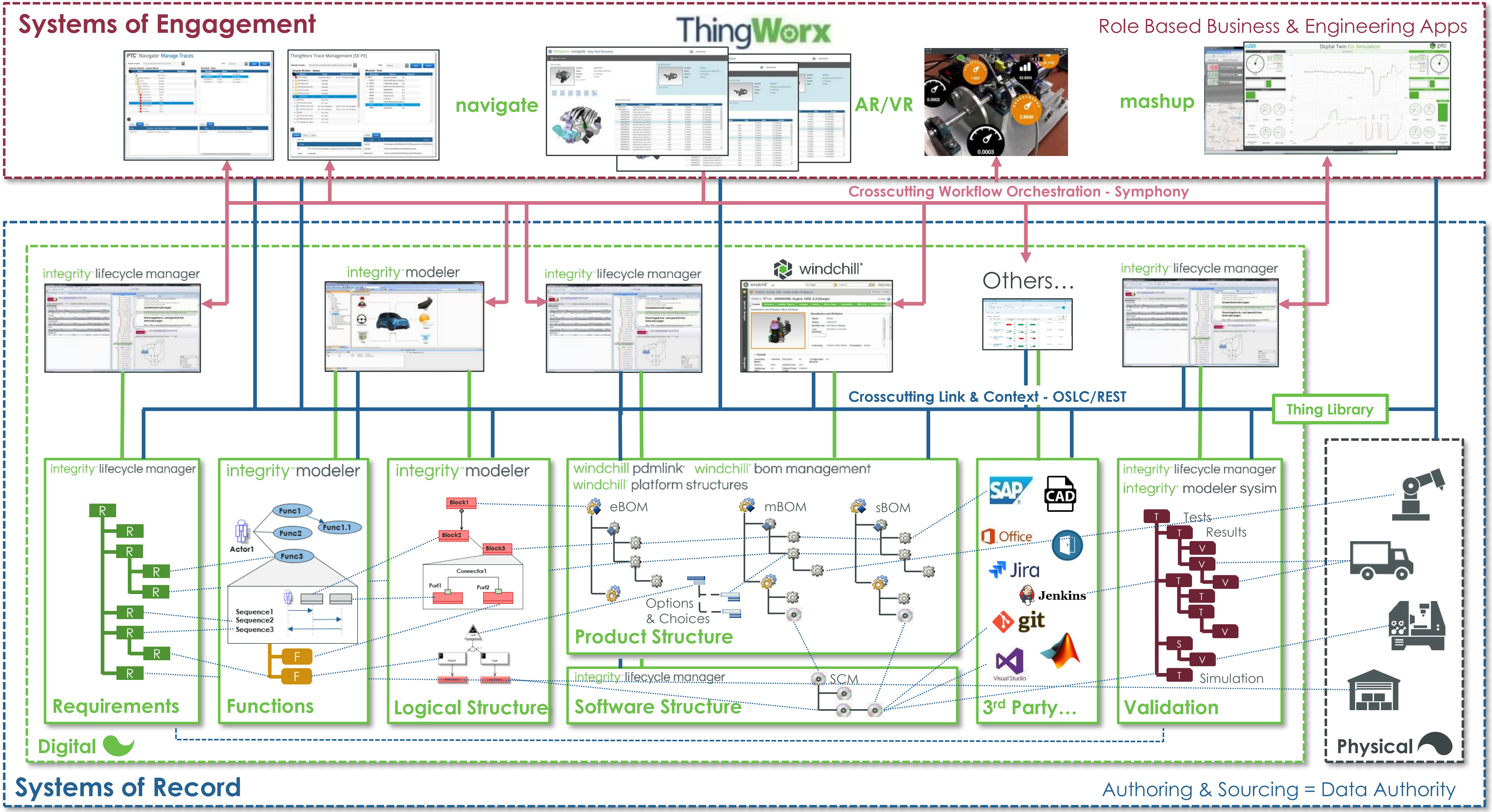
Digital Product Definition

SE System of Record	Democratization	Link & Trace	Systems of Systems	Simulation - V&V	Part of Twin
Requirements	Navigate™	R-F-L-P	Modular Design	Co-simulation	System PLE
System Functions	Web UIs	Design Flow	Component Reuse	x-in-the-loop	
System Structures	Role Based UIs	Impact Analysis	IoT Design	Trade Studies	
Engineering Processes	Visual Modeling	Certification	Flow to Software	Test Management	

DIGITAL PRODUCT TRACEABILITY

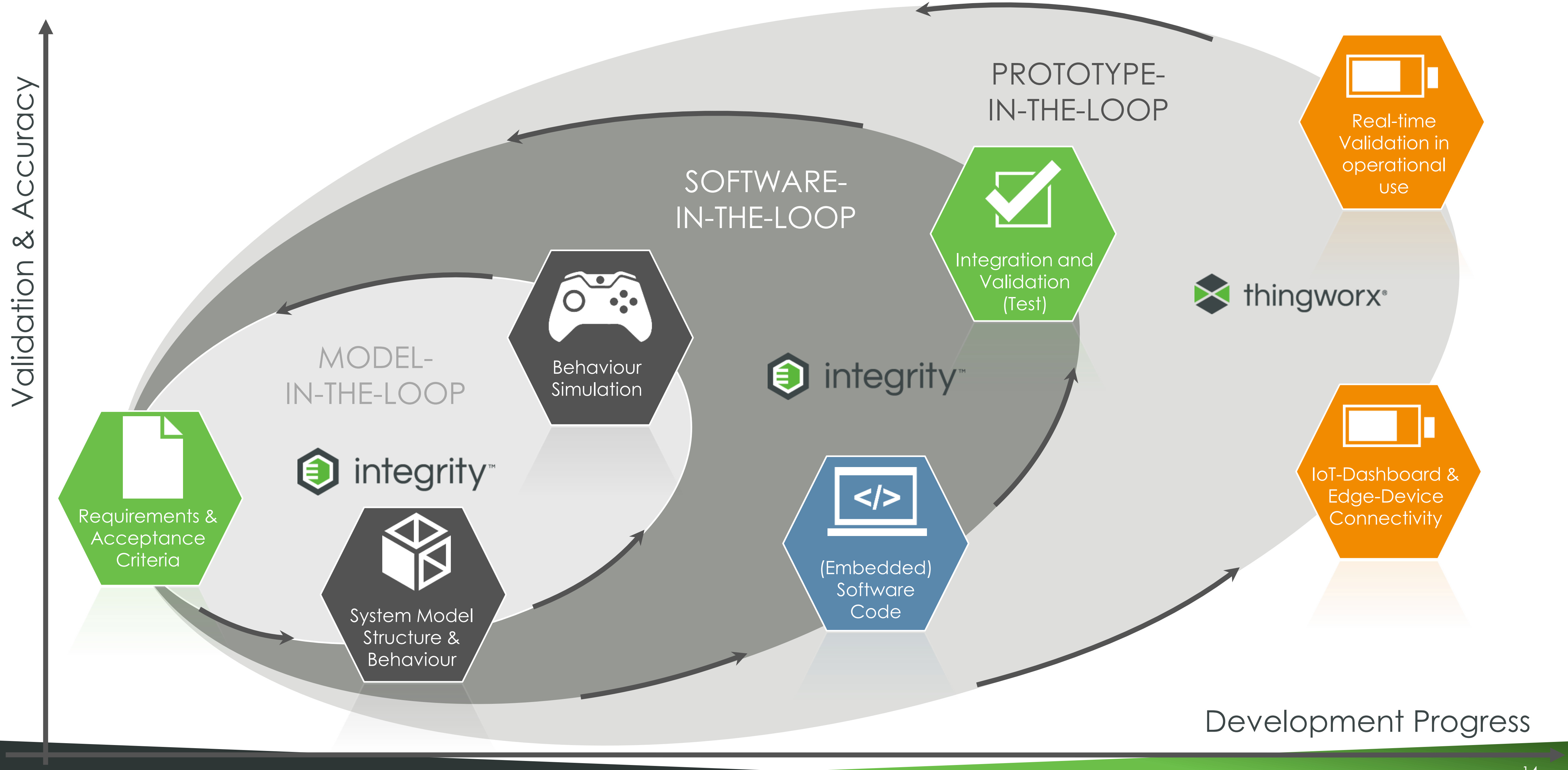


Requirements…..'satisfied by' System Functions…..'allocated to' Logical Parts…
…'implemented by' Physical Parts…..'sending & receiving' real world data



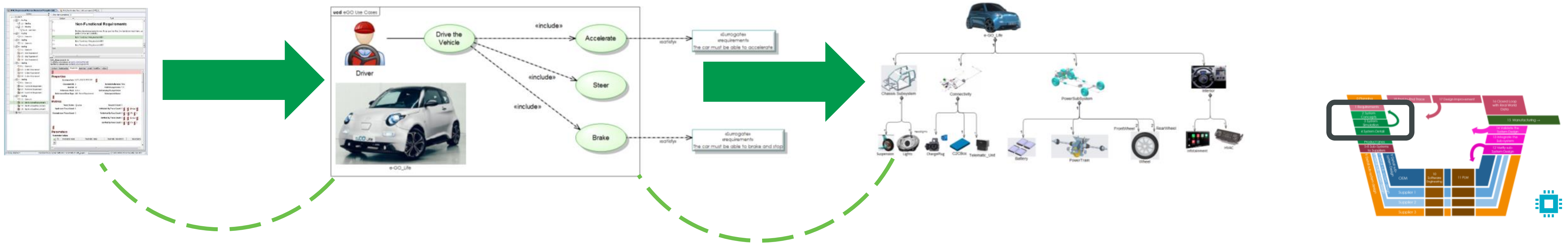
Systems of Engagement
ThingWorx
Role Based Business & Engineering Apps
navigate
AR/VR
mashup
Crosscutting Workflow Orchestration - Symphony
integrity lifecycle manager
integrity modeler
integrity lifecycle manager
windchill
Others…
integrity lifecycle manager
Crosscutting Link & Context - OSLC/REST
Thing Library
integrity lifecycle manager
integrity modeler
integrity modeler
windchill pdmlink windchill bom management
windchill platform structures
eBOM
mBOM
sBOM
Options
& Choices
Product Structure
integrity lifecycle manager
SCM
Software Structure
SAP
CAD
Office
Jira
Jenkins
git
Visual Studio
3rd Party…
integrity lifecycle manager
integrity modeler sysim
Tests
Results
Simulation
Validation
Requirements
Functions
Logical Structure
Actor1
Func1
Func1.1
Func2
Func3
Sequence1
Sequence2
Sequence3
Block1
Block2
Block3
Connector1
Port1
Port2
Digital
Physical
Systems of Record
Authoring & Sourcing = Data Authority

FROM REQUIREMENTS TO PROTOTYPE-IN-THE-LOOP VALIDATION



HIGH-LEVEL SYSTEM DESIGN

- Objective(s); Design the high level concepts (& context) of the whole product
- Scenario; Model the high-level GO car concepts
- Role(s); Whole Systems Engineer
- Product(s); Integrity Modeler (refining Integrity Lifecycle Manager requirements)
- Open Standards; SysML & OSLC
- Benefits; Visual design for stakeholder agreement & feature allocation



