FlexTech

CentraleSupélec-ESTIA Chair

DIGITAL TWINS FOR HUMAN-SYSTEMS INTEGRATION

GUY ANDRÉ BOY

FLEXTECH CHAIR UNIVERSITY PROFESSOR
CENTRALESUPÉLEC (UNIVERSITÉ PARIS SACLAY) & ESTIA

PURPOSE

Digital twins are not only a question of technology. They should be seen as tools for **human-centered design** and **operations support**…

- Show that digital twins (DTs) are useful for
  - Human System Integration (HSI)
  - during the whole life cycle of a system
  - anticipation, preparation, creativity and experience feedback management
- Show that DTs can be qualified as FlexTech
  - from rigid automation to flexible autonomy
  - dealing with the unexpected
  - Well-being, safety, sustainability and efficiency
- Put the artificial at the service of the natural, and not the other way around

MY WORLD FOR ~40 YEARS…

From correction…

… to interaction

… to integration

… and other things

HUMAN-CENTERED DESIGN (HCD)

HCD for whom?

- e.g., Pilots, controllers, maintenance personnel, airlines, etc.
- Engineering designers, developers, manufacturers, certifiers, etc.

HCD assumes that there is always the human element everywhere

- How do we consider the human element?
- What are the theoretical and practical methods and tools?

HCD of sociotechnical systems in a digital world

- Co-designing Technology, **Organization** and People's activities (TOP Model)
- Think about the **life cycle of systems**

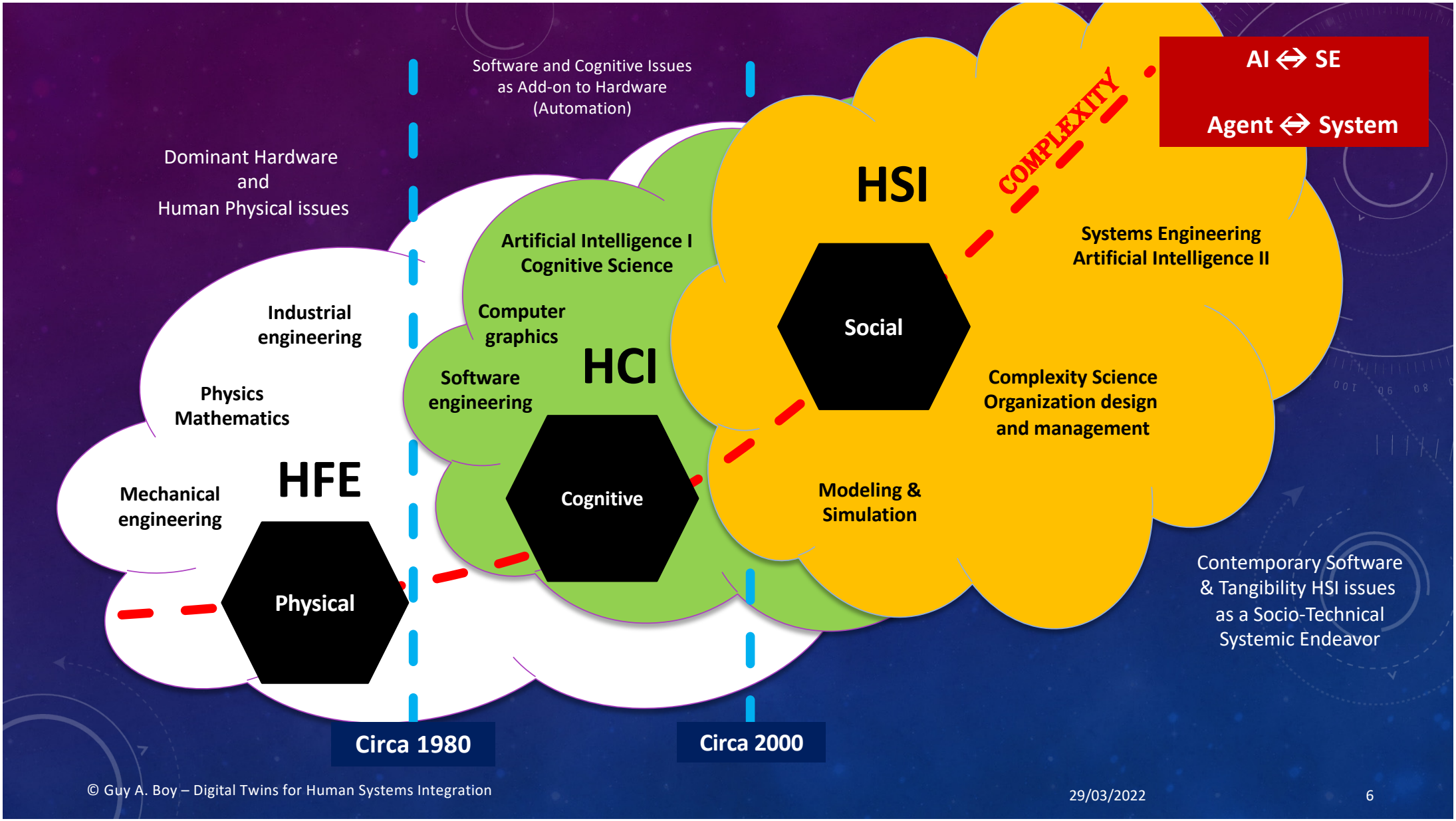
HSI HUMAN SYSTEMS INTEGRATION

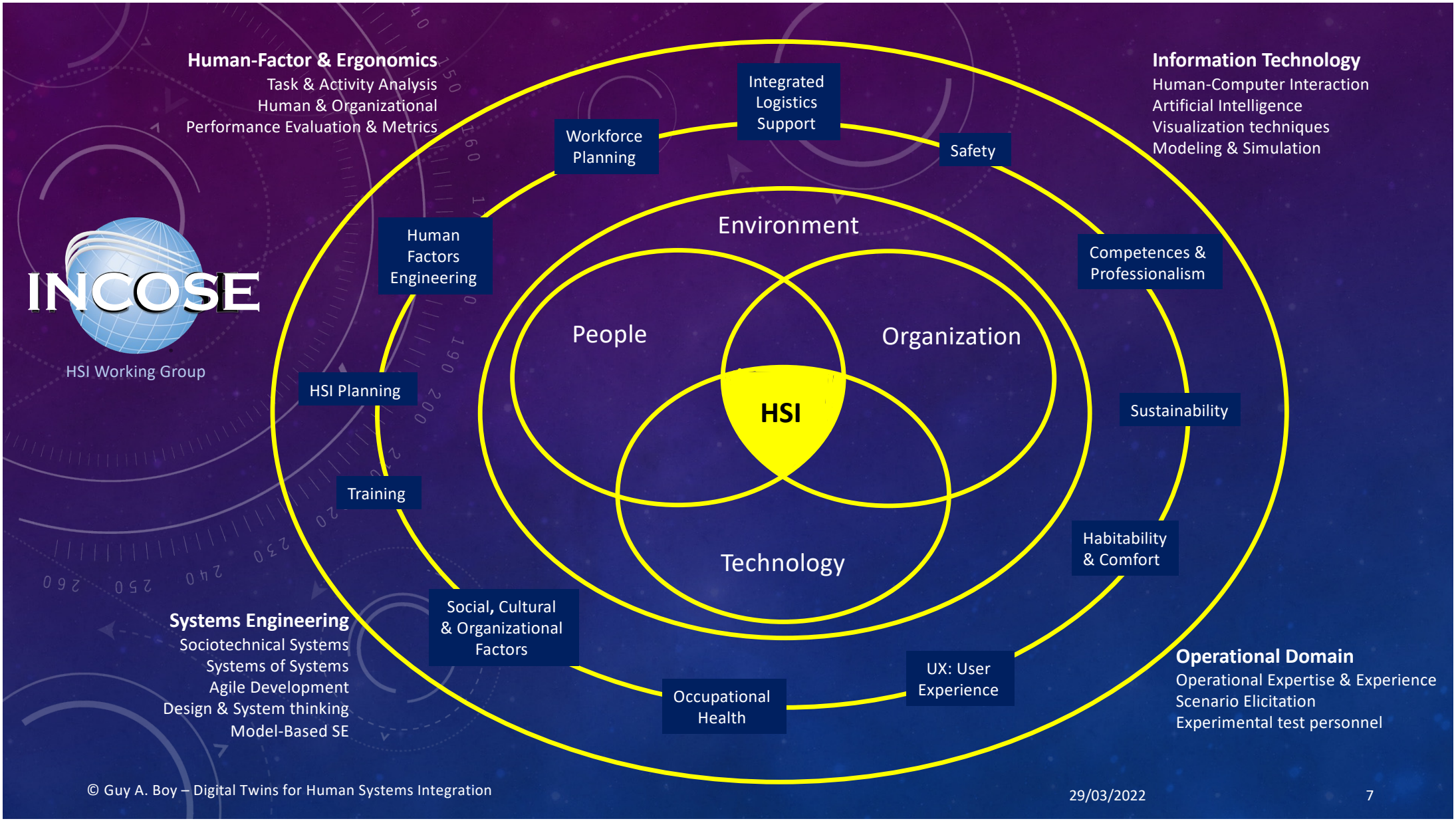
=

HCD HUMAN-CENTERED DESIGN

+

SE SYSTEMS ENGINEERING


Software and Cognitive Issues
as Add-on to Hardware
(Automation)
Dominant Hardware
and
Human Physical issues
AI ↔ SE
Agent ↔ System
COMPLEXITY
HSI
Artificial Intelligence I
Cognitive Science
Systems Engineering
Artificial Intelligence II
Industrial
engineering
Computer
graphics
Social
HCI
Software
engineering
Physics
Mathematics
Complexity Science
Organization design
and management
HFE
Mechanical
engineering
Cognitive
Modeling &
Simulation
Physical
Contemporary Software
& Tangibility HSI issues
as a Socio-Technical
Systemic Endeavor
Circa 1980
Circa 2000

