CoRoSect

Industrial Insect Production
Novel Perspectives

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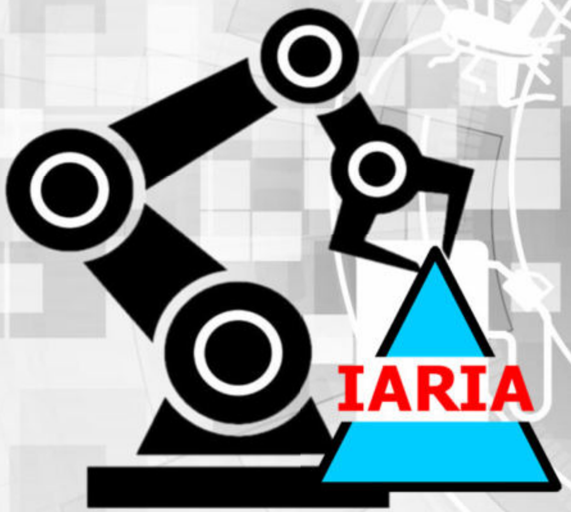
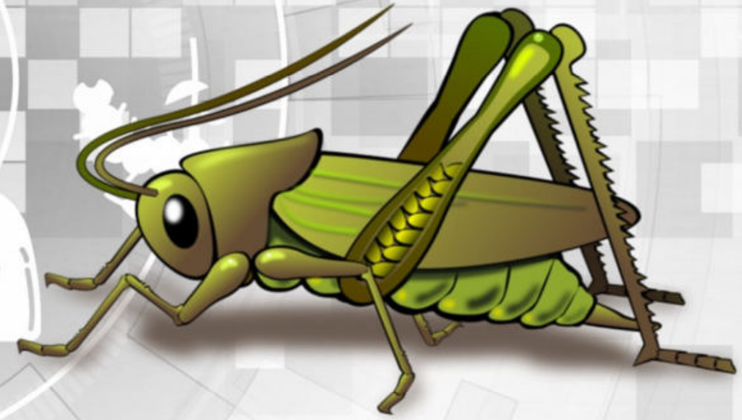
Mainstreaming insect farming





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Robotnik | AGV R | NASEKOMO | ENTOMOTECH | ENTOCYCLE | Italian Cricket farm | Invertapro | Field Lab Robotics | f/h | AgriFood DIH Lithuania | CIHEAM Bari

Short Bio

Prof. Mäkiö joined in 2013 the University of Applied Sciences Emden / Leer as a full professor in computer sciences. Prof. Mäkiö has had a leading role in both international and national industrial and research projects. Prof. Mäkiö has developed innovative teaching methods which have been successfully applied in a number universities. Prof. Mäkiö has participated in multiple national and international research projects. He has been for many years guest professor in international and national universities.

Motivation

- The **food security** represents the big **challenge** of the 21st century because:
  - World population growth results in a 75% growth in the demand for meat by 2050 compared to 2005/2007.
  - By 2030 over 9 billion people + animals raised for food or kept for companion purposes, will need to be fed.

Possible solution: Insects as a novel source of food and feed ← **Insect farming**

Life cycle assessment of cricket farming in north-eastern Thailand

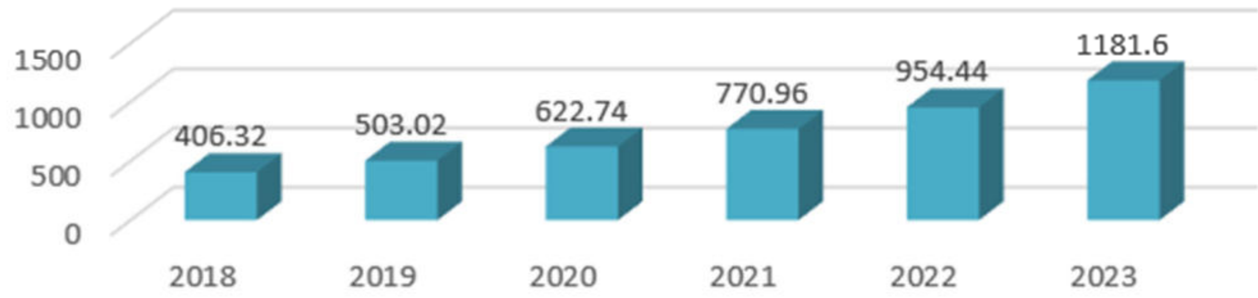
Why Insect Farming

The use of insects as food and feed is in not documented as harvesting, marketing and consumption do not appear in national statistics.

Global insect market growth estimated to go up from about €344 million in 2018 up to €7 billion by 2030

In Europe, directly or indirectly about 40,000 persons employed in insect farming.

Edible Insects: Market Value in million US dollars 2018-2023



Why Insects as Food and Feed?

Insect Orders	Protein (% Dry Matter)	Fat (% Dry Matter)	Fiber (%)	Energy (kcal/100 g)
Blattodea (cockroaches)	57.30	29.90	5.31	-
Coleoptera (adult beetles, larvae)	40.69	33.40	10.74	490.30
Hemiptera (true bugs)	48.33	30.26	12.40	478.99
Hymenoptera (ants, bees)	46.47	25.09	5.71	484.45
Isoptera (termites)	35.34	32.74	5.06	
Lepidoptera (butterflies, moths)	45.38	27.66	6.60	508.89
Odonata (dragonflies, damselflies)	55.23	19.83	11.79	431.33
Orthoptera (crickets, grasshoppers, locusts)	61.32	13.41	9.55	426.25

Insects…

- are efficient at converting their diets into protein and polyunsaturated fatty acids compared to conventional livestock.
- have a high content in calcium, iron and zinc

Insect meals can replace 25- 100% of soy- or fishmeal depending on the animal species.