THE SYSTEM UNDER DEVELOPMENT

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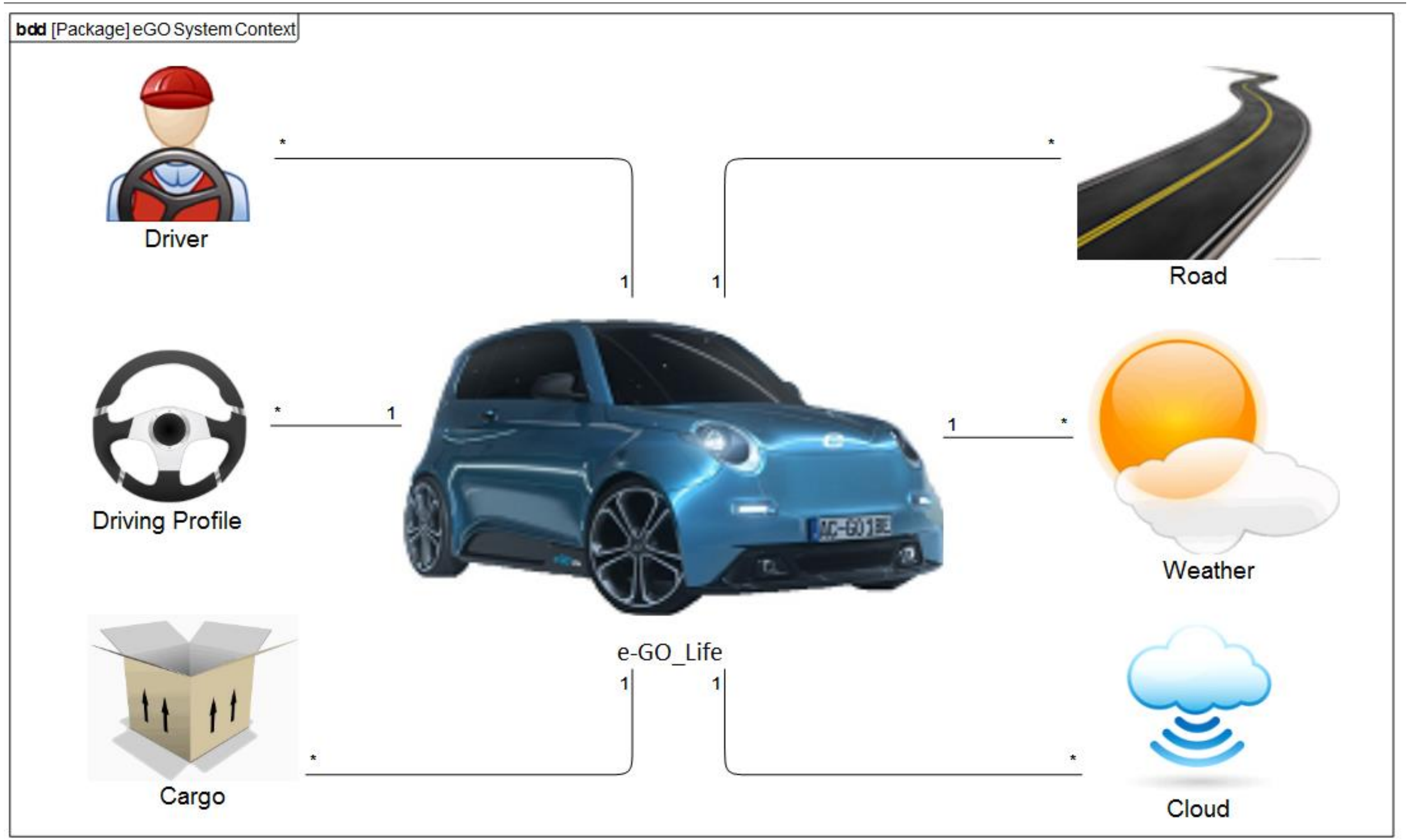
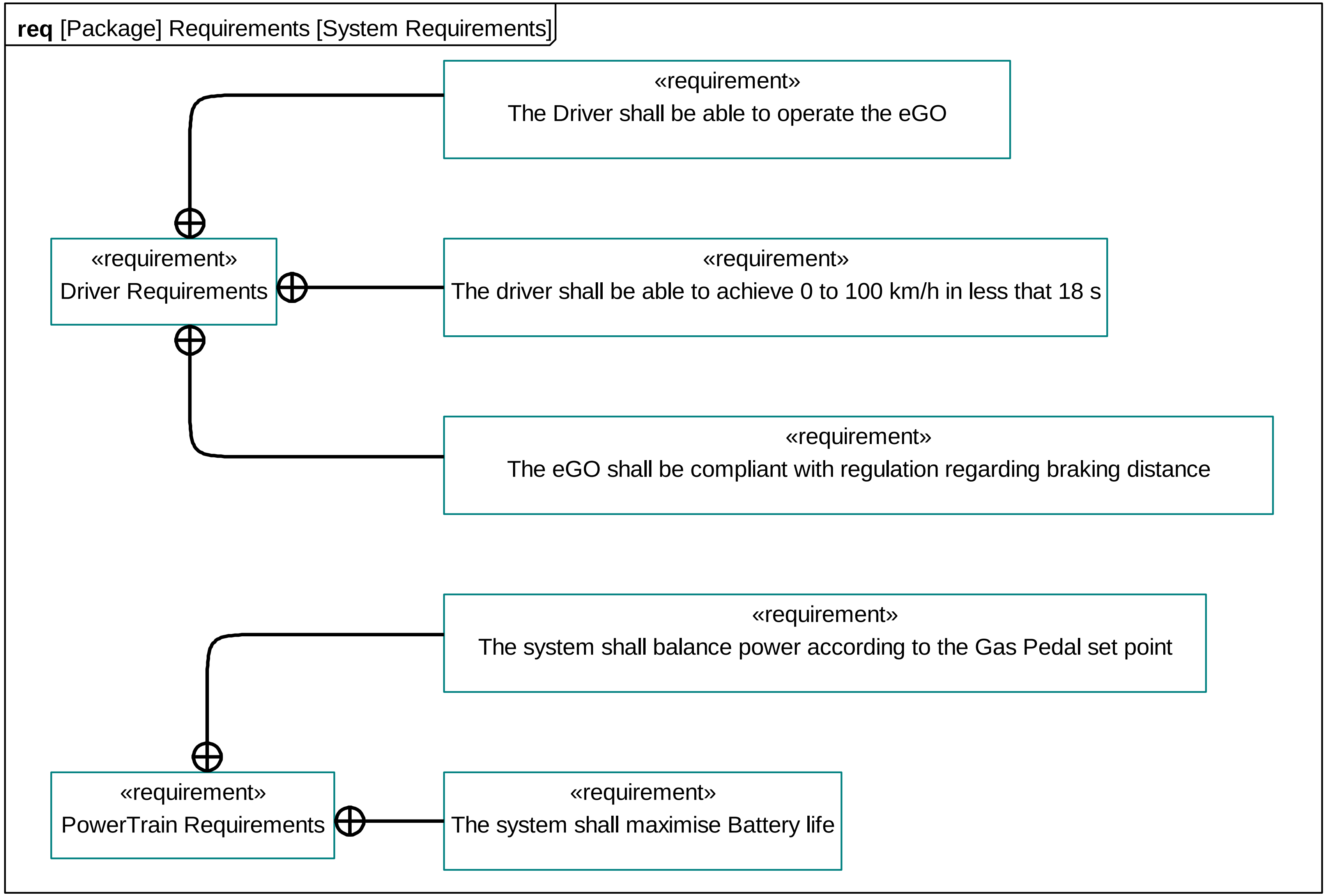
e.GO Life An Electric Vehicle Under Development