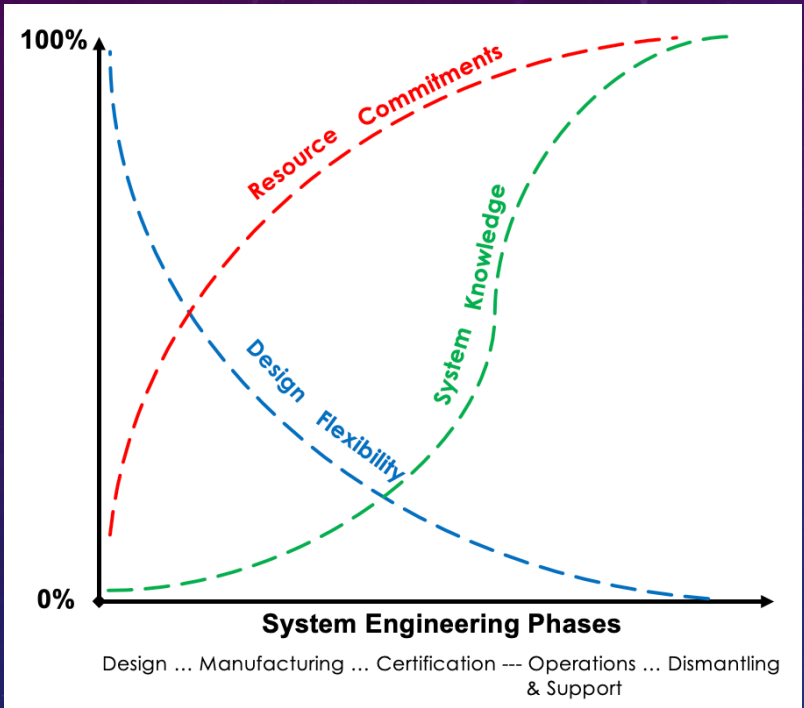

Human-Factor & Ergonomics
Task & Activity Analysis
Human & Organizational
Performance Evaluation & Metrics
Information Technology
Human-Computer Interaction
Artificial Intelligence
Visualization techniques
Modeling & Simulation
INCOSE
HSI Working Group
Integrated Logistics Support
Workforce Planning
Safety
Human Factors Engineering
Environment
Competences & Professionalism
People
Organization
HSI
HSI Planning
Sustainability
Training
Habitability & Comfort
Technology
Social, Cultural & Organizational Factors
UX: User Experience
Occupational Health
Systems Engineering
Sociotechnical Systems
Systems of Systems
Agile Development
Design & System thinking
Model-Based SE
Operational Domain
Operational Expertise & Experience
Scenario Elicitation
Experimental test personnel

INTEGRATION

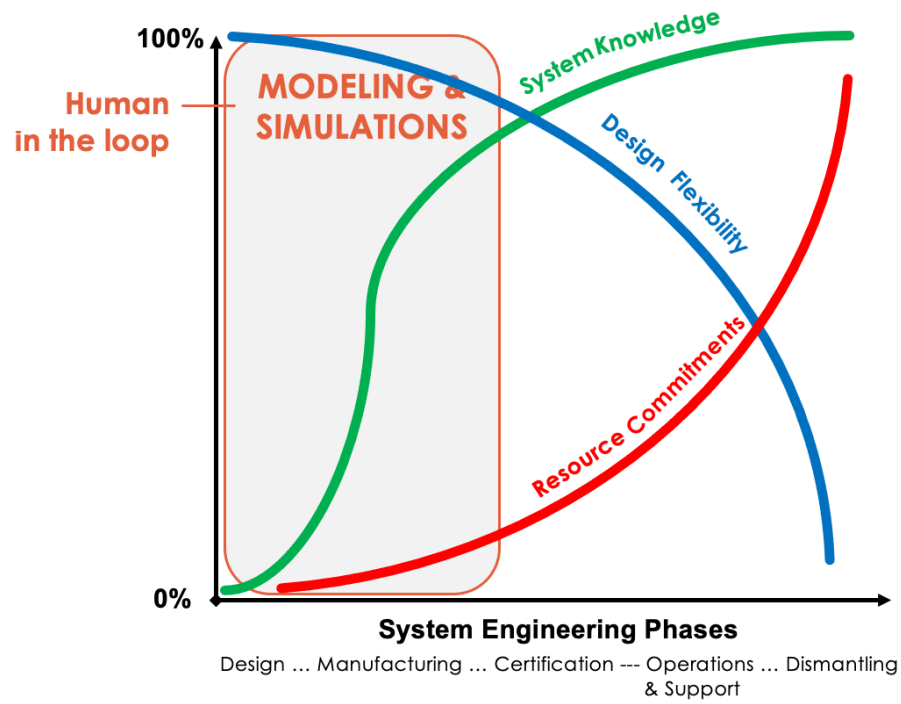
FROM THE EARLY STAGES OF DESIGN

LIFE-CYCLED HUMAN SYSTEMS INTEGRATION

Technology-centered

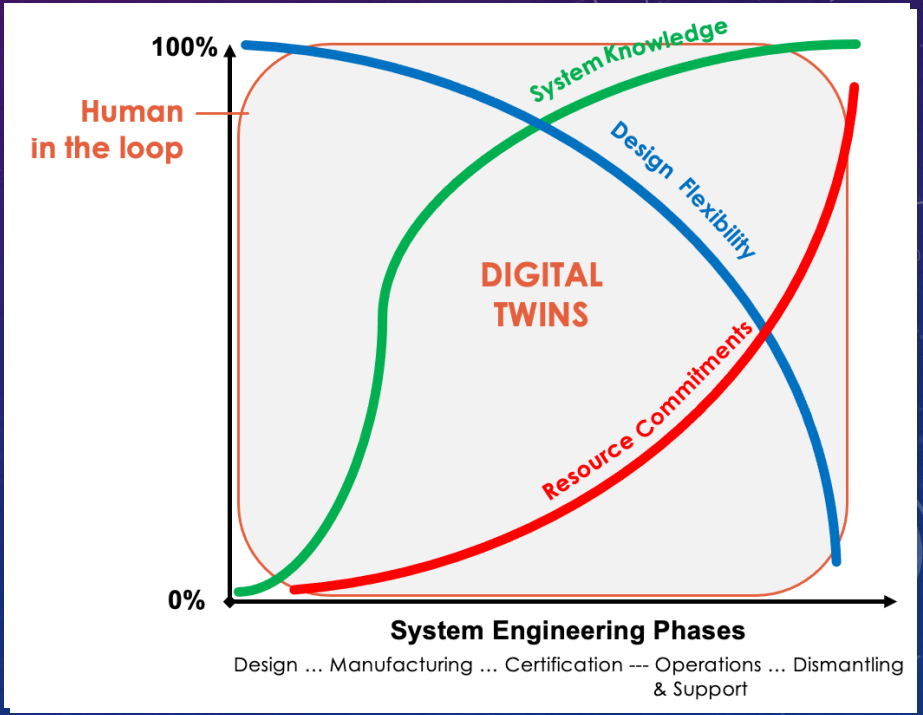


Human-centered



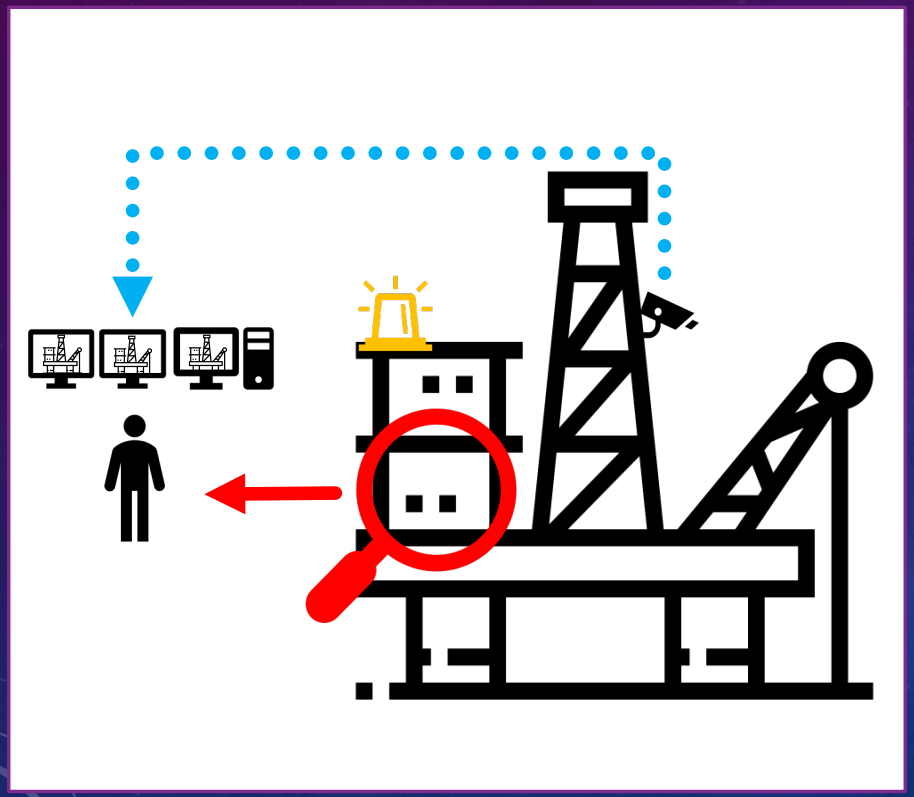
DIGITAL TWINS

- Expanding HITLS
  - During the whole life cycle
  - “what if?”
- Vivid documentation
  - Integration of experience feedback
  - Organizational memory
- DTs as virtual assistants
  - Multi-agent collaboration
  - Mediators for collaborative work