Why Insect Farming?

- Insects…
  - have low environmental footprint over their entire life cycle (less greenhouse gases, lower ammonia emission comp. with e.g. pigs)
  - Farming is not necessarily land-based → does not require land clearing to expand production
  - efficient at converting their diets into protein and polyunsaturated fatty acids compared to conventional livestock
- Some insect species which are considered as feed can be reared on low-value organic by-products, and even convert livestock manure in high quality fertilizer → agricultural waste converted to source
  - In 2011 1.3 billion tons organic by-products are produced globally on an annual basis which is valued at US$ 750 billion
  - Marginal probability of zoonotic diseases, associated to insects‘ consumption

Obstacles to widespread adoption

- Acceptance by EU customers to use insects as food and feed may be rabidly reached but…
  - The insect production can’t commercially compete with traditional food and feed sources.
    - significant difference in the context of food security only if the mass-production process is innovated and standardized.
    - Need to research and develop cost-effective, energy-efficient and safe rearing, harvest and postharvest processing technologies
    - No worldwide standards for the production and trade of insects and insect products
  - Today in the EU insects are as fish feed and pet food – the use as poultry feed not authorized
  - Limiting factor in the EU – high labour costs and no adequate level of mechanization and automation of insect production processes.

Mechanization and Automation of Insect Farming is needed

Need to couple research on bionomics and life cycle of insects for food and feed with new tools and protocols for mechanization and automation of insect farming

Technical Expert Consultation on Assessing the Potential of Insects as Food and Feed in Assuring Food Security, Rome on 23–25 January 2012

CoRoSect

Robotics & AI: An Extra Set of Hands for Insect Farming
CoRoSect goals…

CoRoSect provides **a novel robotization concept** enabling up-scaling and optimizing a number of insect production facilities utilizing state-of-the-art robotization **and artificial intelligence technologies**.

CoRoSect makes possible setting up **dynamic work cells**, where a single human worker is **aided by several robots, artificial intelligence and smart sensors across** the stages of insect production.

The CoRoSect solution is **modular, scalable, expandable** and adaptable to the challenges of end-users.

CoRoSect – ambition and objectives

CoRoSect - Cognitive **Ro**botic System for Digitalized and Networked (Automated) In**sect** Farms

Secure sustainable, environmentally friendly food for humans and animals

Bring new insights to **automated insect farming**, allowing for a sustainable growth and automation of insect farms

Create an advanced **safe collaboration environment**, where humans and robots harmoniously share and undertake processing and manipulation tasks (Industry 5.0)

Advance an **AI-based cognitive perception** at different phases of the life cycle of the insect farming process

Develop **cognitive robots** with sophisticated capabilities for robotic actions planning, manipulation, and control

The central goal of the CoRoSect…

To develop an open working environment following the RAMI 4.0 reference architecture as an ICPS, where smart mechatronic systems and humans will collaborate closely and in an intuitive way by exposing and/or consuming services in an I4.0-ecosystem, towards improving the job quality/efficiency and the flexibility in production.

To design and implement novel, efficient, adaptive and robust Industry 4.0-compliant Human-Robot Collaboration (HRC) schemes that will in principle include:

a) Support for learning from human input,

b) Provision for autonomous and human-aware robot trajectory planning (the interface between the desired movements of the robot and the actual execution on the robot),

c) Support for human-machine interactions using Augmented Reality (AR) technologies for situation awareness and human guidance and training.

Towards Industrial Insect Farming

From manual insect production to automated and digitalised insect production

Industrial Mass-Production vs. Non-Industrial Insect Production

Industrial Revolutions

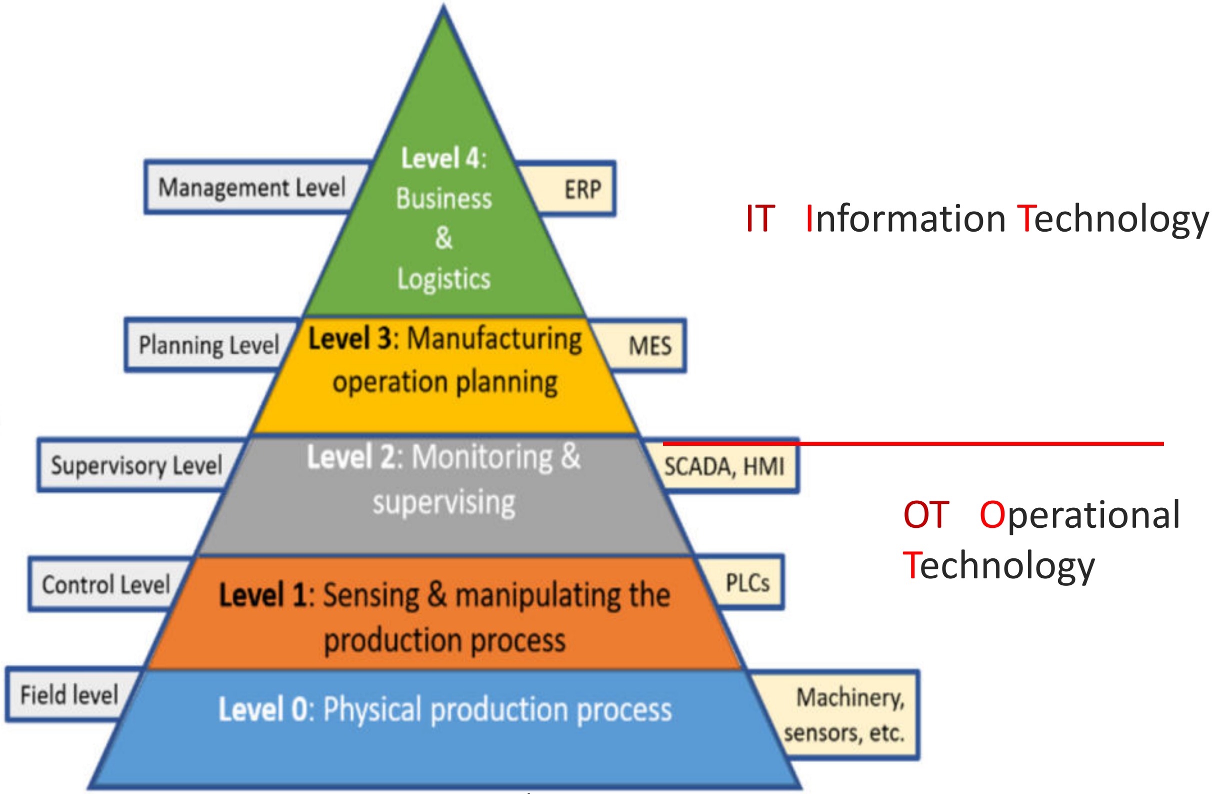
Water and steam power, Mechanisation	Electricity, Mass production, assembly line	Computer and automation, embedded systems	Cyber Physical Systems, Internet of Things
Industry 1.0	**Industry 2.0**	**Industry 3.0**	**Industry 4.0**
End of 18th century	End of 19th century	Early 1970s	Early 2000s