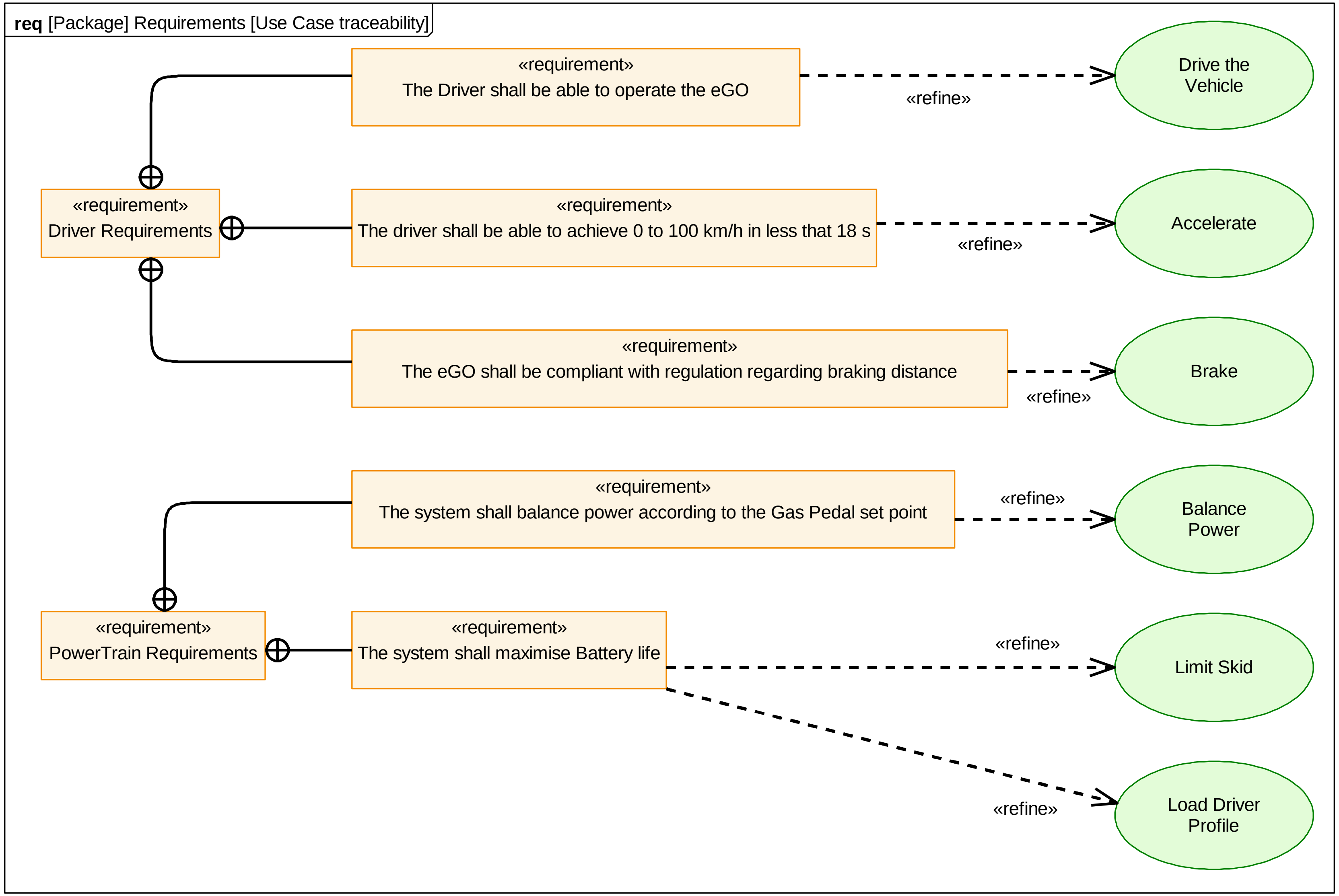
THE ELECTRIC CAR CONTEXT DIAGRAM



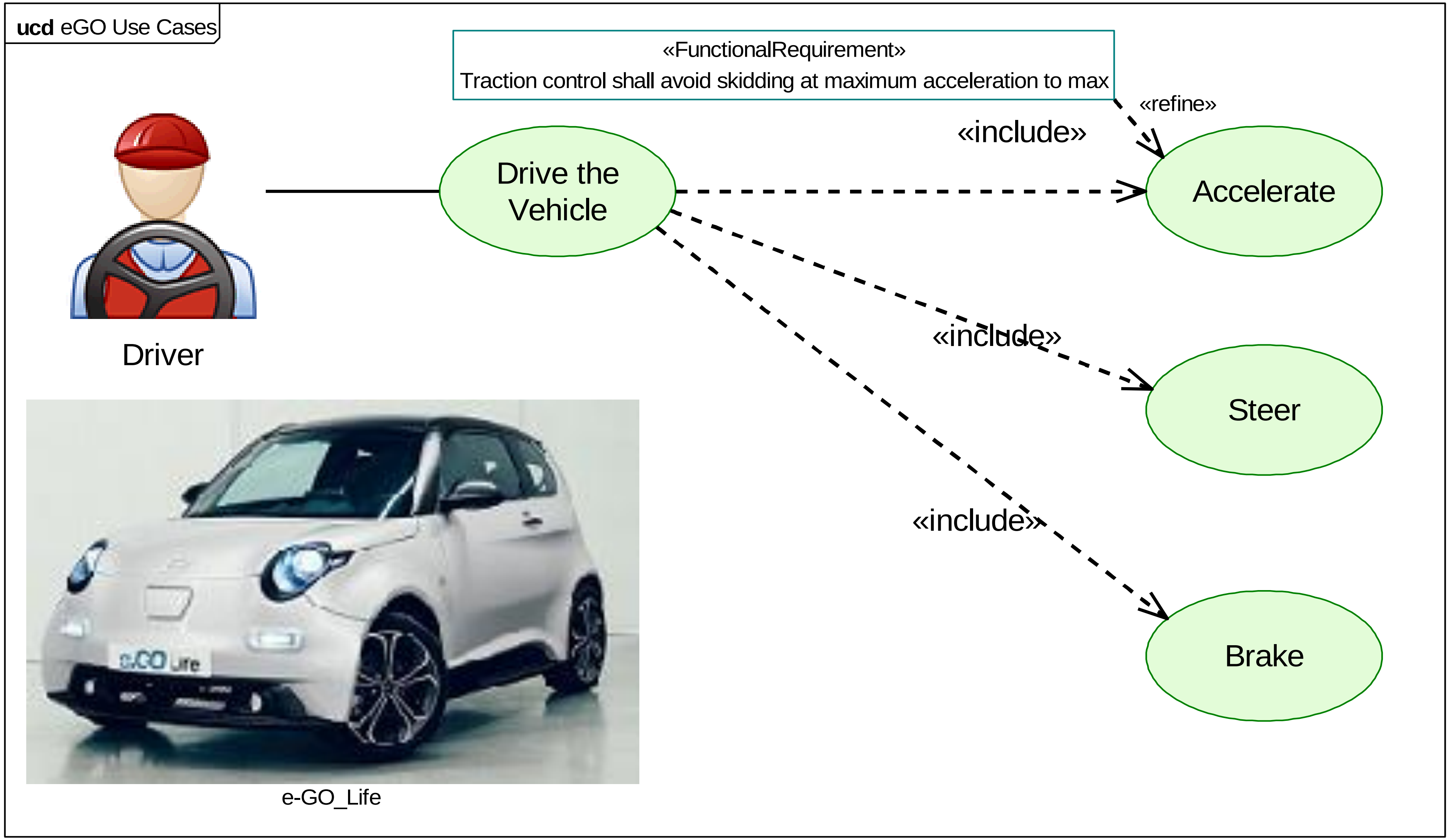
SYSTEM REQUIREMENTS



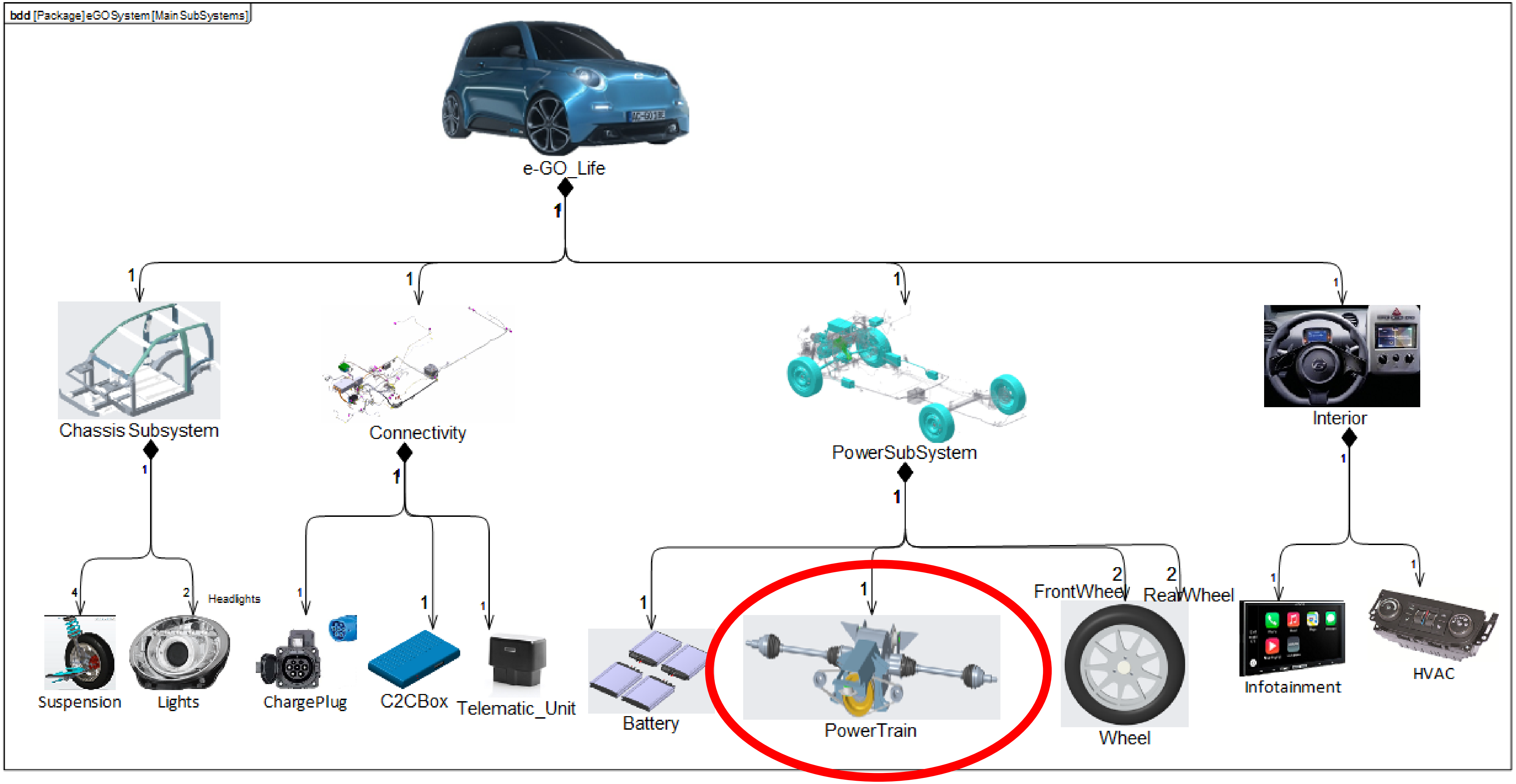
TRACEABILITY FROM REQUIREMENTS TO USE CASES



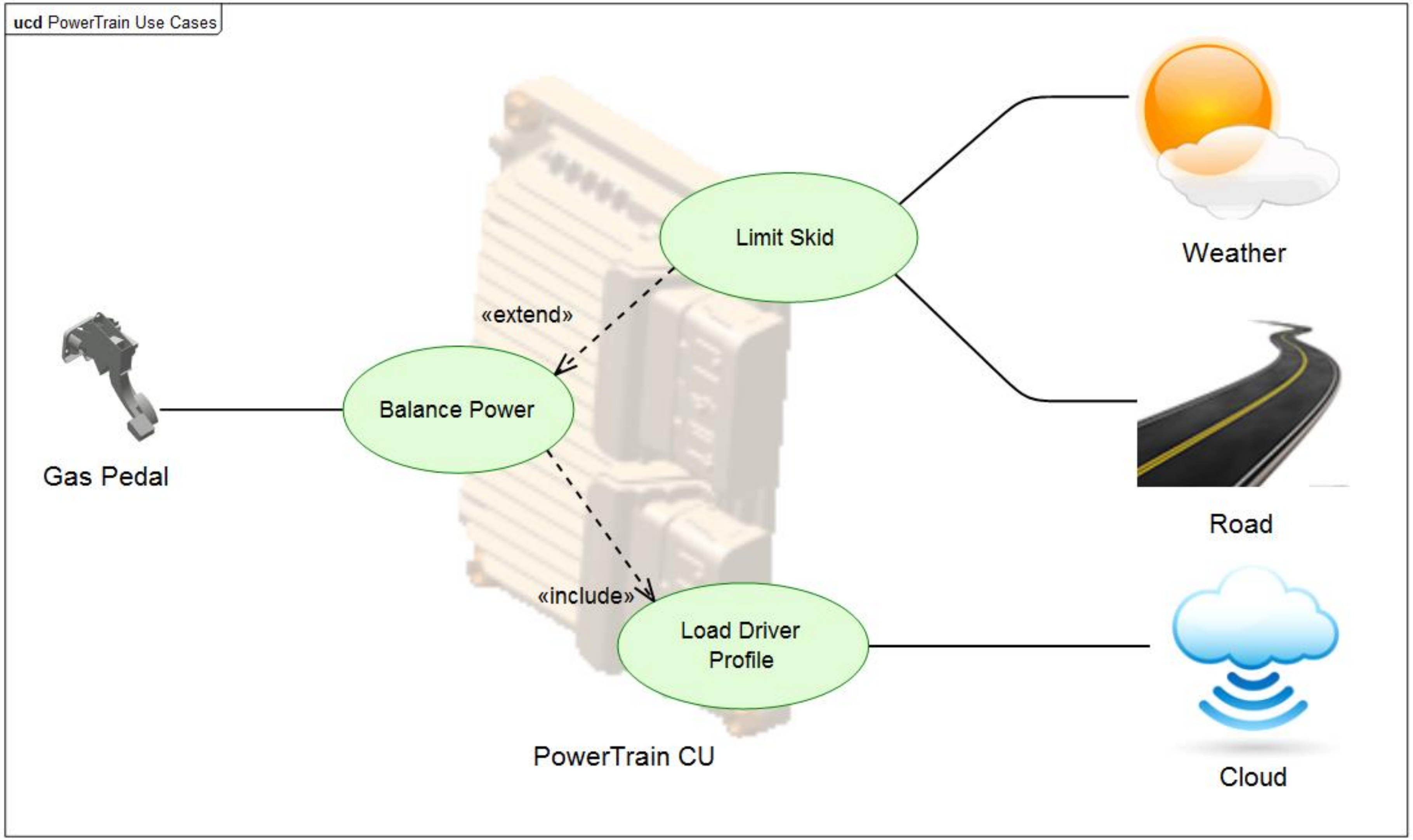
SYSTEM USE CASES



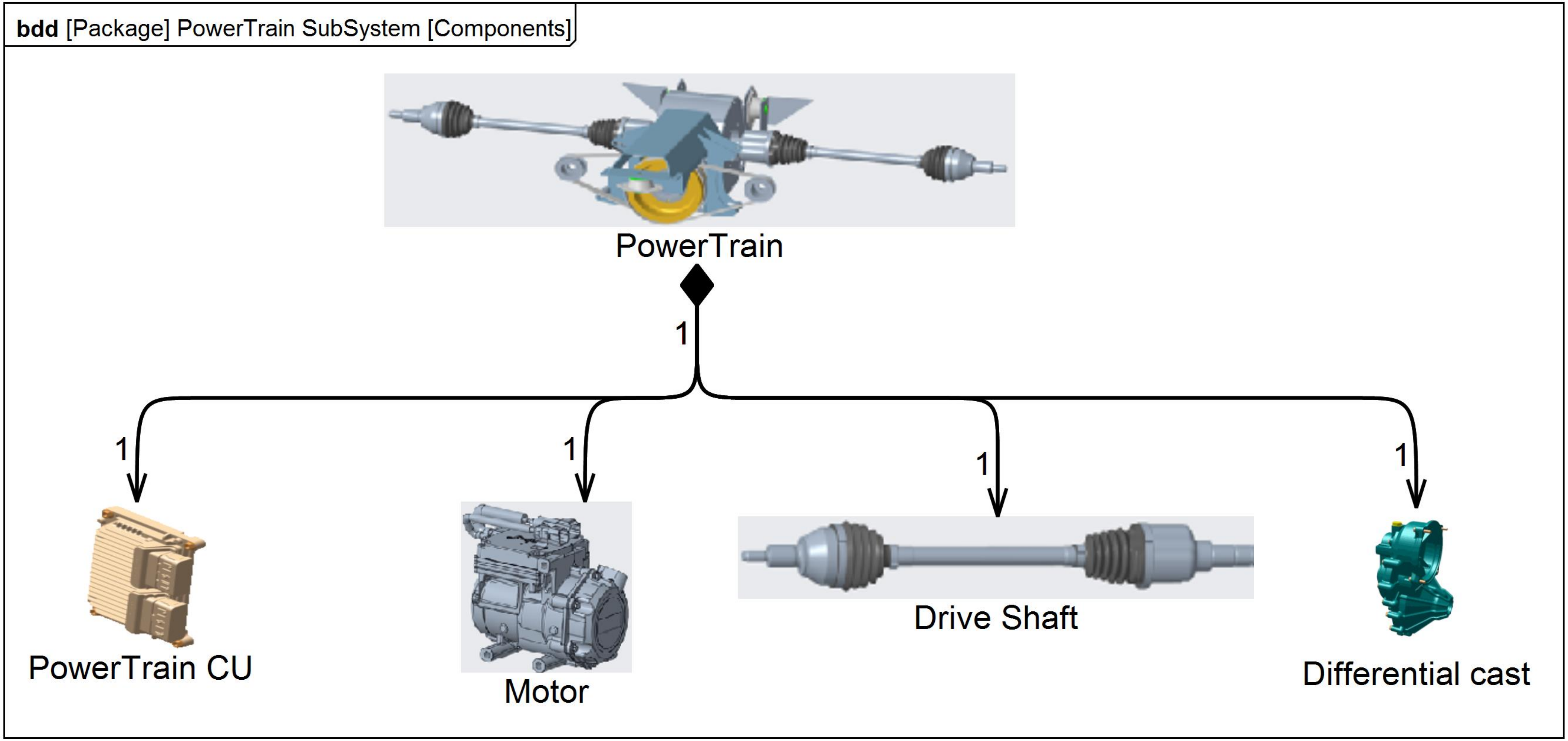