JUNA - LEARNING DIGITAL TWIN

SITUATION AWARENESS ASSISTANT SYSTEM INTEGRATING EXPERIENCE FEEDBACK



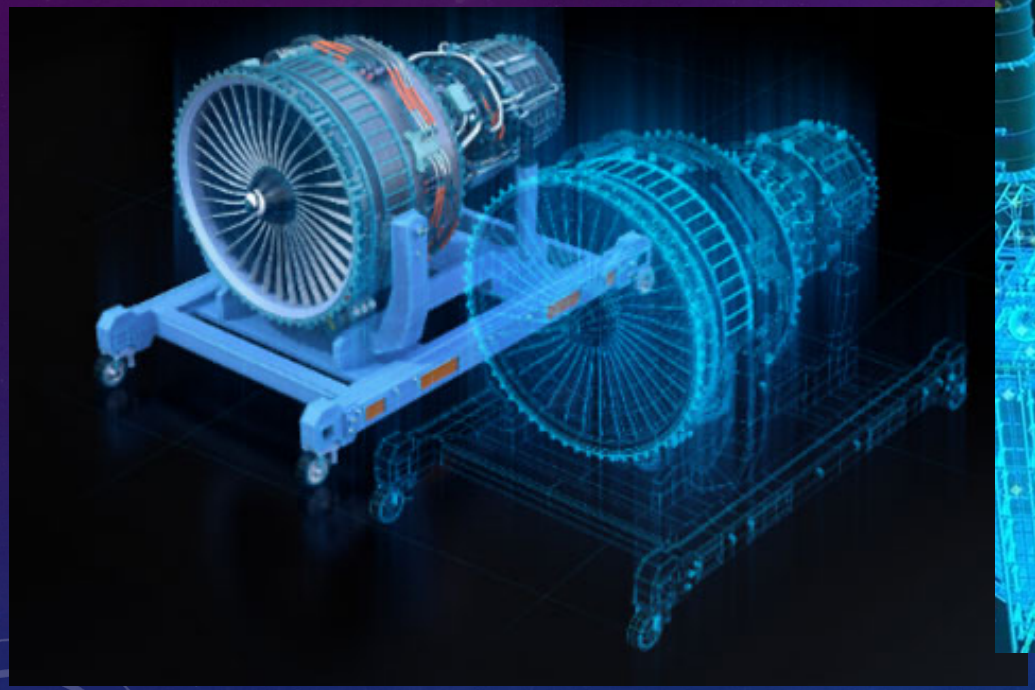
"A digital twin is a dynamic representation of a physical system using interconnected data, models, and processes to enable access to knowledge of past, present, and future states to manage action on that system."

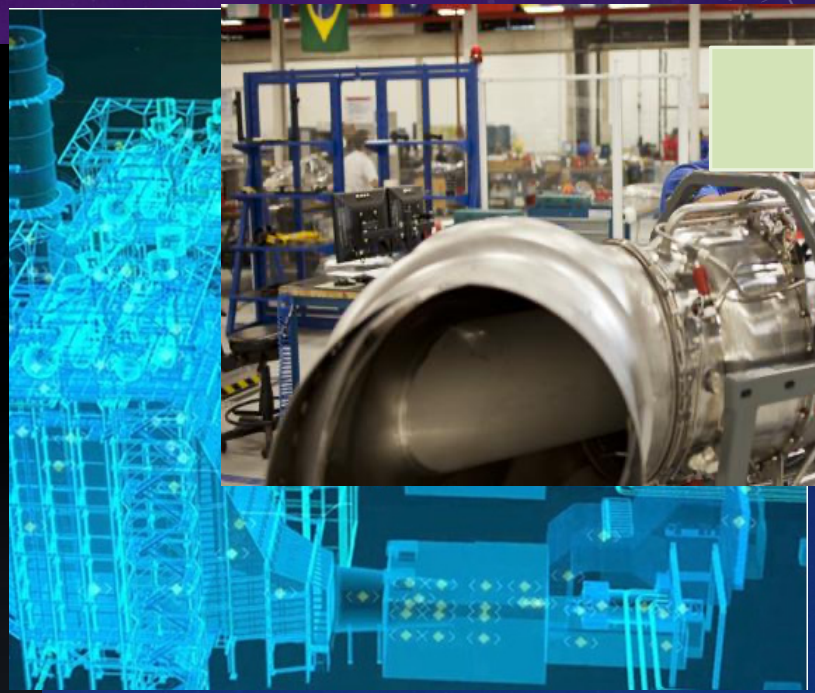
(Camara Dit Pinto, 2021)

Reality anchors:

physical or cognitive resources that allow human operators to apprehend reality at operations time

HUMAN-CENTERED DESIGN OF A DIGITAL TWIN FOR HELICOPTER ENGINE MAINTENANCE





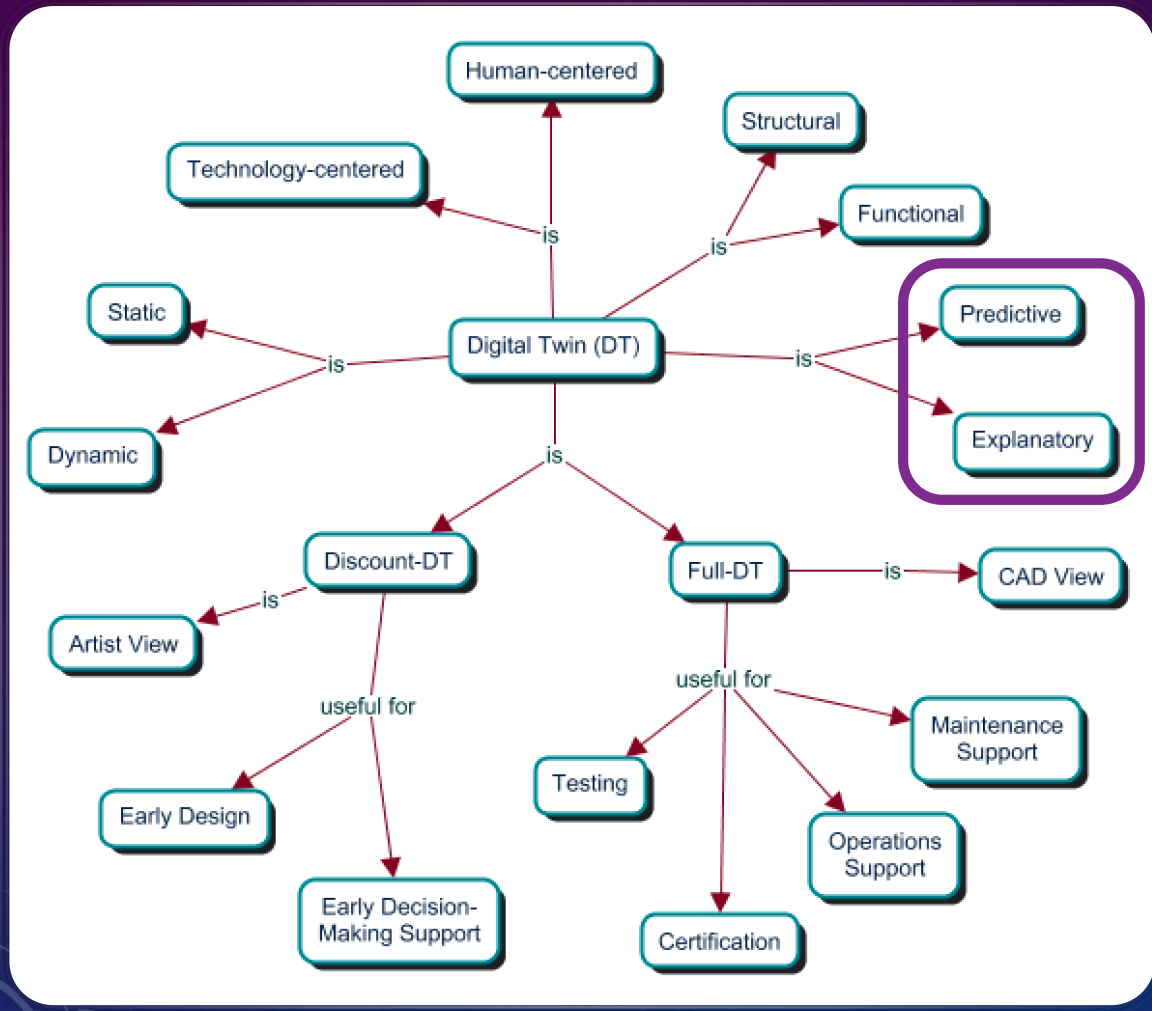
DIGITAL TWINS

- Extensions of models used in model-based systems engineering (MBSE)
- Documentation of the design process and the solutions developed (and those not chosen)
- Human-in-the-loop simulation support to engineering design (Virtual HCD)
- Active documentation to represent, simulate, and communicate on the system (traceability)