T I M E →

Industry 3.0

Disadvantages:

- Hardware-based structure, functions are associated with hardware
- Functions are bound to hardware, proprietary protocols
- Hierarchy-based communication with adjacent levels of ISA-95
- Final product is isolated
- Lacking connection with the immediate business environment



ISA-95 Automation pyramid

Industry 4.0 – Smart Factory

Artificial Intelligence (AI)

Digital Passport

Predictive Maintenance

Big Data

Digital Twin

Sensors

Internet-of-Things (IoT)

Smart Factory

Actuators

Industry 4.0

Smart Car

Cyber-Physical Systems

Smart Building

Digital Transformation

Additive Manufacturing

cyber-physical systems monitor the physical processes of the factory and make decentralized decisions

physical systems become Internet of Things, communicating and cooperating both with each other and with humans in real time via the wireless web

Why Industry 4.0 in the Insect Farming?

Technological development (enablers)

- Internet and wireless connectivity, Internet of Things (IoT)
- Affordable sensors (Additive Manufacturing – 3D printing)

Getting smaller, cheaper and more powerful

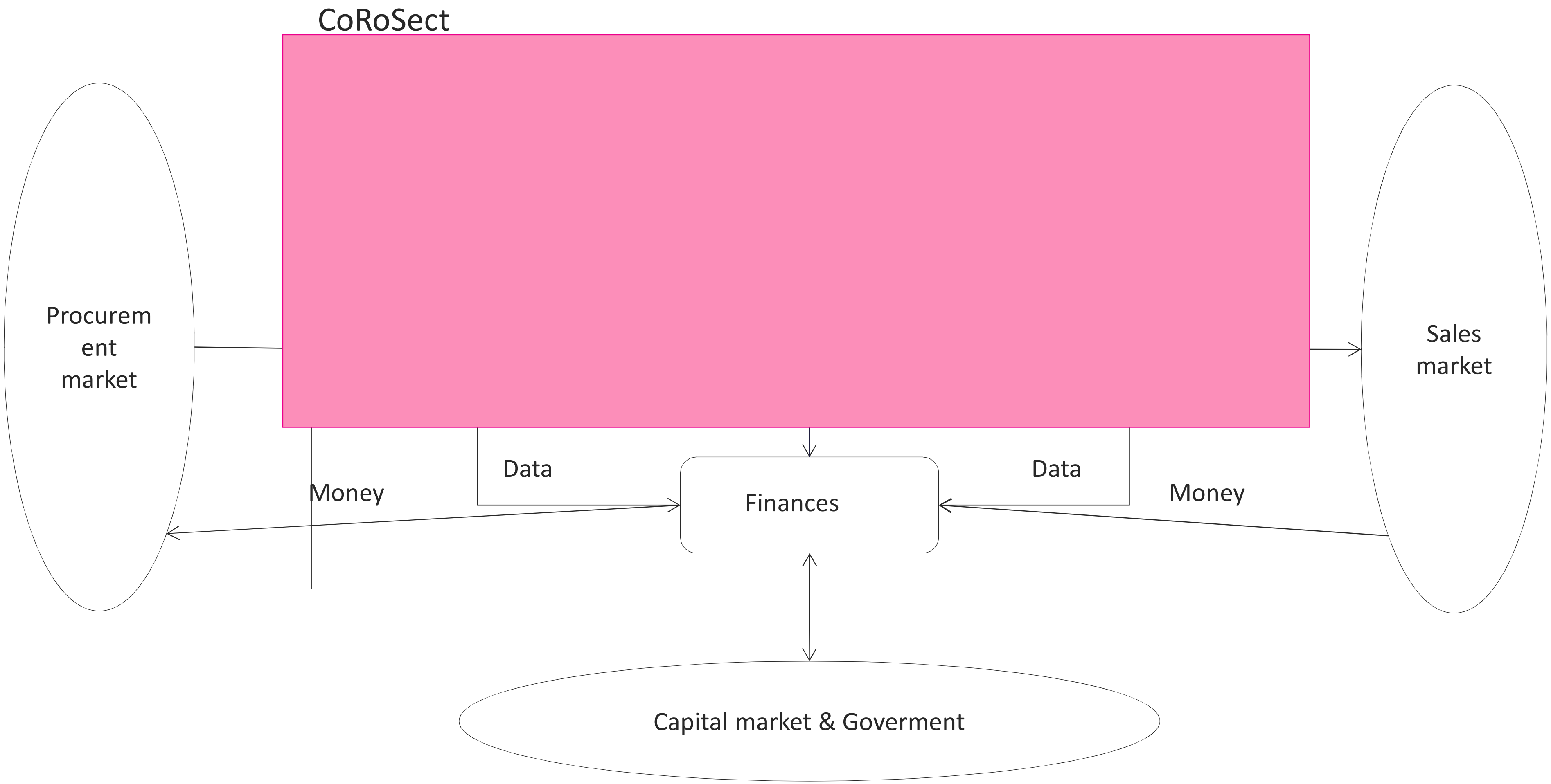
Business requirements

- Customization and personalization of products and services.