MAIN VEHICLE SUBSYSTEMS



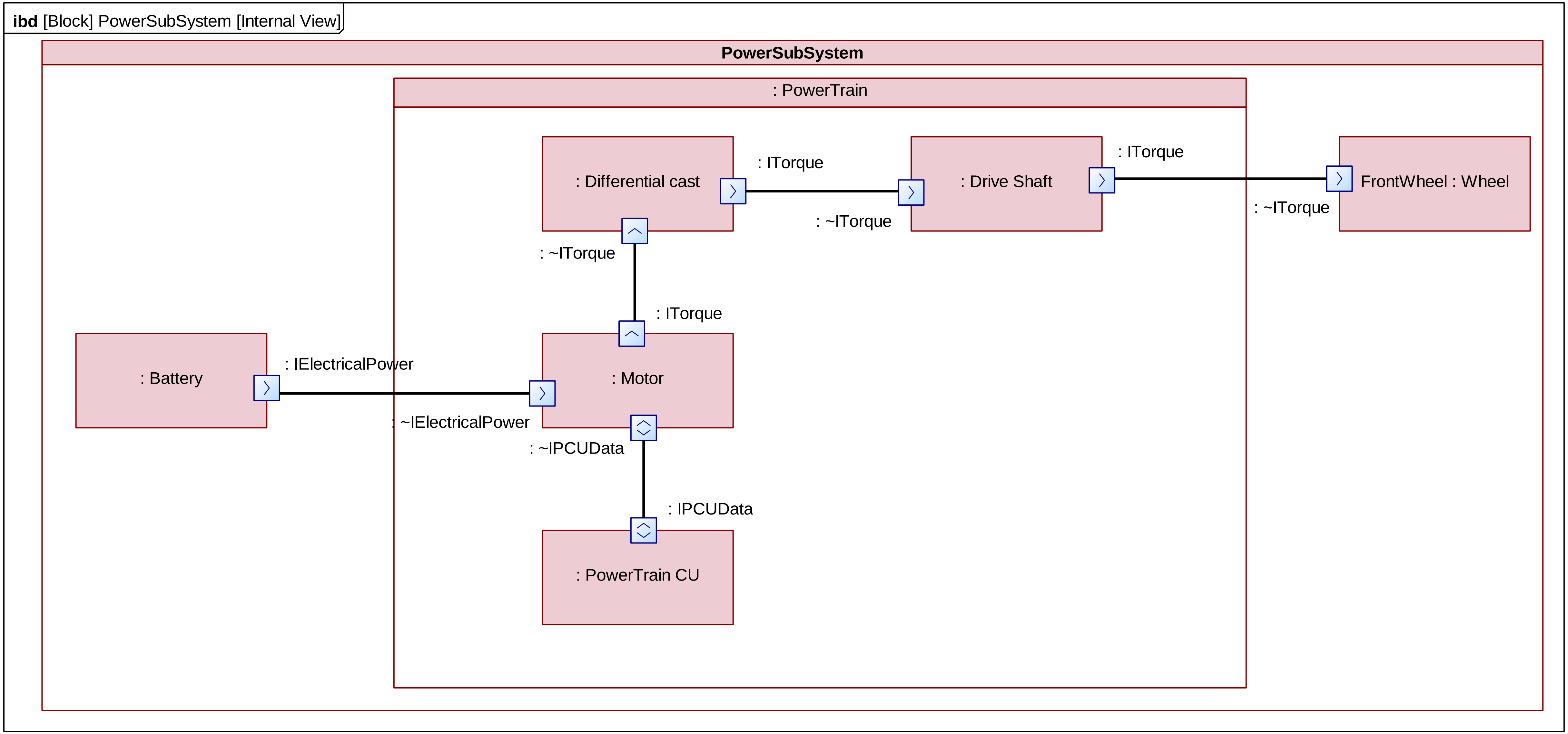
POWER TRAIN USE CASES



POWER TRAIN SUBSYSTEM STRUCTURE



POWER SUBSYSTEM INTERNAL VIEW



ACCELERATE USE CASE SEQUENCE

Accelerate

Description

par

Get Gas Pedal position

Balance Power

Set Motor load

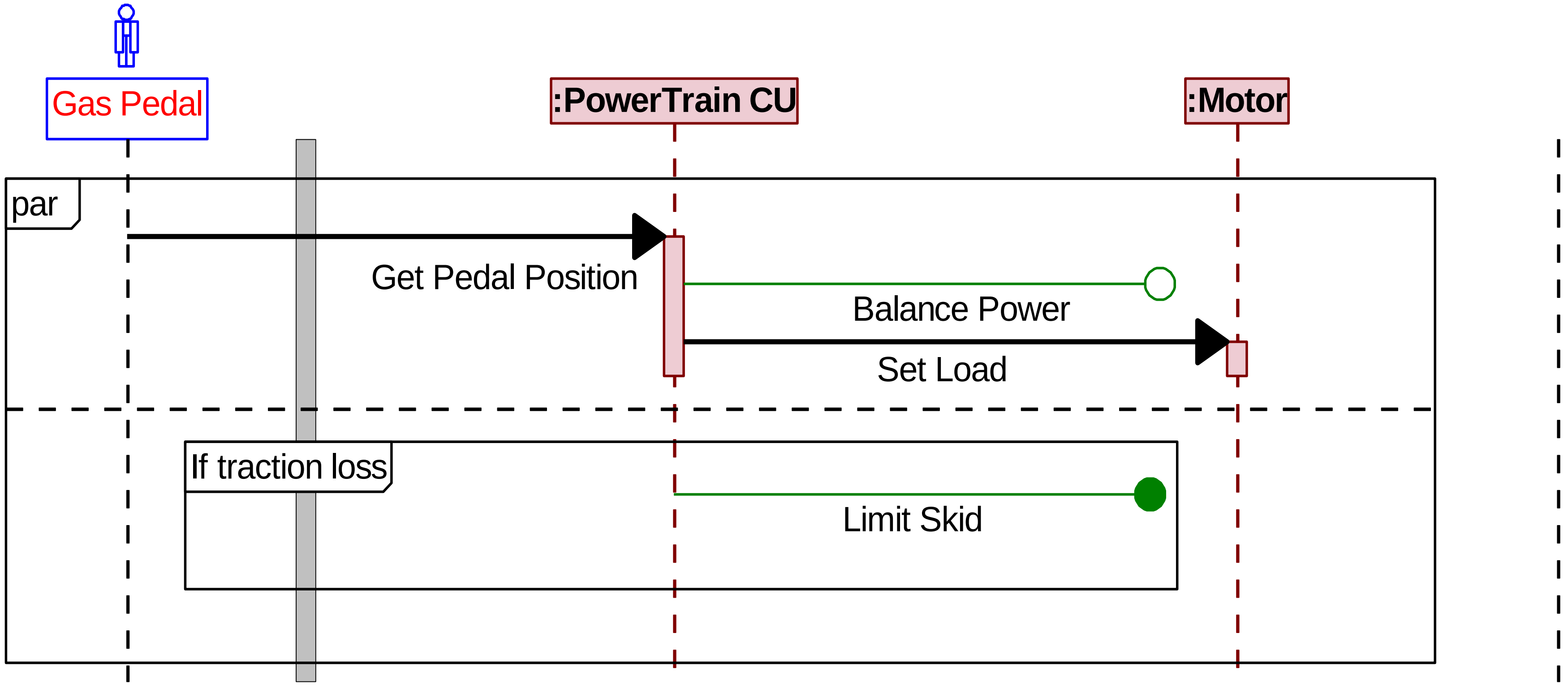
also par

If traction loss