MB-HSI

Chapter in the
Handbook of MBSE
to appear in 2022

DIGITAL TWIN DEFINITION & PROPERTIES



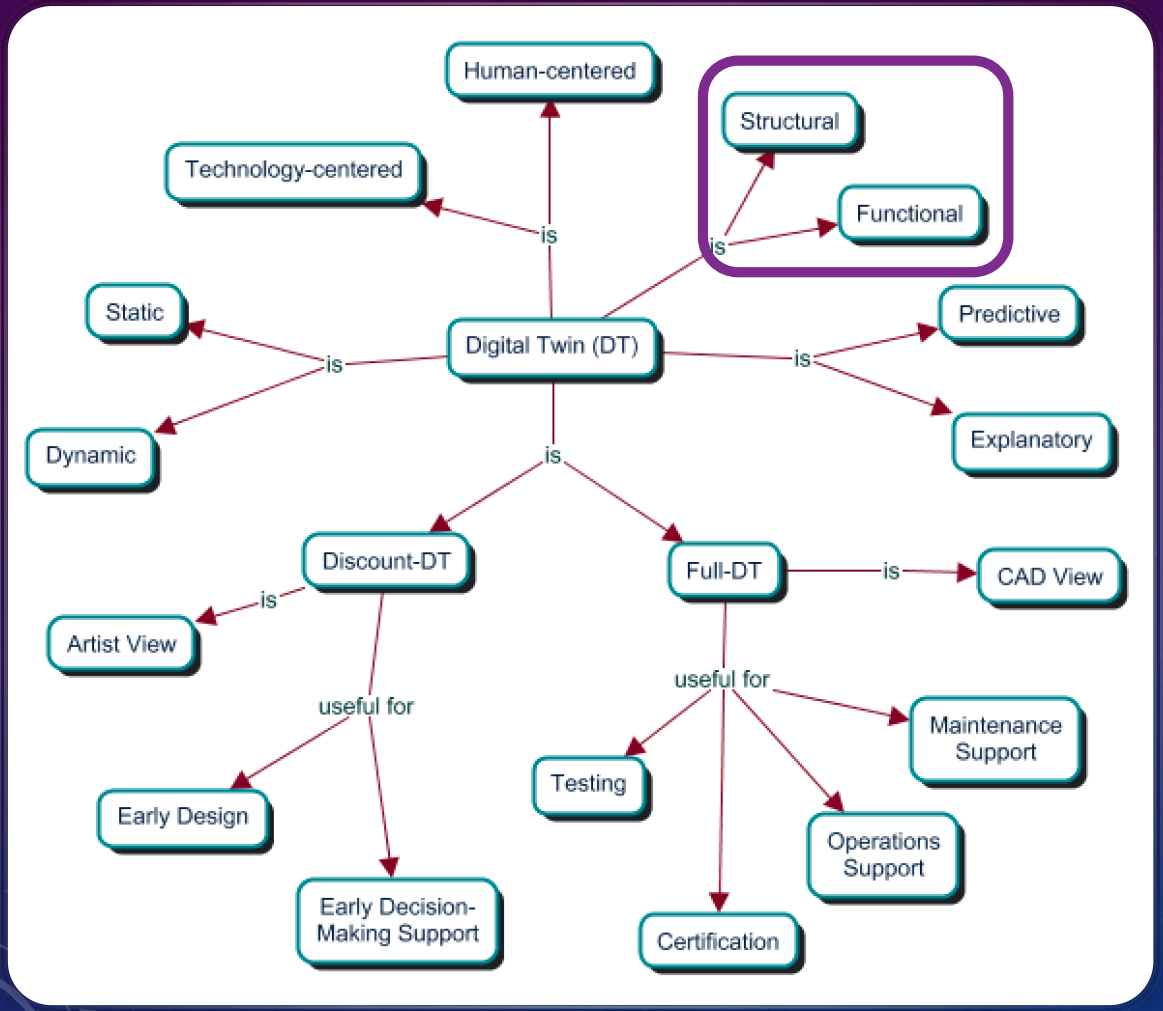
Predictive DT

very well-tested digital analog
simple & defined in a limited context
short-term, rigid and focused

Explanatory DT

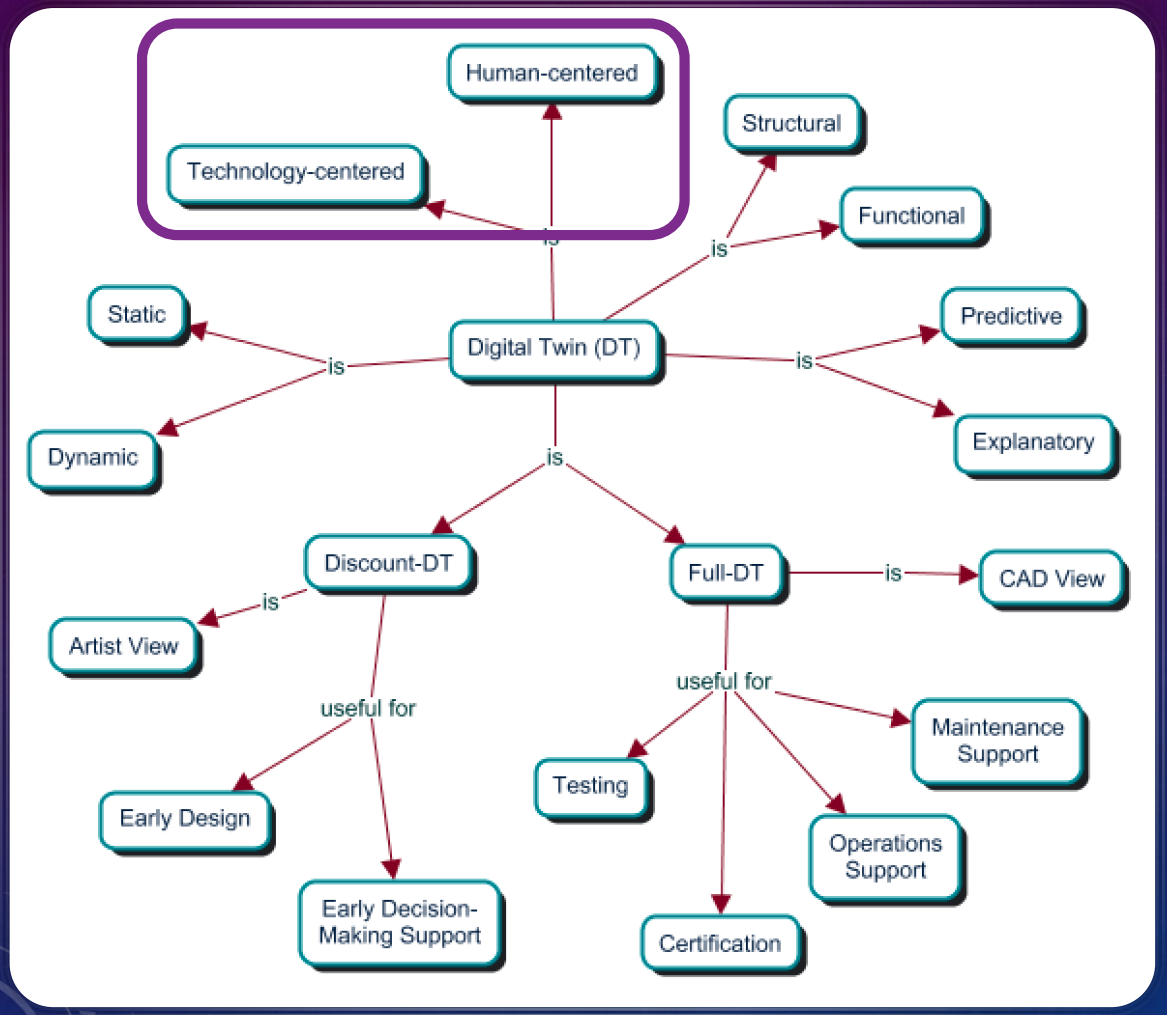
defined by an ontology of the domain
longer-term, flexible and generic
for analysis, design and evaluation
for documenting

DIGITAL TWIN DEFINITION & PROPERTIES



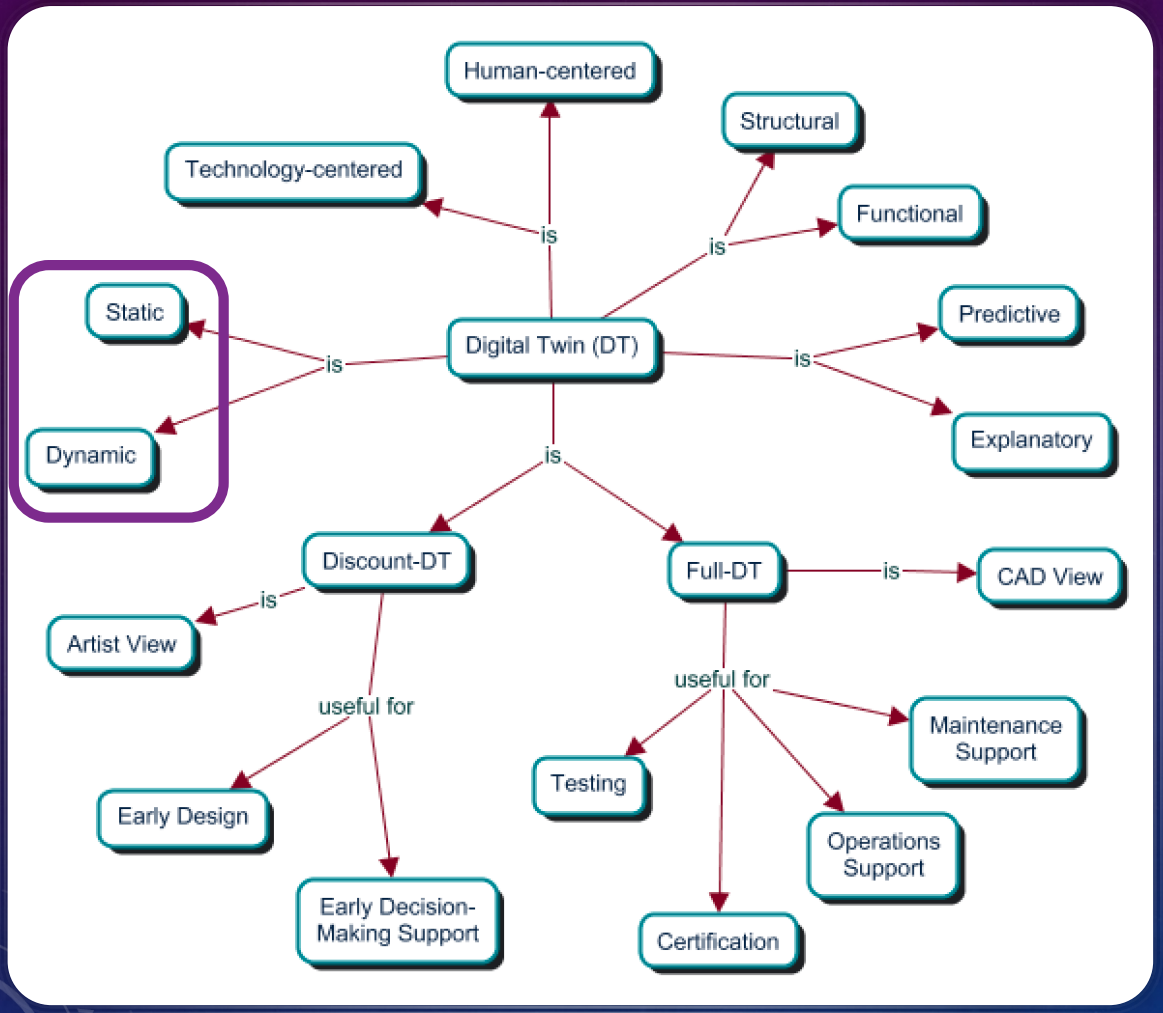
- system representation
- system visualization
- for function allocation