- Increasing efficiency by optimization and cost reduction of production processes.
- Improving supply chain.

Societal requirements

- Demographic challenge
- Environmental sustainability
- Lack of labor force + high labor costs
- Food security

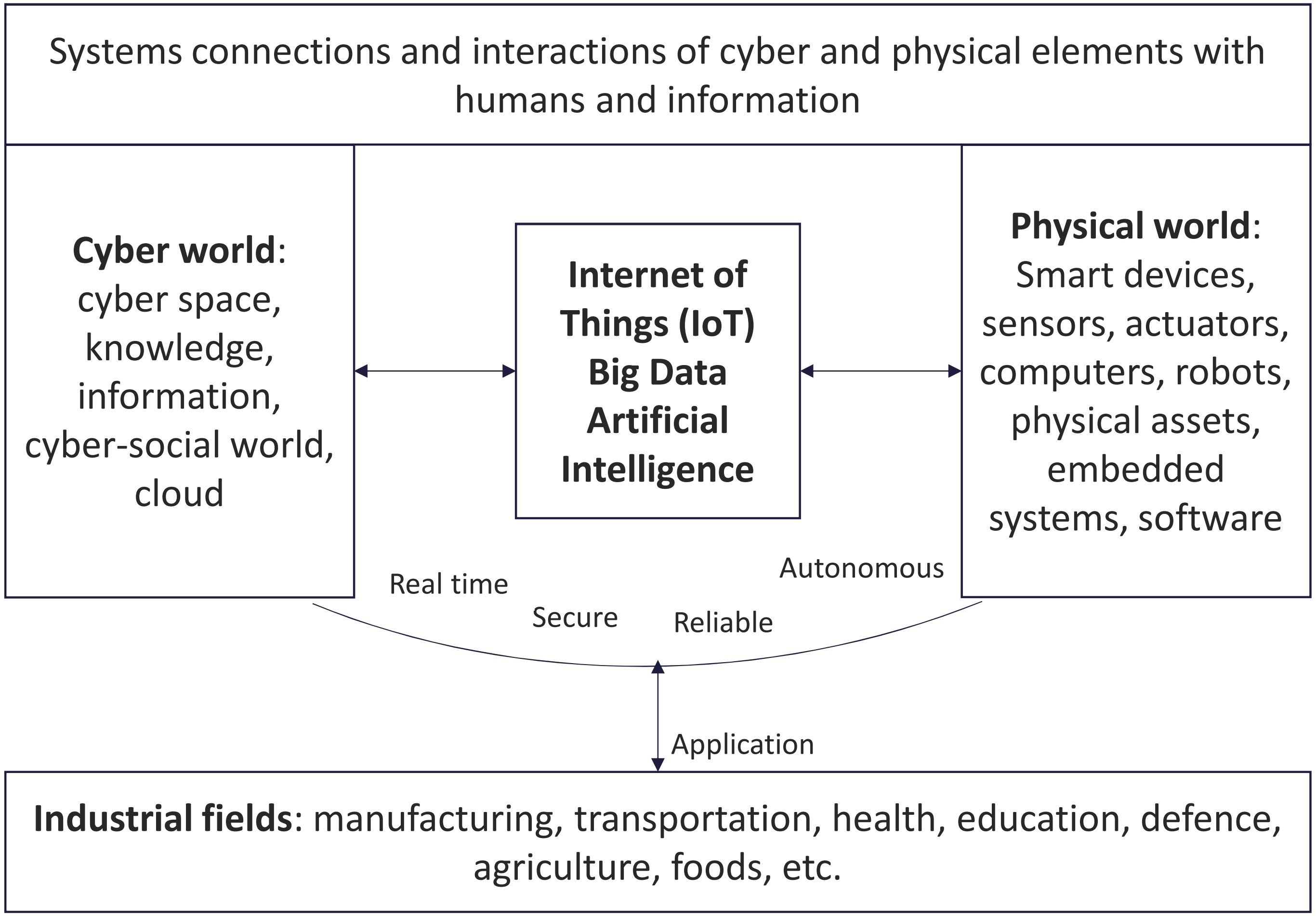
Why Industry 4.0 in the Insect Farming? - Company as a System



Characteristics of Intelligent Production Environment

Digitization Aspect	*Description*
Automation	Substitute a human's involvement with a work activity with a digital solution for the purely computational or purely data processing aspects of a business process, especially those aspects that are repetitive in nature and well understood.
Control	Use a digital solution to monitor (applying specified business rules) the actions and decisions being taken, regardless of whether the monitored operating procedures are digitized or handled by humans.
Empowerment	Use a digital solution to increase the likelihood that the comprehensive set of data and information required for an action or decision will be available for use at the time the action or decision is to be taken.
Collaboration	Use a digital solution to increase the likelihood that the expertise and authority required for an action or decision will be present at the time the action or decision is to be taken.