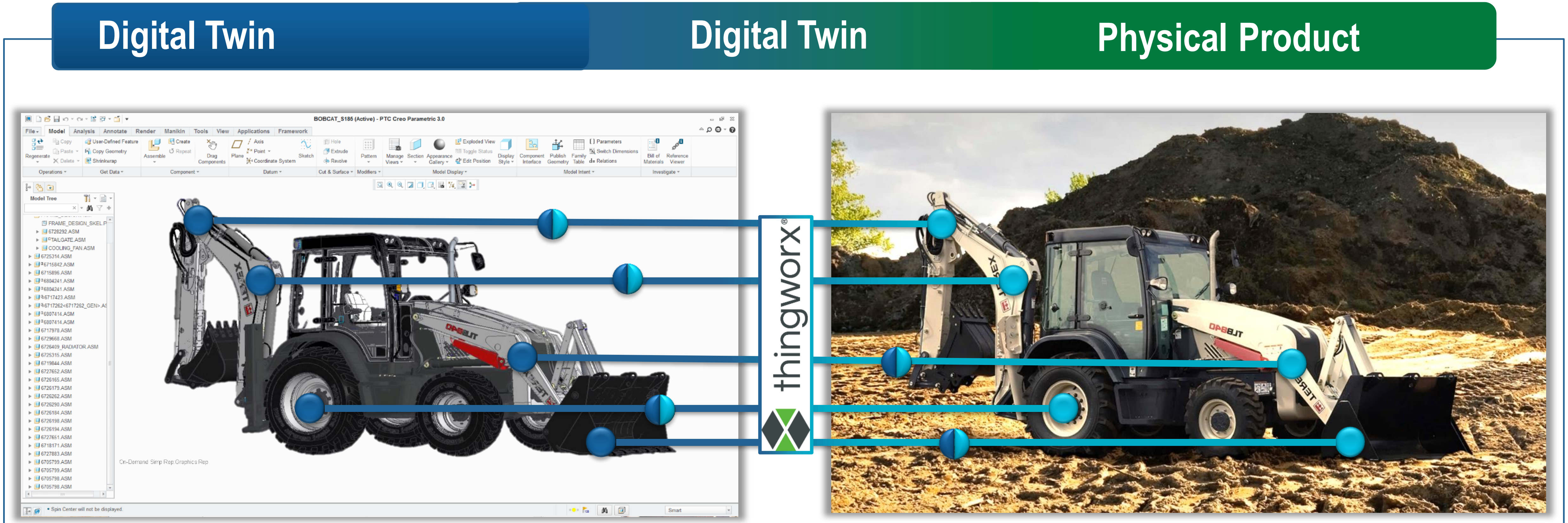
Limit Skid

End If

end par



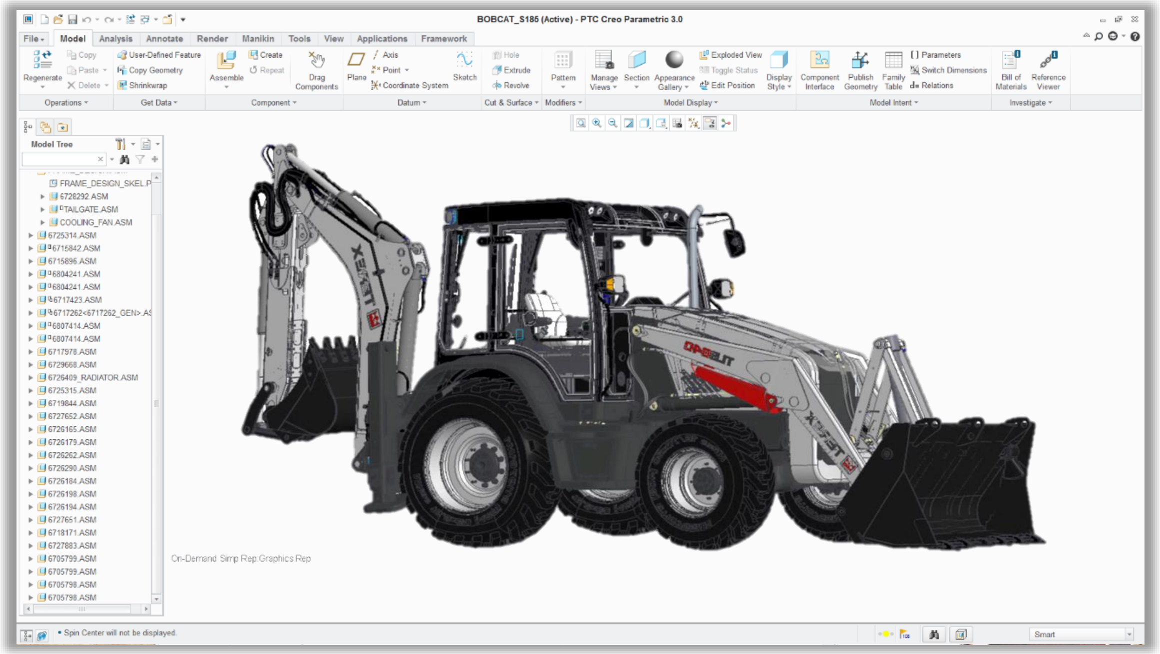
A MISSING CONNECTION FOR ENGINEERING… DESIGN MODEL OPTIMIZATION



Digital Twin: A digital representation of a unique occurrence of a physical product, used to gain greater insight into that product's state, performance and behavior.