DIGITAL TWIN DEFINITION & PROPERTIES



- recipient of RETEX information
- support for system performance
- for both system design and usages
- support traceability
- support logistics along the whole life cycle of a system

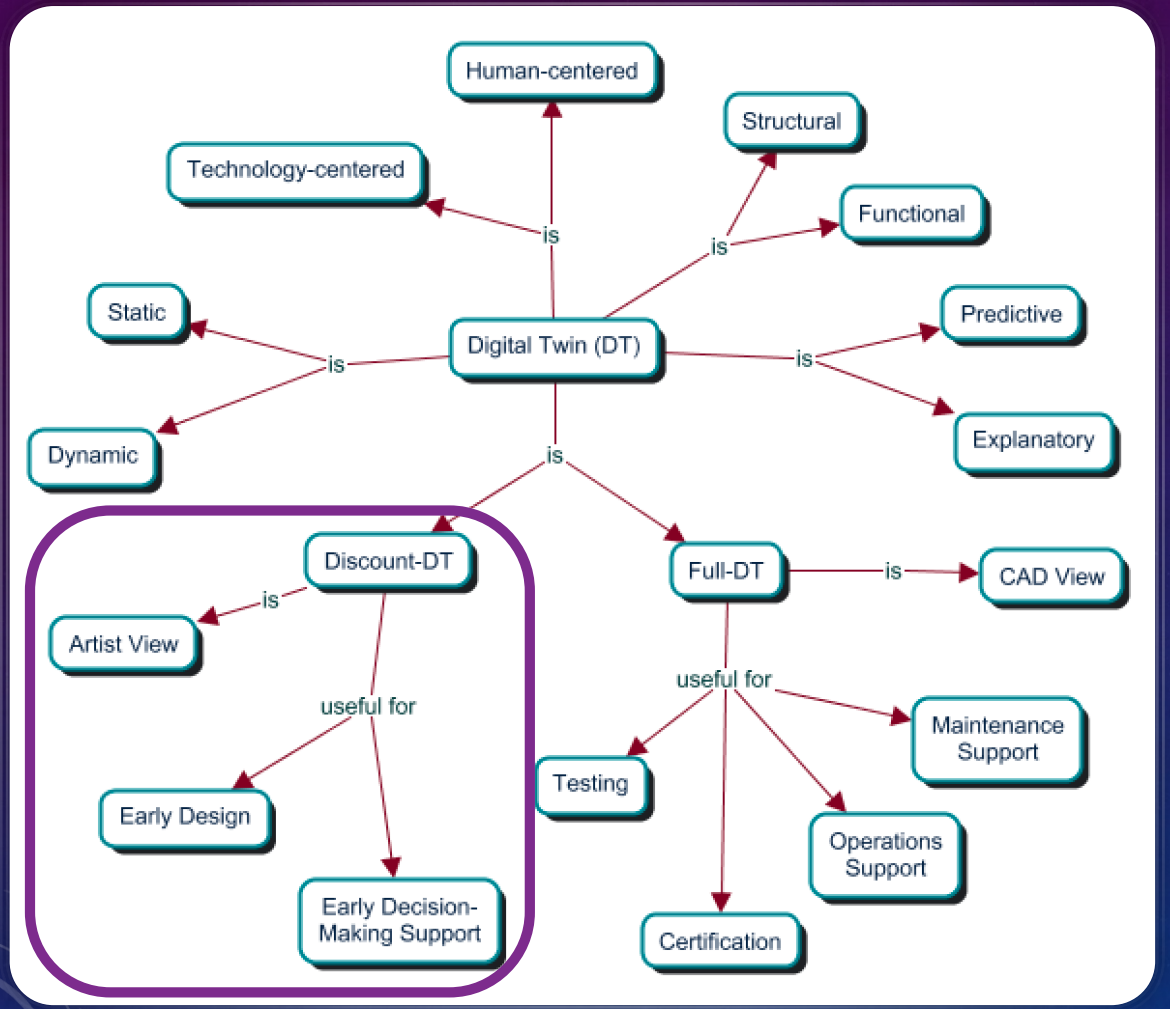
DIGITAL TWIN DEFINITION & PROPERTIES



System description
along system's life cycle

Active documentation
virtual HCD

DIGITAL TWIN DEFINITION & PROPERTIES

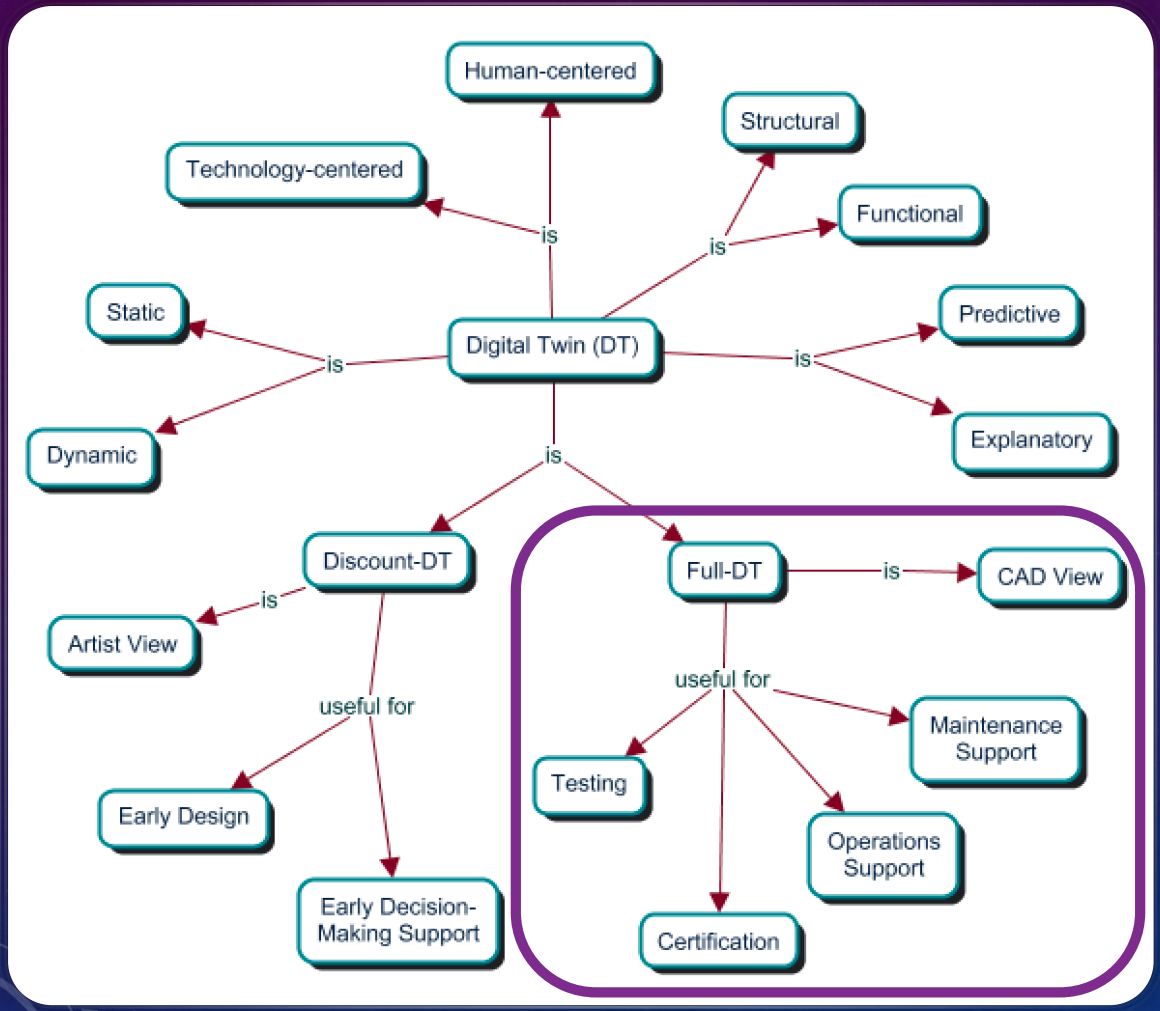


Design thinking support
- vision support
- mediating design support

Human-in-the-loop simulation
- activity analysis support
- emergent functions discovery

Agile development support
- creativity support
- modification & validation support