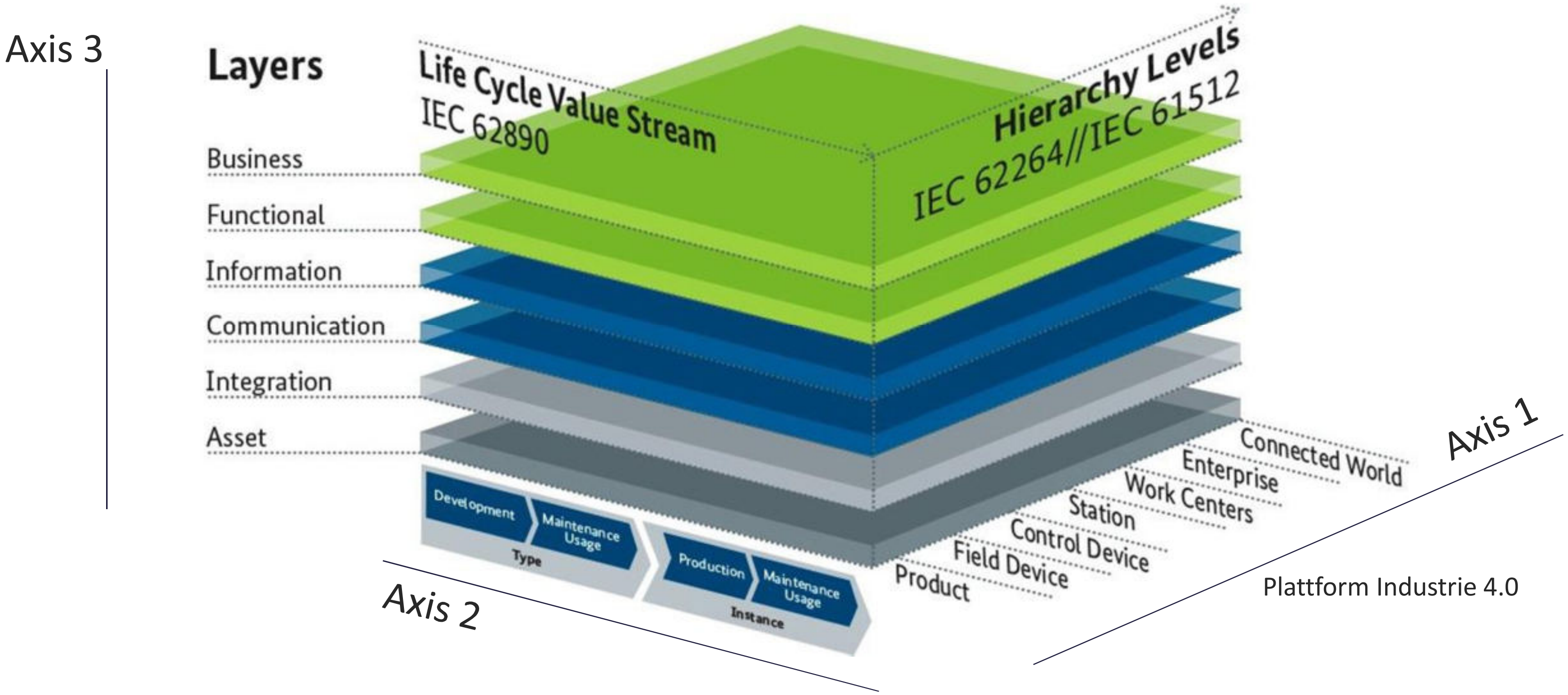
Industrial CPS – key elements



How can we approach manufacturing based on the new technological developments to meet the requirements of Industry 4.0 in the insect farming?

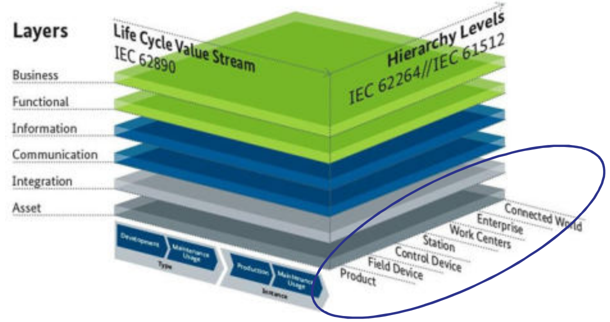
At the same time bearing in mind the social, ethical and legal challenges of human-robot collaboration in an industrial environment

Reference Architecture Model Industry 4.0 - RAMI 4.0



RAMI 4.0 - a three-dimensional map that shows how to approach the topic of Industry 4.0 in a structured way.

Axis 1 – Hierarchy: the Factory



Smart Factory

Connected World

Enterprise

Work Centres

Station

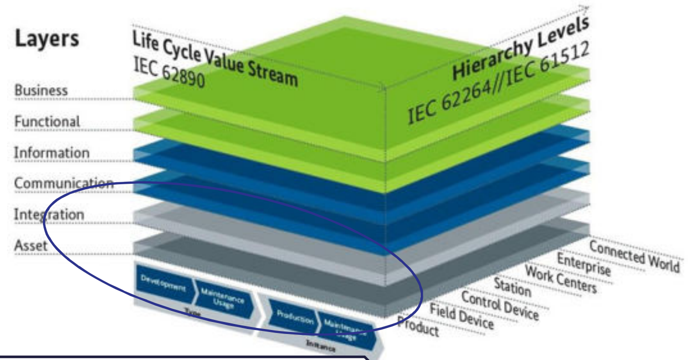
Control Device

Field Device

Product

- Flexible systems and machines
- Functions are distributed throughout the network
- Participants interact across hierarchy levels
- Communication among all participants
- Product is part of the network