REAL-WORLD **DATA DRIVEN DESIGNS**
DESIGN MODEL OPTIMIZATION

Digital Prototype

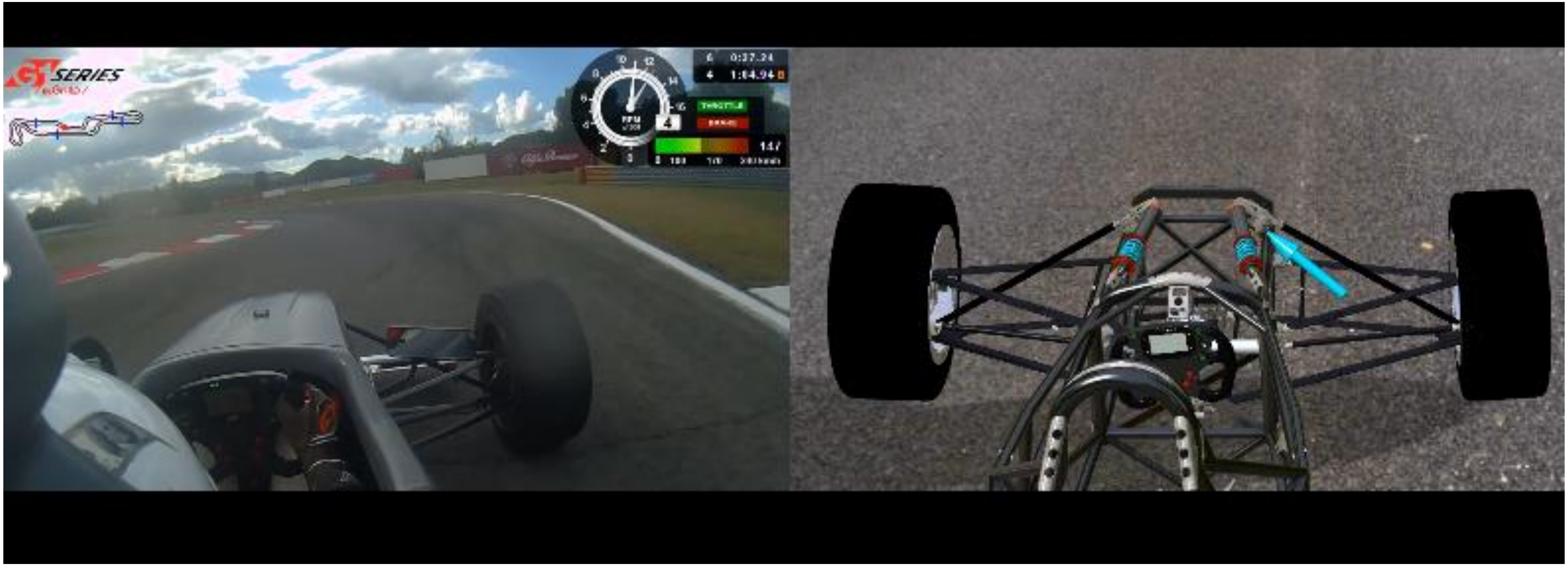


Product Population

ASSUMPTION

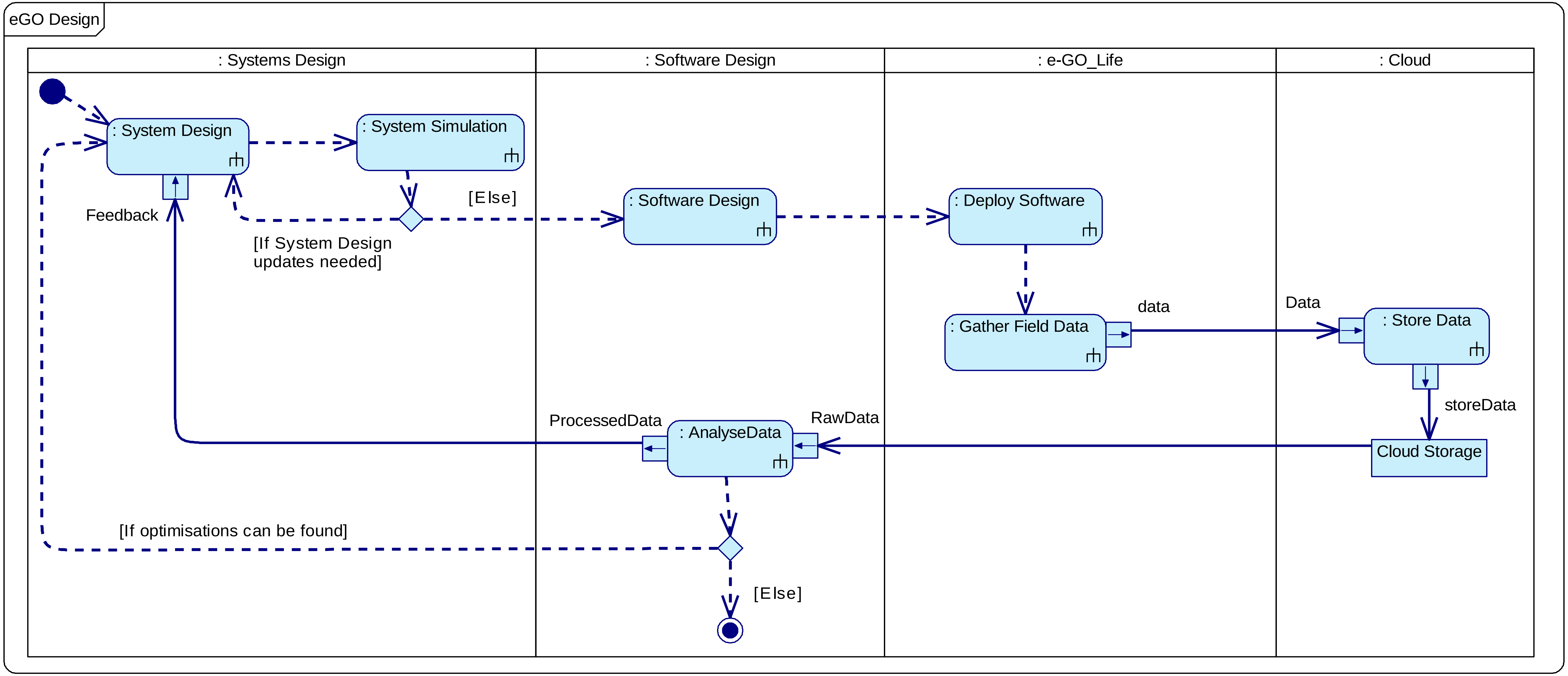
REALITY

DESIGN MODEL OPTIMIZATION BY FEEDING BACK FIELDED SENSOR DATA INTO DESIGN MODEL

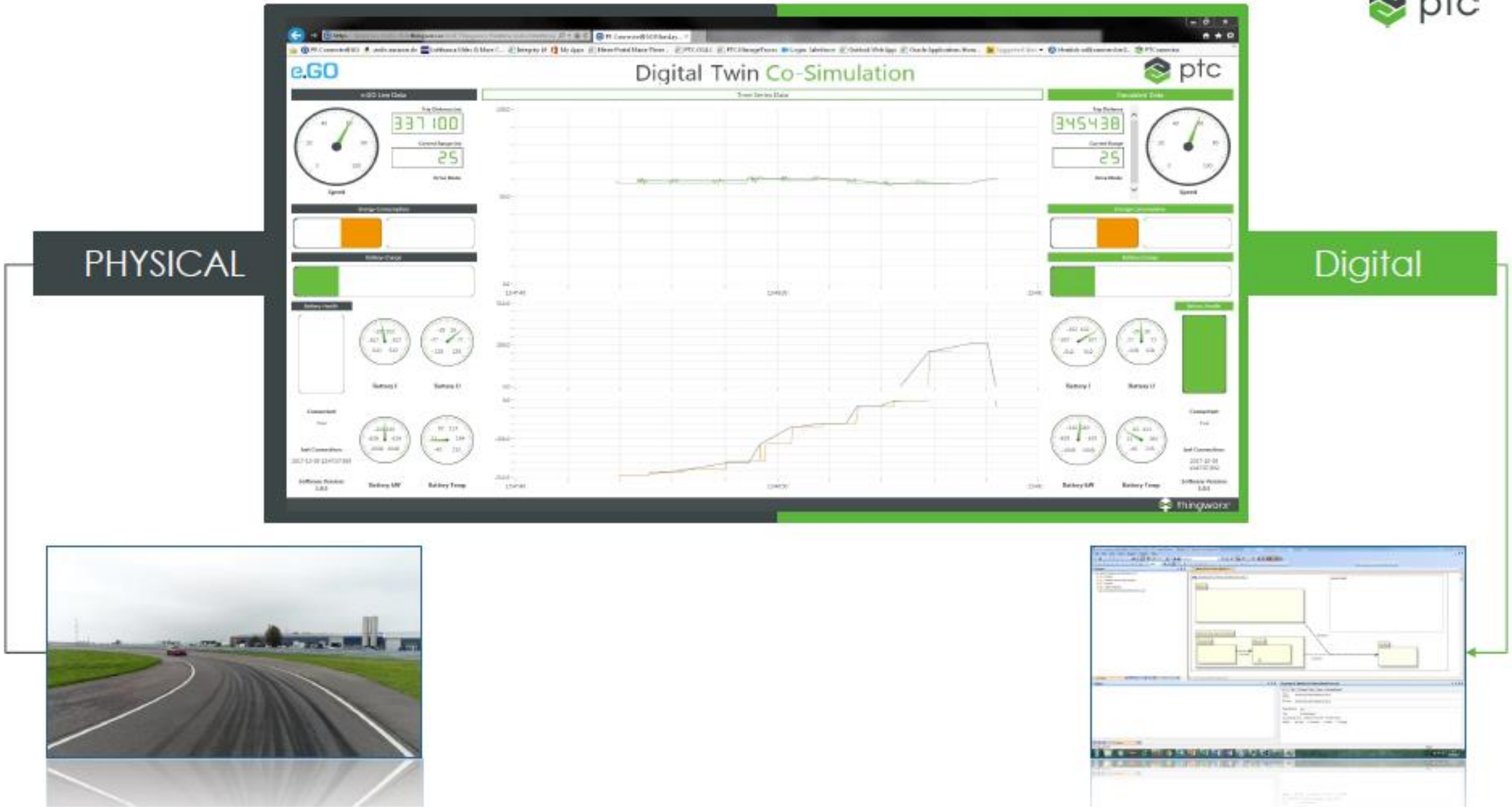


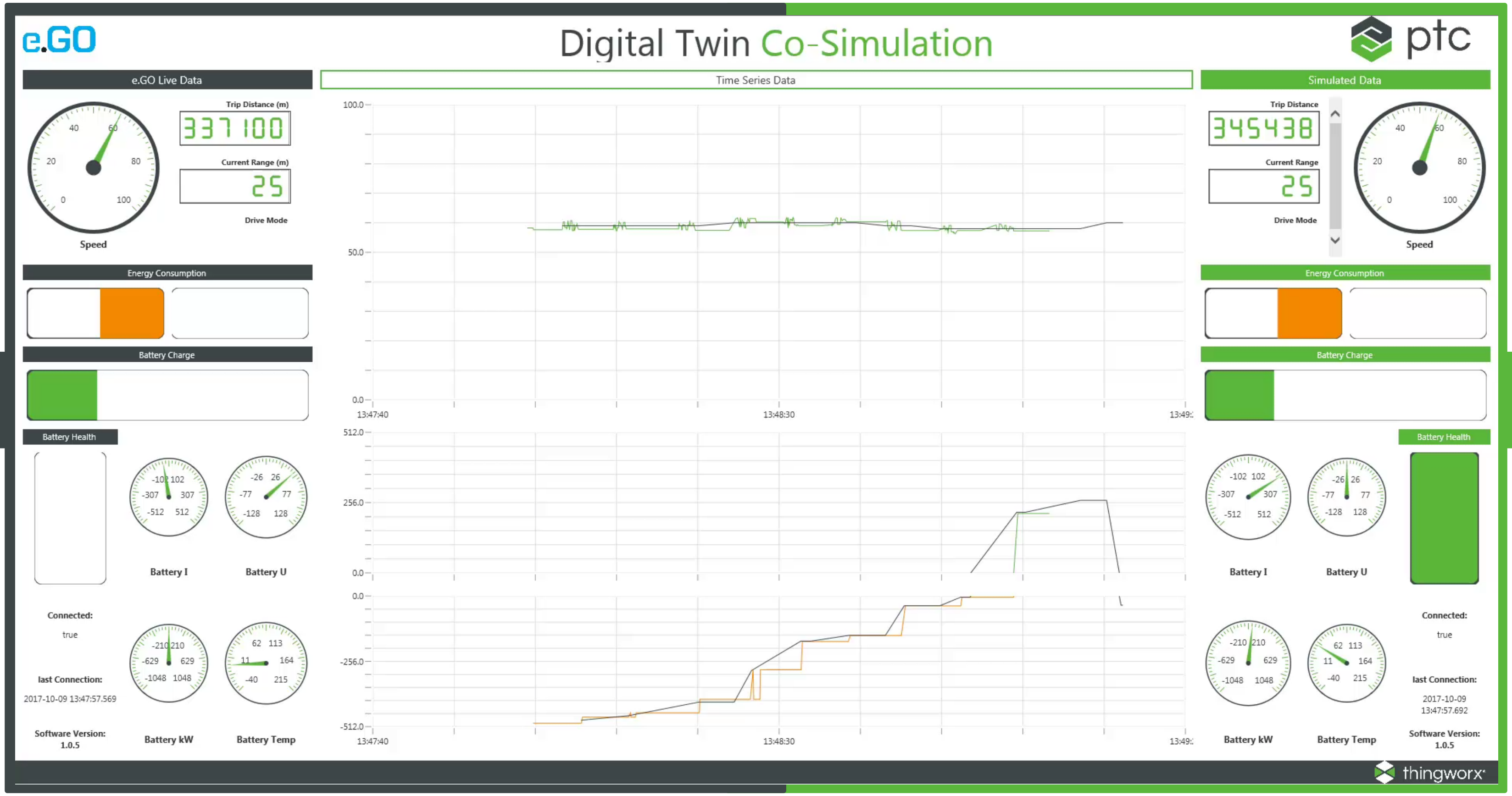

G1 SERIES
by Griiip

SIMULATION SYSTEM DESIGN ACTIVITY DIAGRAM



SYSTEM MODEL OPTIMIZATION BY FEEDING BACK FIELDED SENSOR DATA INTO INTEGRITY MODELER SYSIM
EGO LIFE USE CASE





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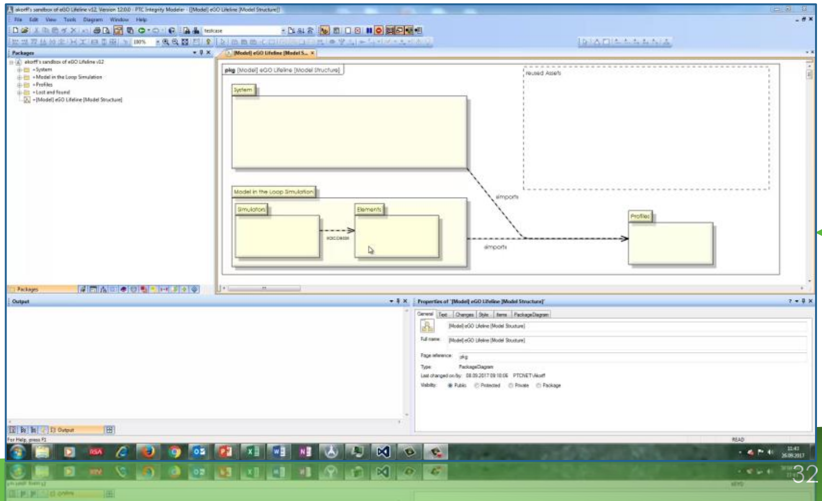
Physical