DIGITAL TWIN DEFINITION & PROPERTIES



Formative evaluation

- iterative design & development
- scenario-based design support

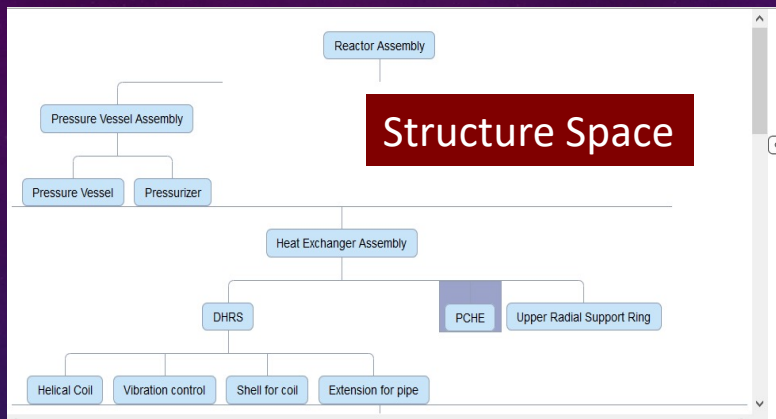
Summative evaluation

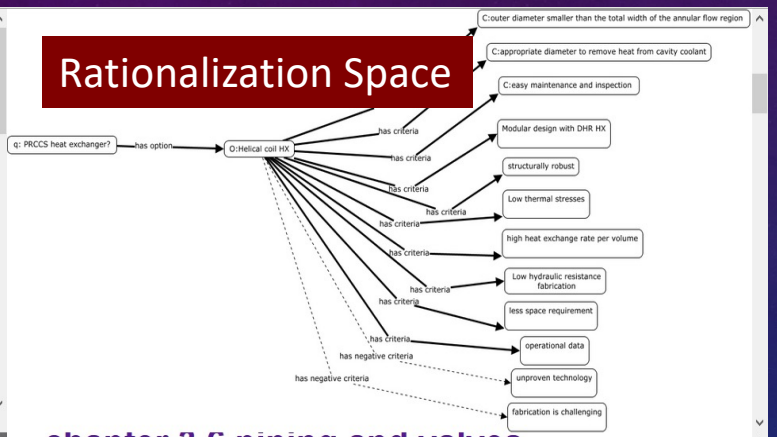
- validation
- certification

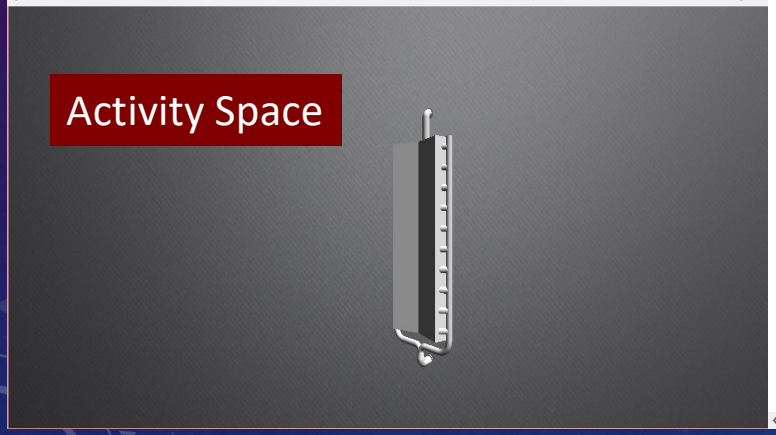
Operations support

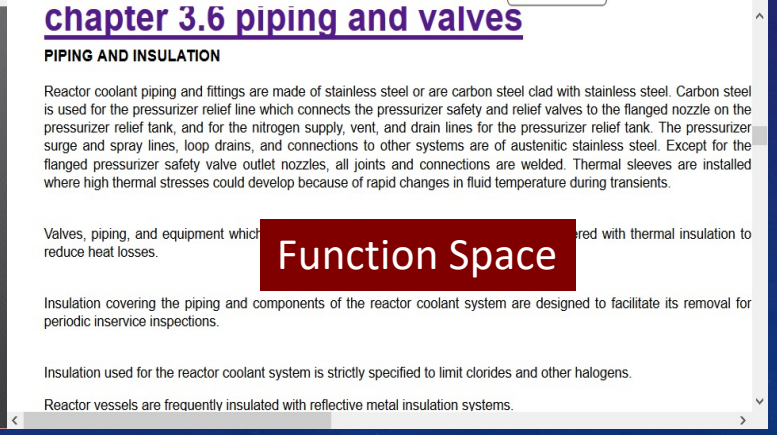
- performance
- maintenance

DESIGN CARD (DC)