Axis 2 – Product Life Cycle



Type: Development → Maintenance Usage

Instance: Production → Maintenance Usage

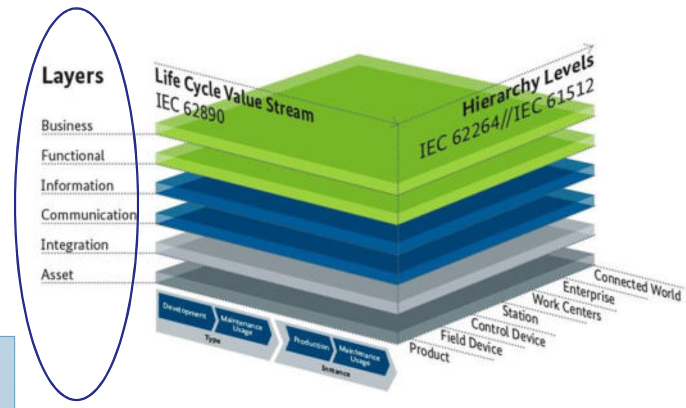
Construction plan:
Development
Computer simulation
Prototype
…

Construction plan:
Maintenance Cycles
Software updates
…

Production:
Product
Data
Serial number
Digital passport
…

Facility management:
Usage
Service
Maintenance
Recycling
…

Axis 3 - Architecture



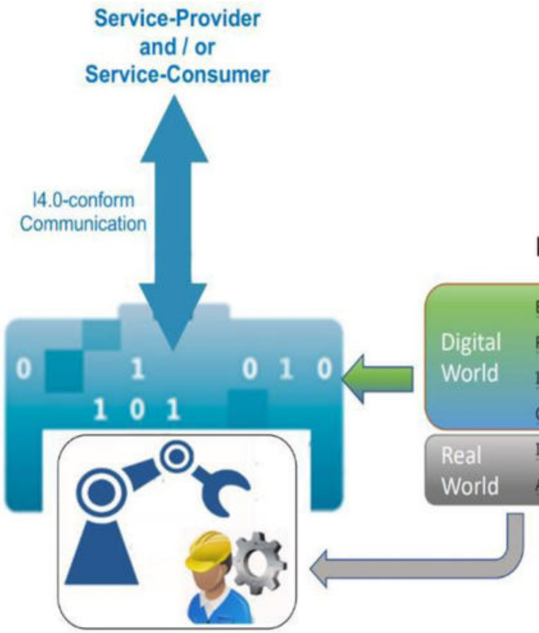
Layers

Digital world

Business	Organisation and business processes
Functional	Functions of assets
Information	Data
Communication	Access to information
Integration	Transition from physical to digital world
Asset	Physical things