Digital



COLLABORATIVE AR/VR DESIGN

Collaborative AR/VR Design

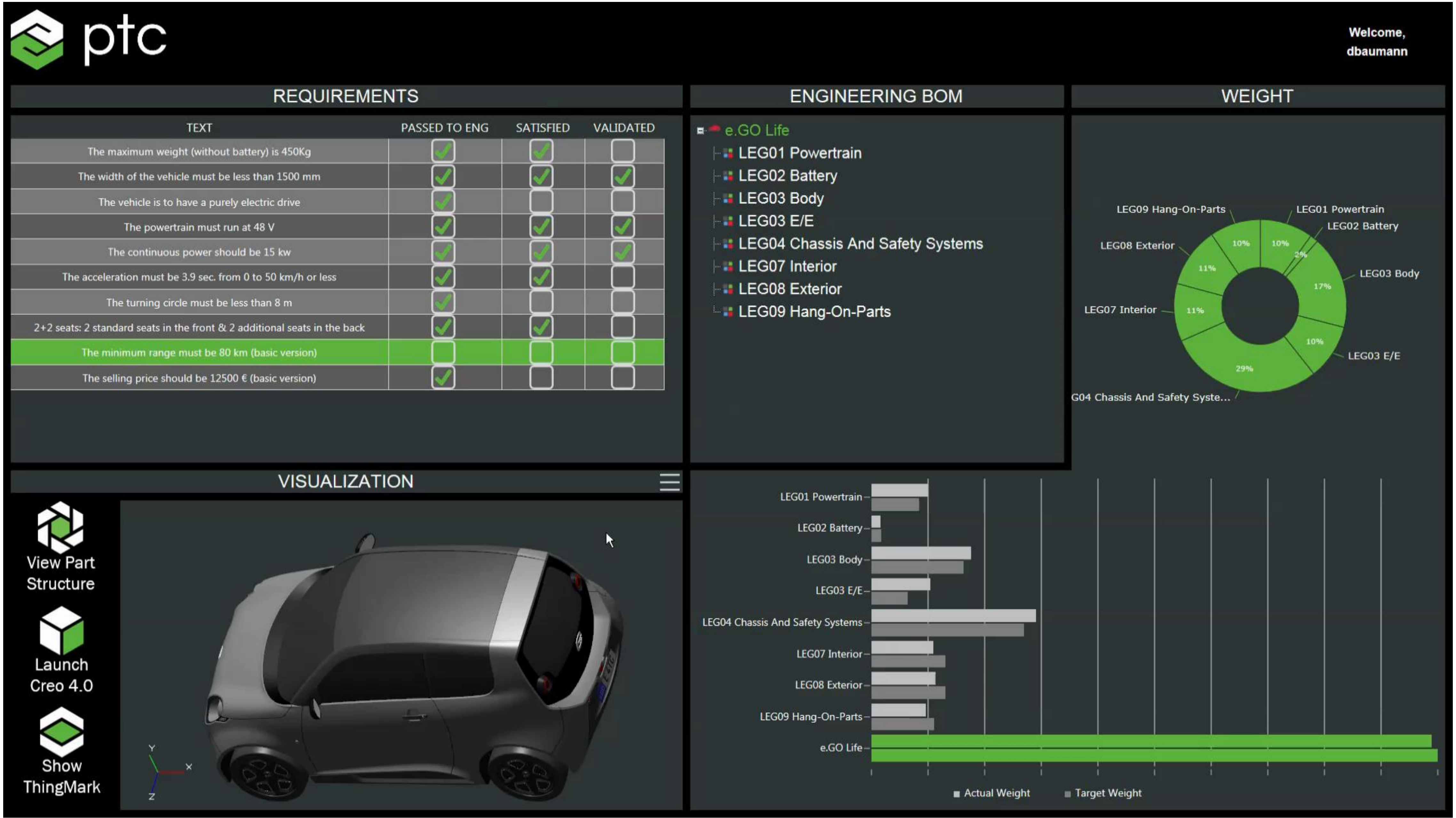
More frequent and immersive design reviews throughout the product development process

- Increase participation of stakeholders from disparate locations
- Make better decisions by capturing voice, drawn, and text input directly into the design history of the product
- Reduce costs associated with sophisticated design reviews by identifying potential issues early in the process

PTC Solutions:

creo® windchill® thingworx®

EASY ACCESS TO THE DIGITAL PRODUCT DEFINITION FOR THE ENTIRE ENTERPRISE WITH CONNECTED DIGITAL ENGINEERING



AGILE, PROTOTYPE-DRIVEN DEVELOPMENT THROUGH AUGMENTED REALITY

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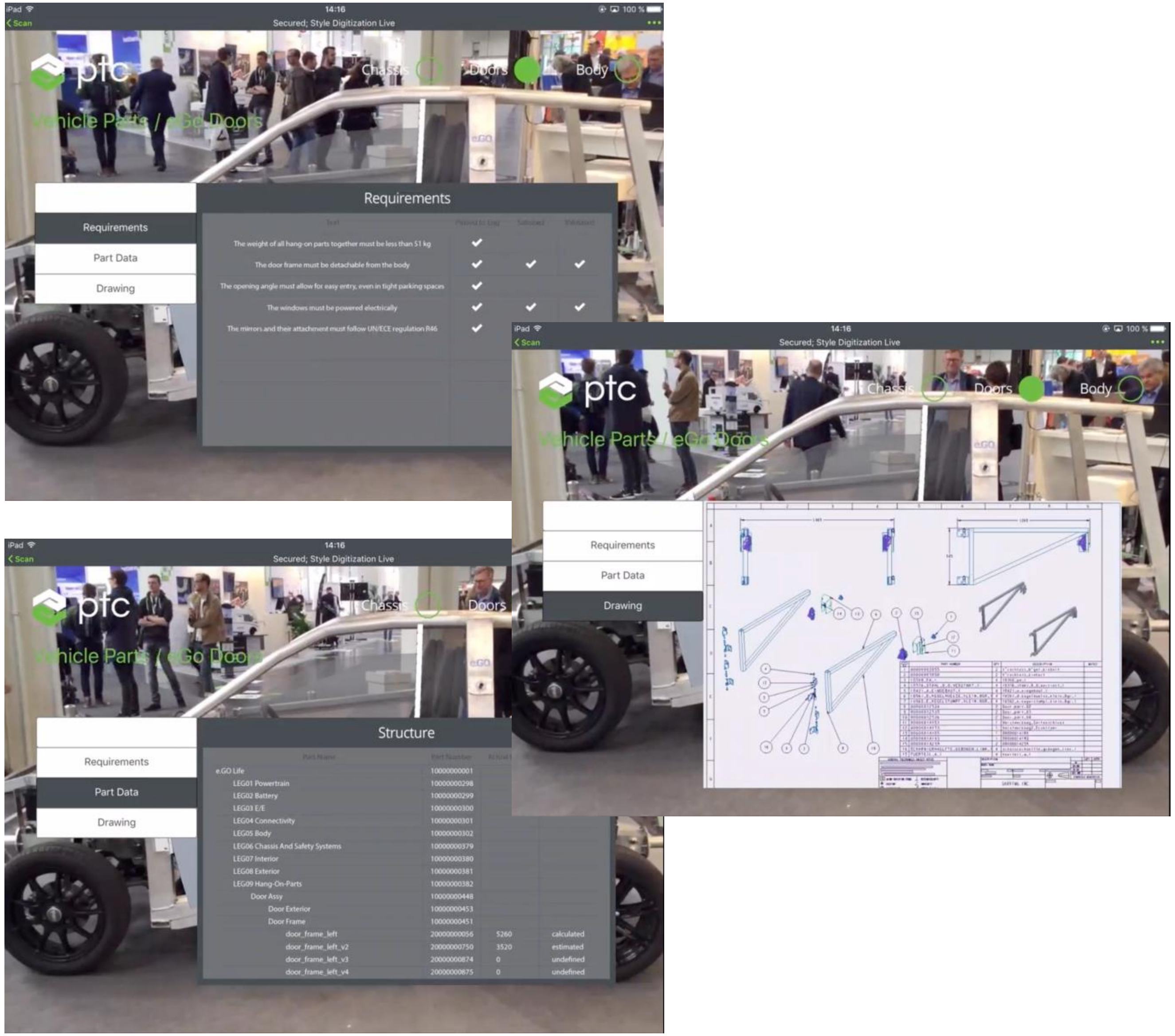
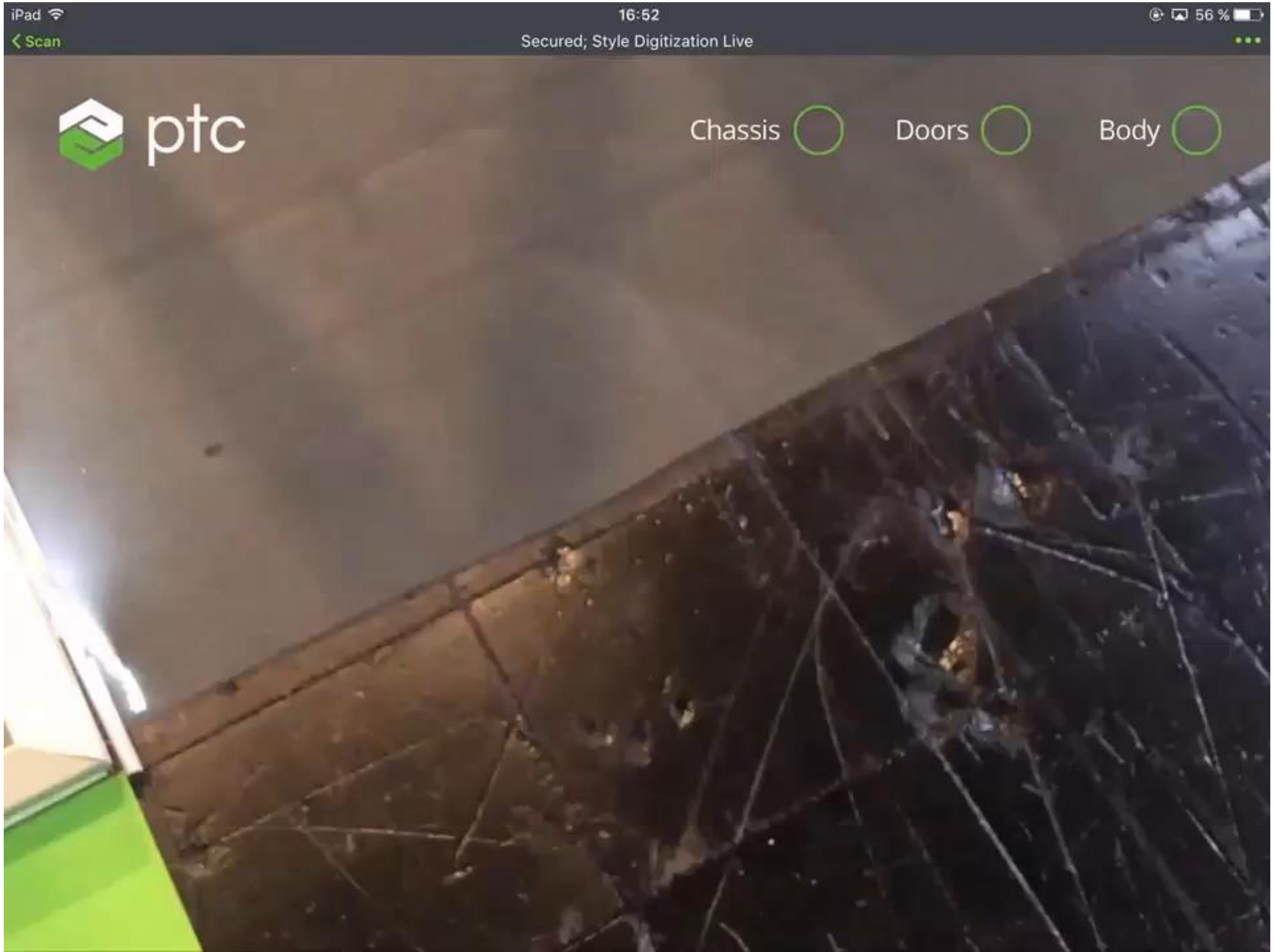
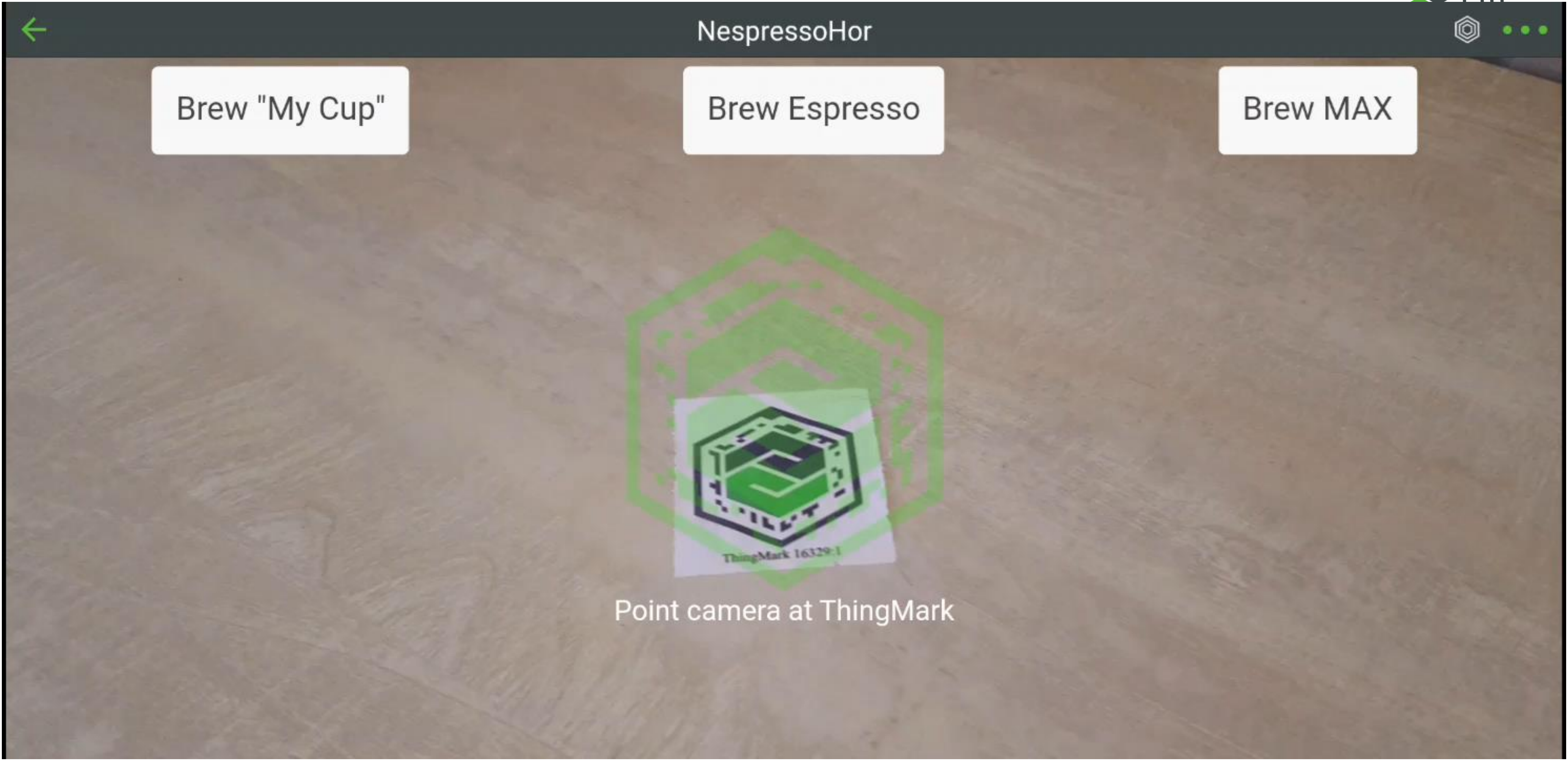