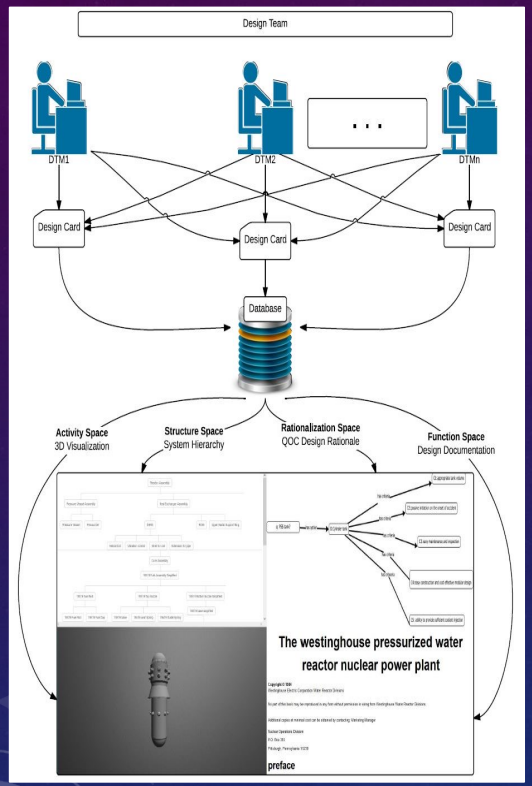


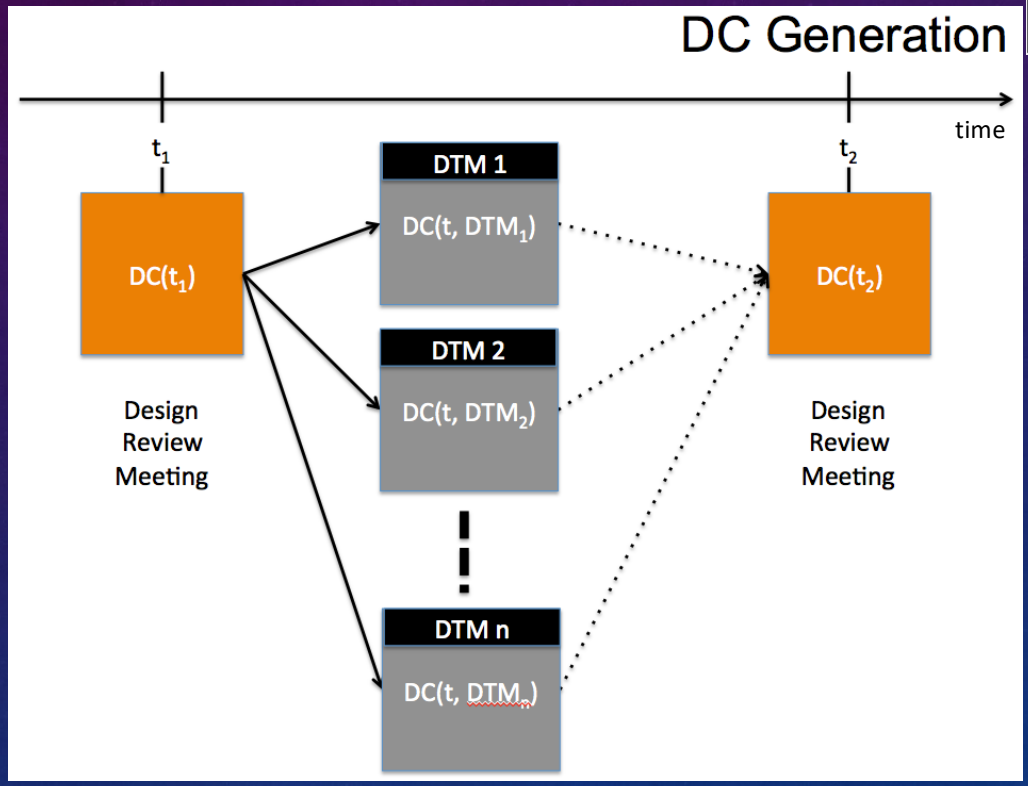


Structure Space	Rationalization Space
Activity Space	Function Space

DIGITAL TWINS AS ACTIVE DESIGN DOCUMENTS

DESIGN CARD EVOLUTION

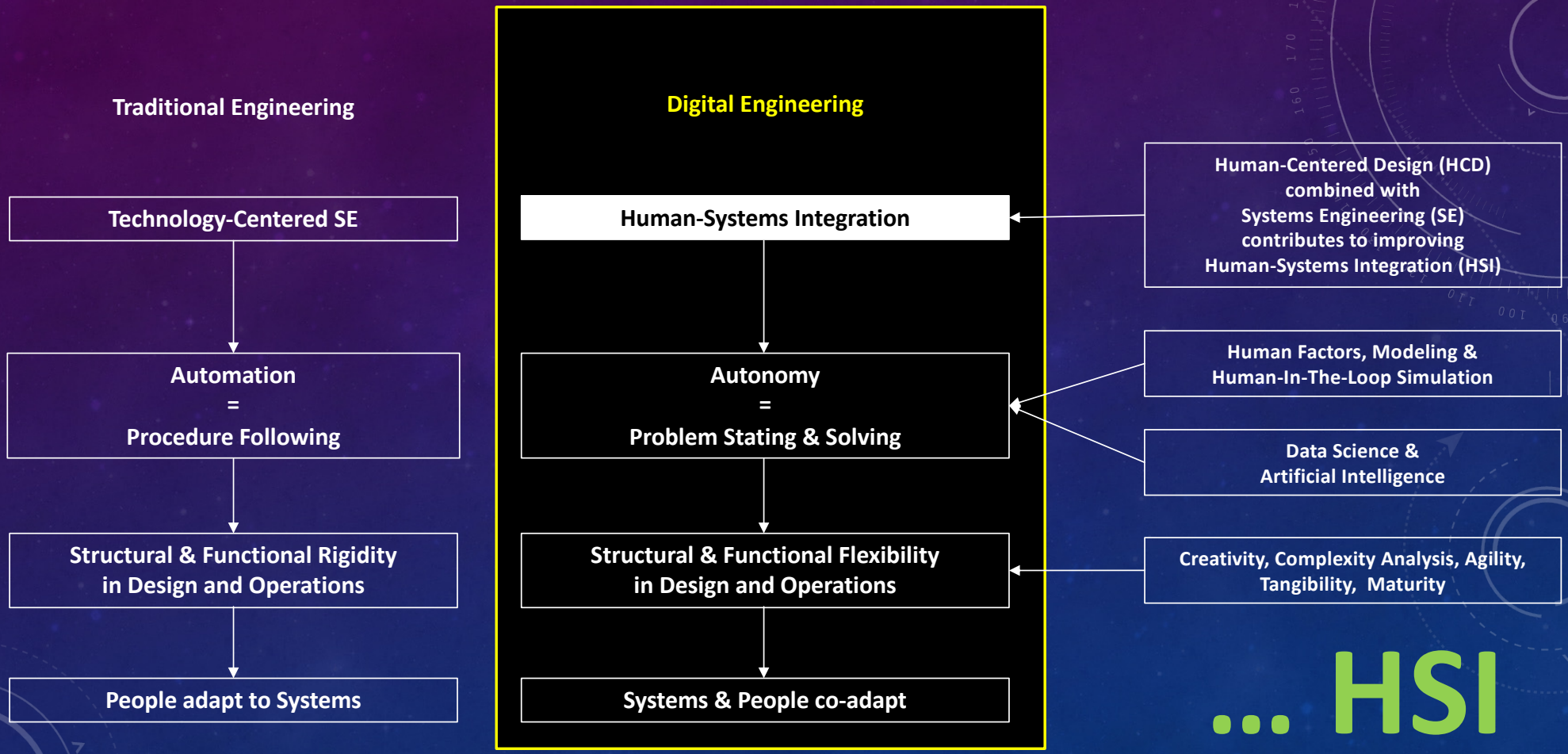




Structure Space	Rationalization Space
Activity Space	Function Space

DIGITAL TWINS AS ACTIVE DESIGN DOCUMENTS

TOWARD MORE AUTONOMY & FLEXIBILITY



INTEGRATION

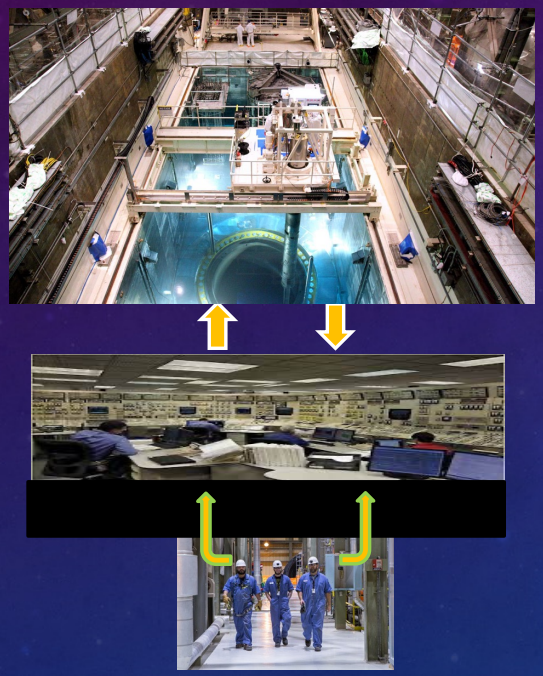
FROM PURPOSE TO MEANS

FROM MEANS TO PURPOSE

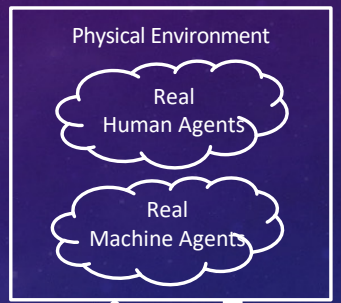
Engineering

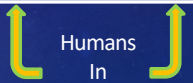
Ergonomics
Automation

Human
Factors



Tangible
Human-Centered Engineering



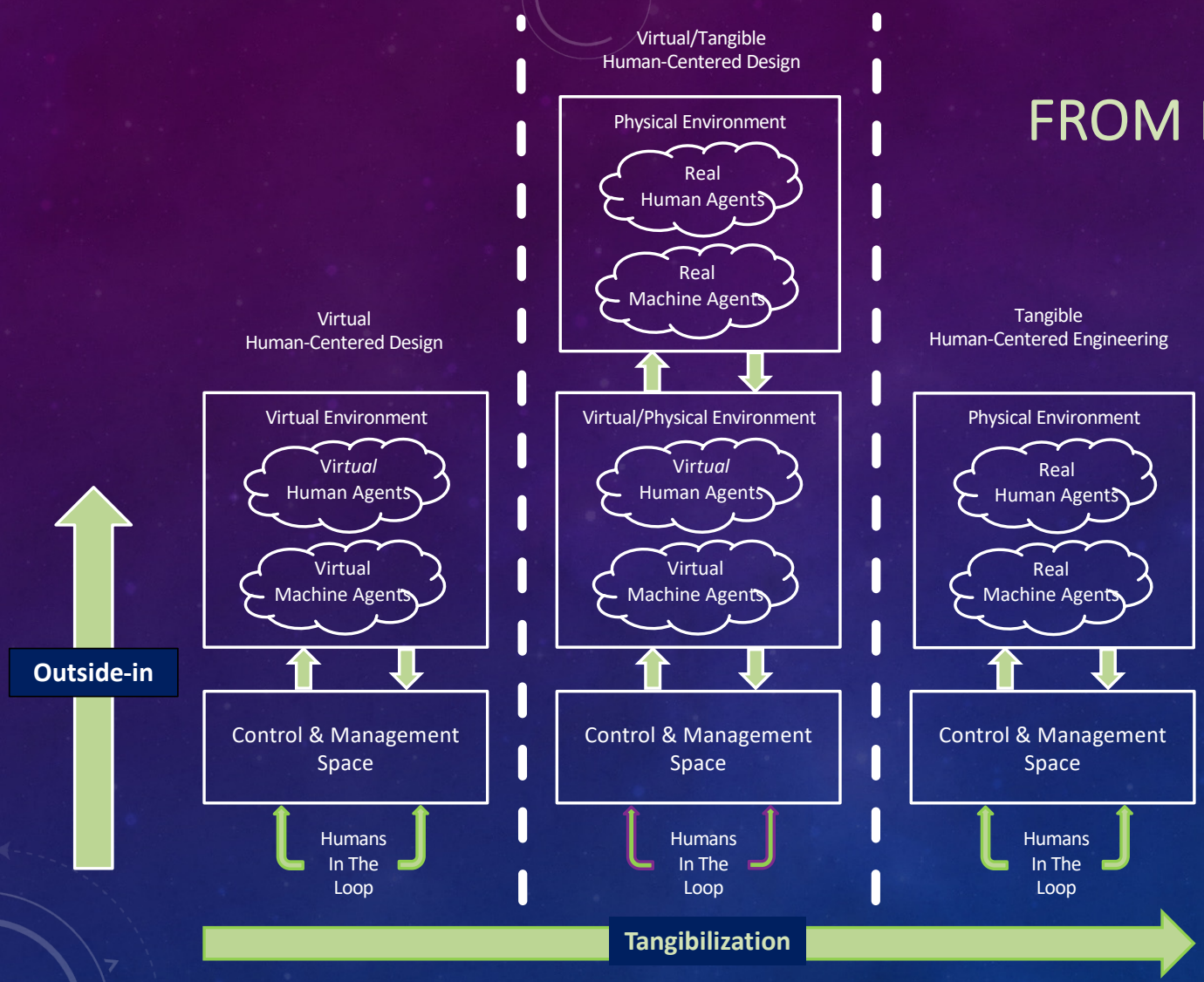


20th century approach

Engineering,
Ergonomics,
HCI &
Automation

FlexTech
CentraleSupélec-ESTIA Chair

FROM PURPOSE TO MEANS



21ST CENTURY APPROACH

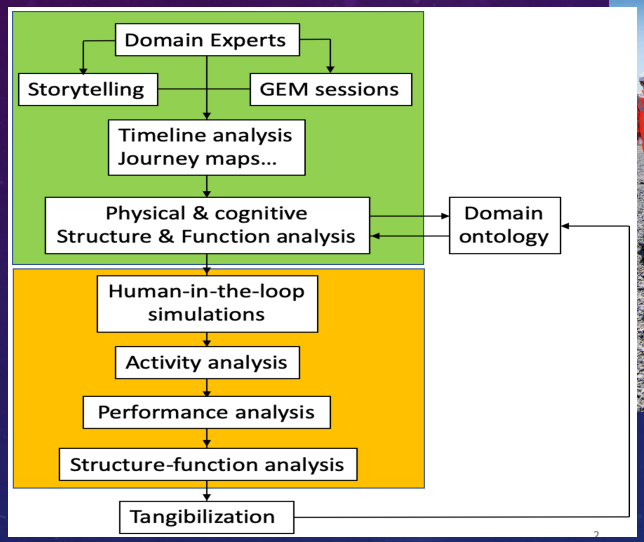
HSI

FlexTech

CentraleSupélec-ESTIA Chair

OFF-SHORE OIL & GAS MULTI-AGENT TELEROBOTIC SYSTEMS

Using PRODEC method combined with HITLS

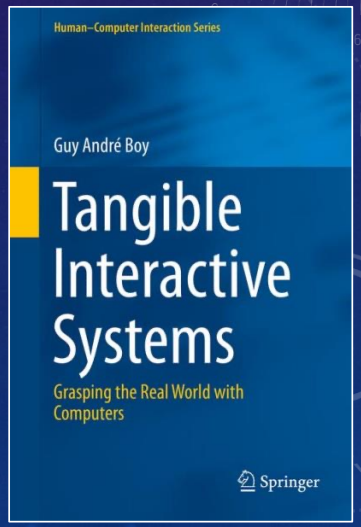


TANGIBILITY: SYSTEMIC ATTRIBUTES

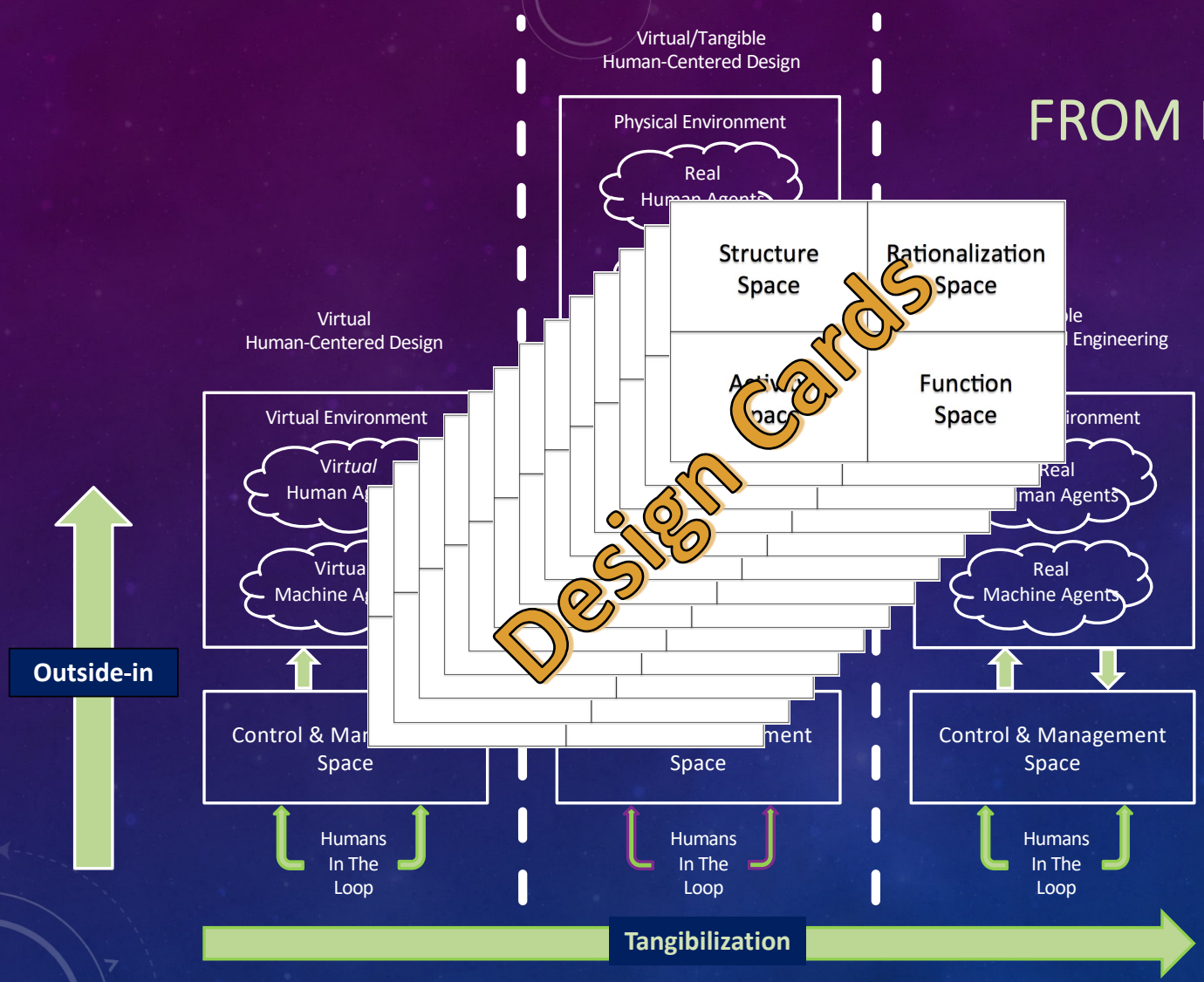
- Complexity → separability, interconnectivity, collaboration, trust, …
- Maturity → TRLs & HRLs & ORLs
- Flexibility (design & operations) → safety nodes, reversibility, FlexTech, …
- Stability/Resilience → passive vs. active, resilience, crisis management, …
- Sustainability → design rationale, knowledge management, …

+ Social Factors →

Shared situation awareness
Cooperative decision-making
Harmonized risk taking
Trust and collaboration



FROM PURPOSE TO MEANS



21ST CENTURY APPROACH

HSI

FlexTech

CentraleSupélec-ESTIA Chair

READINESS LEVELS

Technology

Human

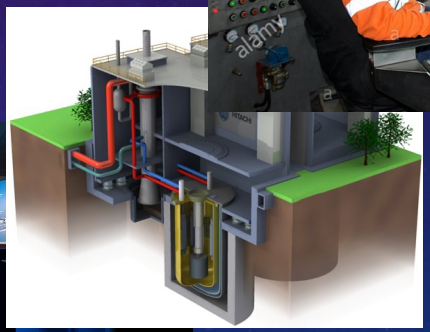
HRL	Description
1	Relevant human capabilities, limitations, and basic human performance issues and risks identified
2	Human-focused concept of operations defined and human performance design principles established
3	Analyses of human operational, environmental, functional, cognitive, and physical needs completed, based on proof of concept
4	Modeling, part-task testing, and trade studies of user interface design concepts completed
5	User evaluation of prototypes in mission-relevant simulations completed to inform design
6	Human-system interfaces fully matured as influenced by human performance analyses, metrics, prototyping, and high-fidelity simulations
7	Human-system interfaces fully tested and verified in operational environment with system hardware and software and representative users
8	Total human-system performance fully tested, validated, and approved in mission operations, using completed system hardware and software and representative users
9	System successfully used in operations across the operational envelope with systematic monitoring of human-system performance

Organizations

ORL-0	**First principles where potential organizational models are explored.**
ORL-1	Goal-oriented research that requires making choices from first principles to practical fully digital organizational setups
ORL-2	Proof of principle development, and active R&D is started in a virtual environment
ORL-3	Virtual agile organizational prototype development and first HITLS (virtual HCD)
ORL-4	Proof of organizational concept development using concrete scenario-based design from fully virtual to more tangible environments