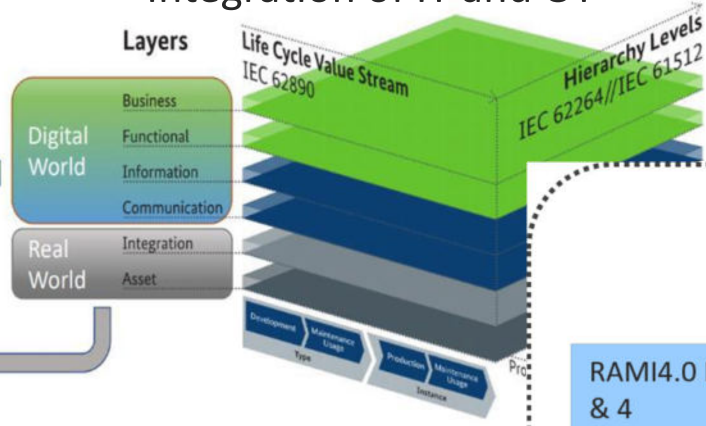
Real world

Asset Administration Shell - AAS



Digital Twin

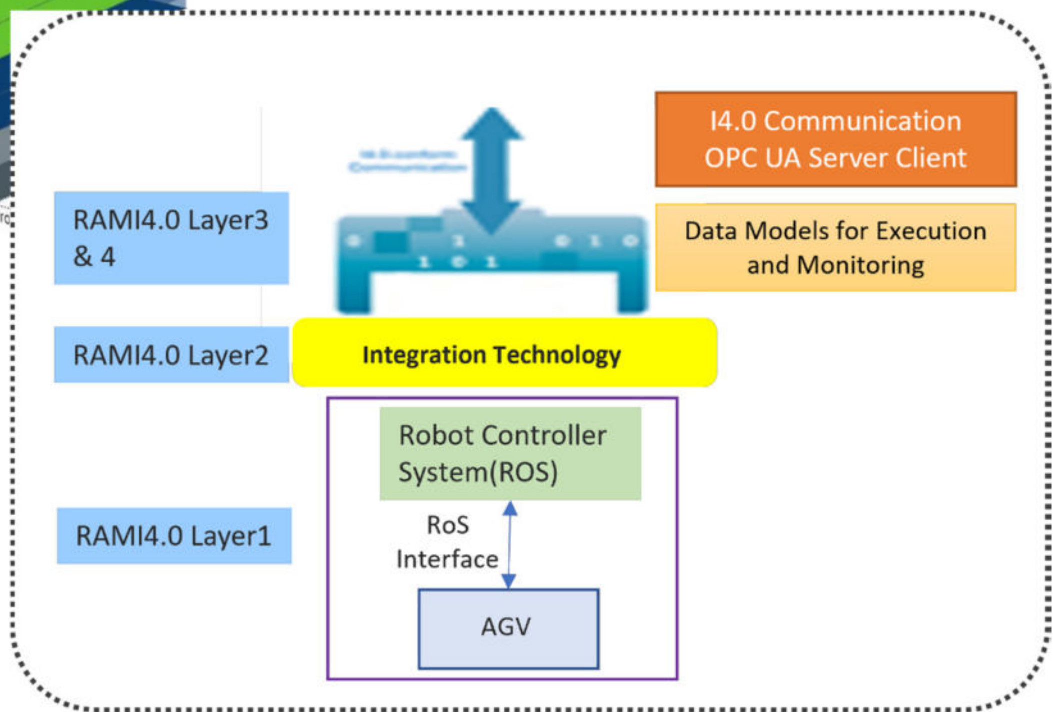
Integration of IT and OT



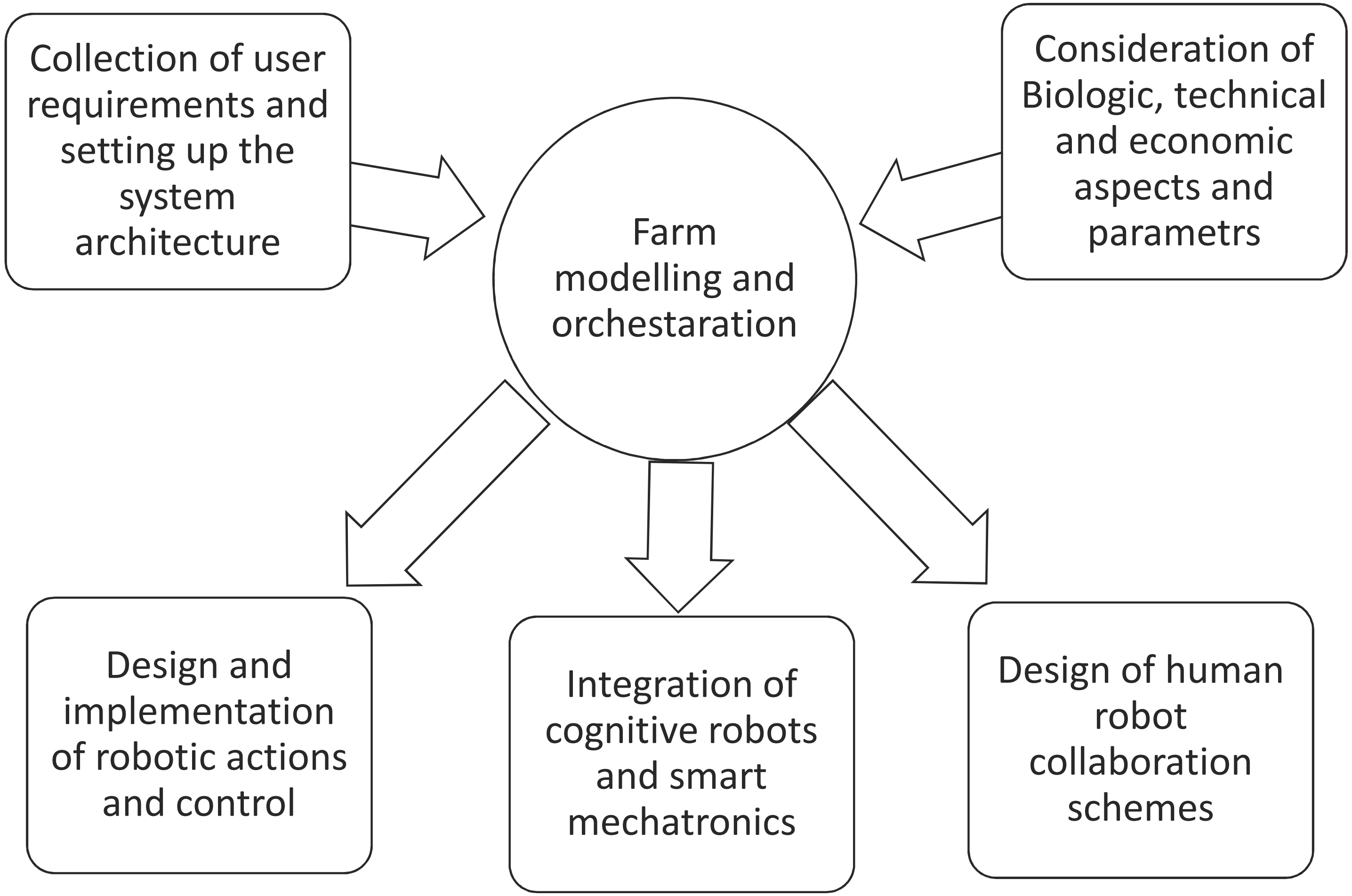
AAS:

- enables a standardised digital representation of assets.
- implements the Digital Twin

An **asset is a component of an Industry 4.0 solution** such as a physical object, software or document.
Asset = everything that requires a "connection" for an Industry 4.0 solution