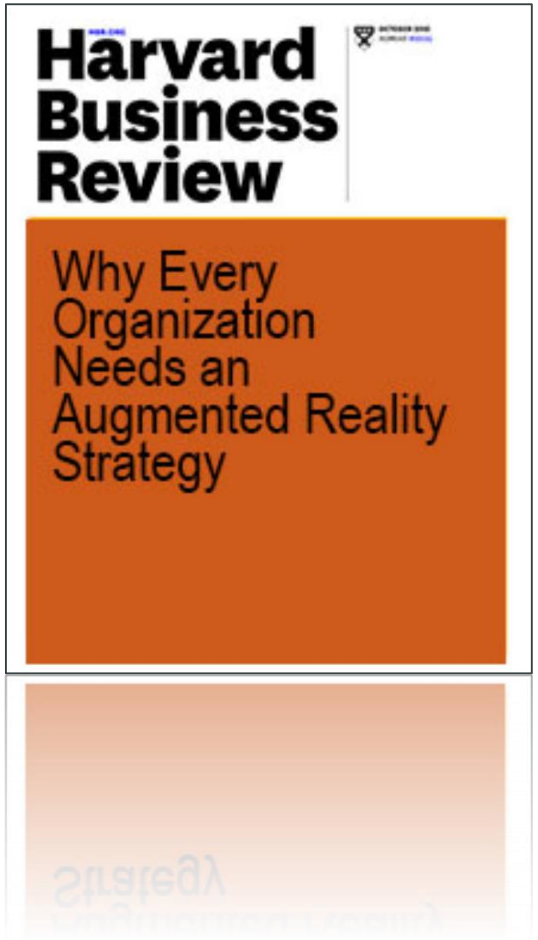
AGILE, PROTOTYPE-DRIVEN DEVELOPMENT THROUGH AUGMENTED REALITY

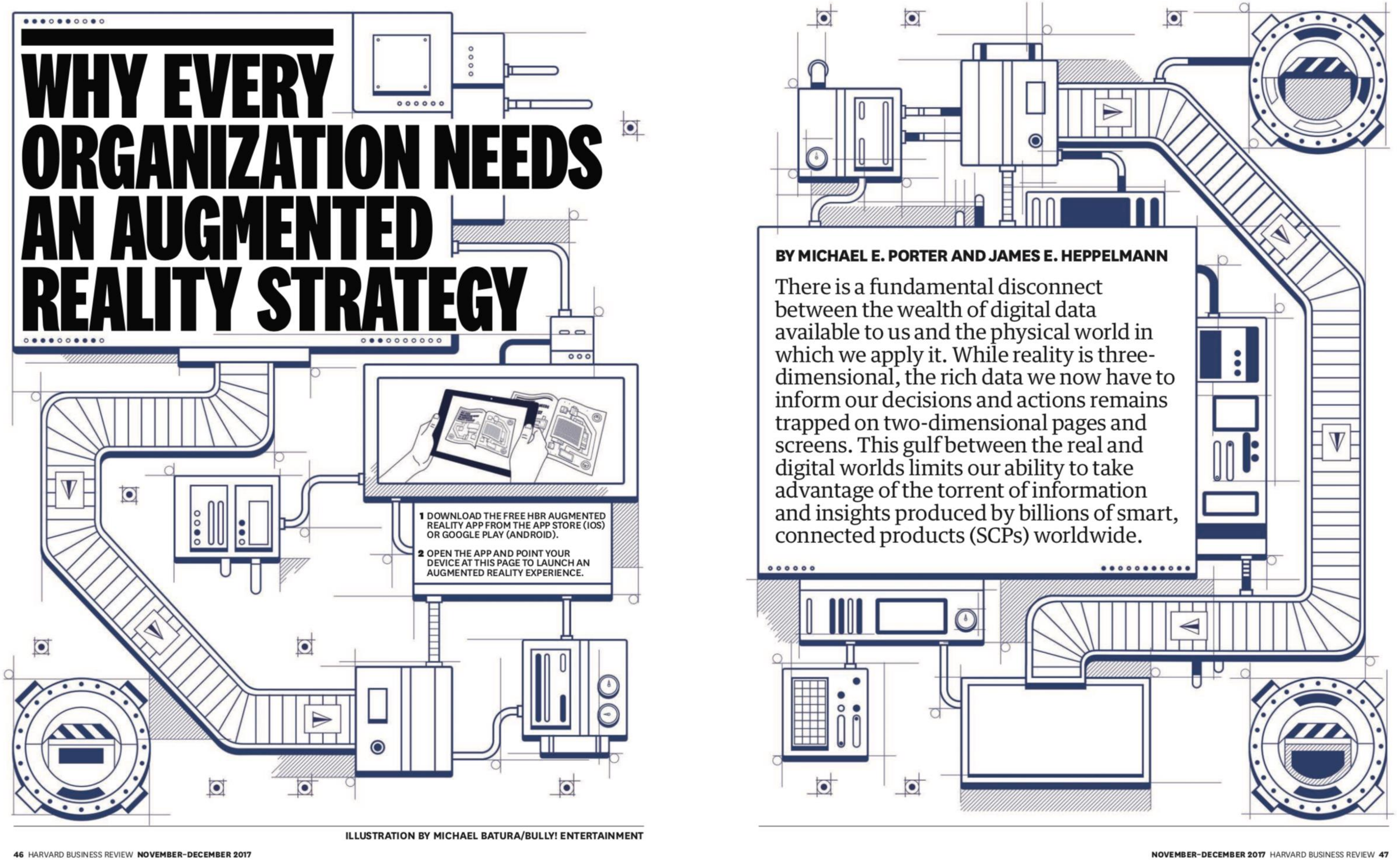
PROTOTYPE-DRIVEN DEVELOPMENT THROUGH AR - VIDEO




NespressoHor
Brew "My Cup"
Brew Espresso
Brew MAX
Point camera at ThingMark

AUGMENTED REALITY WILL DRAMATICALLY INCREASE VALUE CREATION





WHY EVERY ORGANIZATION NEEDS AN AUGMENTED REALITY STRATEGY

1 DOWNLOAD THE FREE HBR AUGMENTED REALITY APP FROM THE APP STORE (IOS) OR GOOGLE PLAY (ANDROID).

2 OPEN THE APP AND POINT YOUR DEVICE AT THIS PAGE TO LAUNCH AN AUGMENTED REALITY EXPERIENCE.

ILLUSTRATION BY MICHAEL BATURA/BULLY! ENTERTAINMENT

BY MICHAEL E. PORTER AND JAMES E. HEPPELMANN

There is a fundamental disconnect between the wealth of digital data available to us and the physical world in which we apply it. While reality is three-dimensional, the rich data we now have to inform our decisions and actions remains trapped on two-dimensional pages and screens. This gulf between the real and digital worlds limits our ability to take advantage of the torrent of information and insights produced by billions of smart, connected products (SCPs) worldwide.

46 HARVARD BUSINESS REVIEW NOVEMBER–DECEMBER 2017

NOVEMBER–DECEMBER 2017 HARVARD BUSINESS REVIEW 47

CONCLUSIONS

- The Digital Twin provides a means of visualizing a system at all phases of development
  - Concept
  - Design
  - Operations
  - Maintenance
  - Etc.
- A Digital Twin requires both the physical system and the digital representation
- Digital Twins can be combined with simulation, MBSE models, AI analytics, etc.

THE ANALOG TWIN

Q&A

Thank You!

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