ORL-5	Assessing organization capability in terms of authority sharing (responsibility, accountability and control), trust, collaboration and coordination, for example
ORL-6	Real-world use-case tests in a wider variety of situations - tangibilization continues
ORL-7	Practical integration with respect to criteria such as safety, efficiency and comfort, at various levels of granularity of the organization – tangibilization continues
ORL-8	Readiness for effective implementation on a real site (fully tangible) based on personnel feedback for deployment approval
ORL-9	Deployment involving both personnel and real machines

A FEW EXAMPLES OF HSI RESEARCH

- Health sociotechnical system
- Future combat air system
- Virtual air traffic control tower
- Small nuclear reactor
- Oil-and-gas telerobotics
- …



A FEW TAKE-AWAYS… FOR DIGITAL TWINS FOR HSI…

- We live in a digital world → **tangibility** is a crucial contemporary issue
- Single-agent ergonomics is not enough → **Socio-ergonomics** using DTs
- Rigid automation is what we know → **Flexible autonomy** is what we need to make using DTs
- How do we deal with the unexpected? → **problem-solving support** using DTs
- From means to purpose (people adapt) → **From purpose to means** (DTs help solving problems)
- Human-machine teaming → what **new human roles**?

Collaborative work requires **education**, **openness**, **empathy** and **enthusiasm**!

This book is a follow-up of previous contributions in Human-Centered Design and practice in the development of virtual prototypes that requires progressive operational tangibility toward Human-Systems Integration (HSI). The book discusses flexibility in design and operations, tangibility of software-intensive systems, virtual human-centered design, increasingly-autonomous complex systems, Human-Factors and Ergonomics of sociotechnical systems, and systems of systems integration.

This is an attempt to better formalize a systemic approach to HSI. Good HSI is a matter of maturity… it takes time to mature. It takes time for a human being to become autonomous, and then mature! HSI is a matter of human-machine teaming, where human-machine cooperation and coordination are crucial. We cannot think engineering design without considering people and organizations that go with it. We also cannot think new technology, new organizations and new jobs without considering change management, especially in digital organizations.

The book will be of interest to industry, academia, those involved with systems engineering, human factors and the broader public.

Features:

- Discusses flexibility in design and operations of complex systems
- Offers tangibility of software-intensive systems
- Presents virtual human-centered design
- Covers autonomous complex systems
- Provides human factors and ergonomics of sociotechnical systems

About the Author:

Guy André Boy is one of the pioneers and a world leader in the study and applications of human centered design and human systems integration. He is also the Chair of INCOSE Human Systems Integration Working Group worldwide.

Ergonomics and Human Factors

CRC Press
Taylor & Francis Group
an informa business
www.crcpress.com

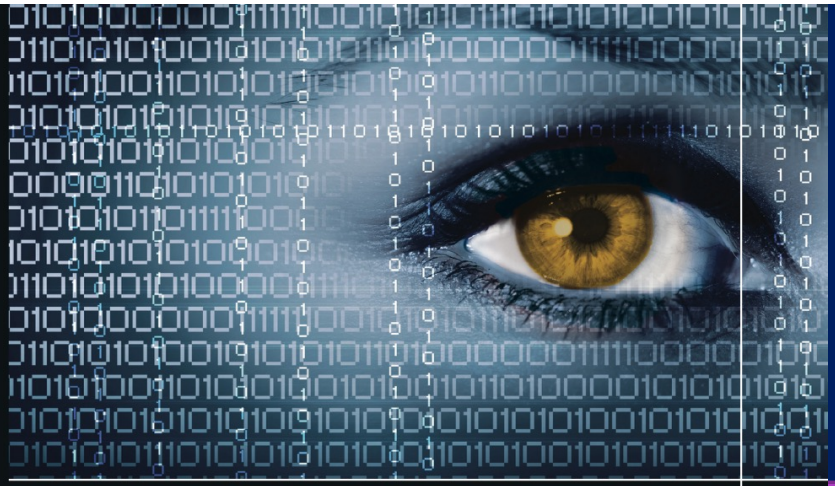
CRC Press titles are available as eBook editions in a range of digital formats

ISBN 978-0-367-35773-3

HUMAN-SYSTEMS INTEGRATION

Guy Andre Boy

CRC Press



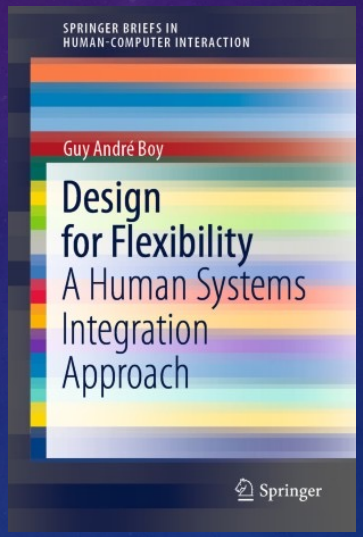
HUMAN-SYSTEMS INTEGRATION

From Virtual to Tangible

Guy Andre Boy

CRC Press
Taylor & Francis Group

… and the last one!



THANK YOU…