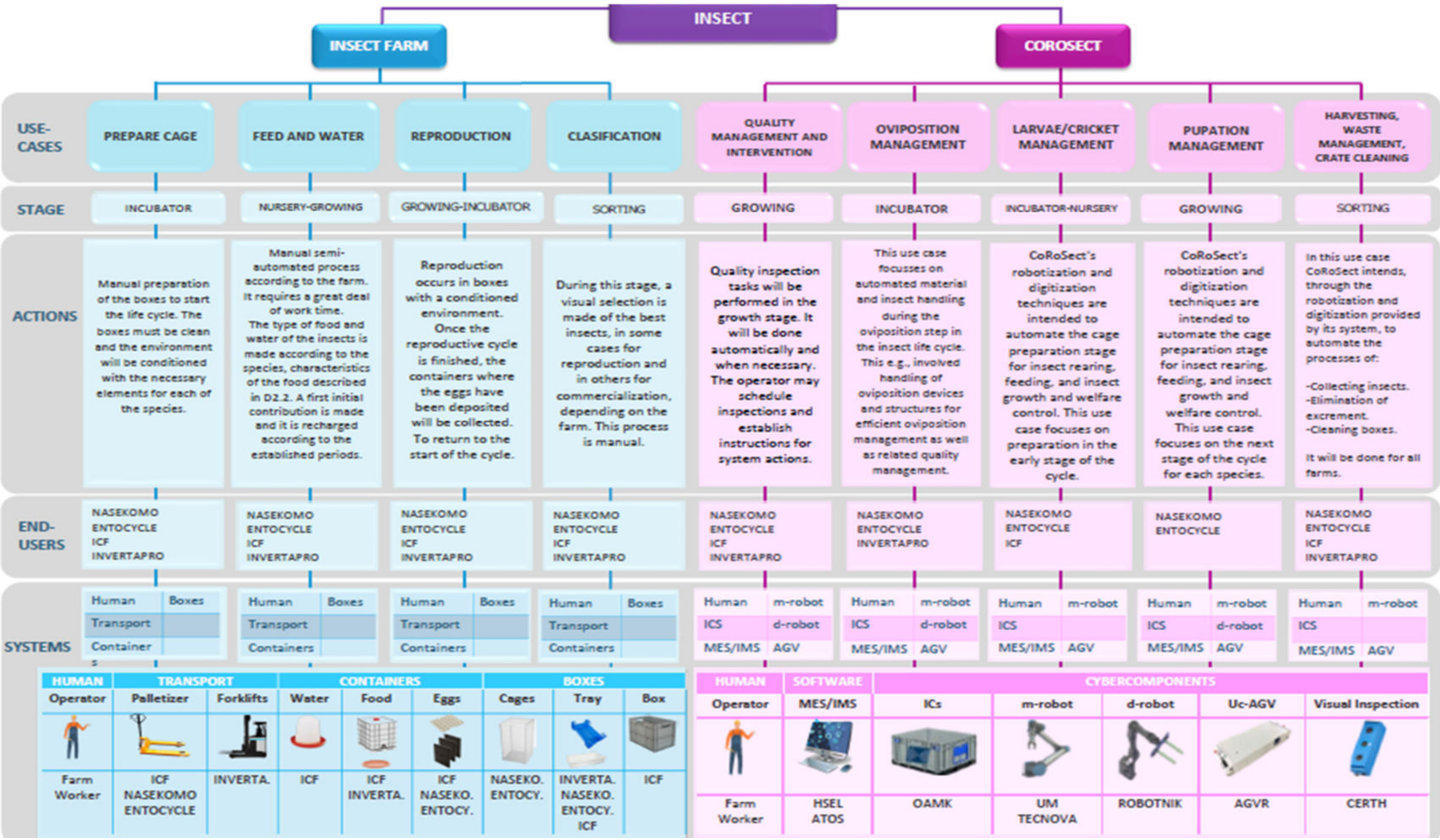


Steps Towards Industrial Insect Farming



Farm-Level Modeling and Orchestration

Steps to define the system operational methodology using collaborative factory floor modelling and real-time orchestration


INSECT
INSECT FARM
COROSECT
USE-CASES
PREPARE CAGE
FEED AND WATER
REPRODUCTION
CLASIFICATION
QUALITY MANAGEMENT AND INTERVENTION
OVIPOSITION MANAGEMENT
LARVAE/CRICKET MANAGEMENT
PUPATION MANAGEMENT
HARVESTING, WASTE MANAGEMENT, CRATE CLEANING
STAGE
INCUBATOR
NURSERY-GROWING
GROWING-INCUBATOR
SORTING
GROWING
INCUBATOR
INCUBATOR-NURSERY
GROWING
SORTING
ACTIONS
Manual preparation of the boxes to start the life cycle. The boxes must be clean and the environment will be conditioned with the necessary elements for each of the species.
Manual semi-automated process according to the farm. It requires a great deal of work time. The type of food and water of the insects is made according to the species, characteristics of the food described in D2.2. A first initial contribution is made and it is recharged according to the established periods.
Reproduction occurs in boxes with a conditioned environment. Once the reproductive cycle is finished, the containers where the eggs have been deposited will be collected. To return to the start of the cycle.
During this stage, a visual selection is made of the best insects, in some cases for reproduction and in others for commercialization, depending on the farm. This process is manual.
Quality inspection tasks will be performed in the growth stage. It will be done automatically and when necessary. The operator may schedule inspections and establish instructions for system actions.
This use case focusses on automated material and insect handling during the oviposition step in the insect life cycle. This e.g., involved handling of oviposition devices and structures for efficient oviposition management as well as related quality management.
CoRoSect's robotization and digitization techniques are intended to automate the cage preparation stage for insect rearing, feeding, and insect growth and welfare control. This use case focuses on preparation in the early stage of the cycle.
CoRoSect's robotization and digitization techniques are intended to automate the cage preparation stage for insect rearing, feeding, and insect growth and welfare control. This use case focuses on the next stage of the cycle for each species.
In this use case CoRoSect intends, through the robotization and digitization provided by its system, to automate the processes of:
-Collecting insects.
-Elimination of excrement.
-Cleaning boxes.
It will be done for all farms.
END-USERS
NASEKOMO ENTOCYCLE ICF INVERTAPRO
NASEKOMO ENTOCYCLE ICF INVERTAPRO
NASEKOMO ENTOCYCLE ICF INVERTAPRO
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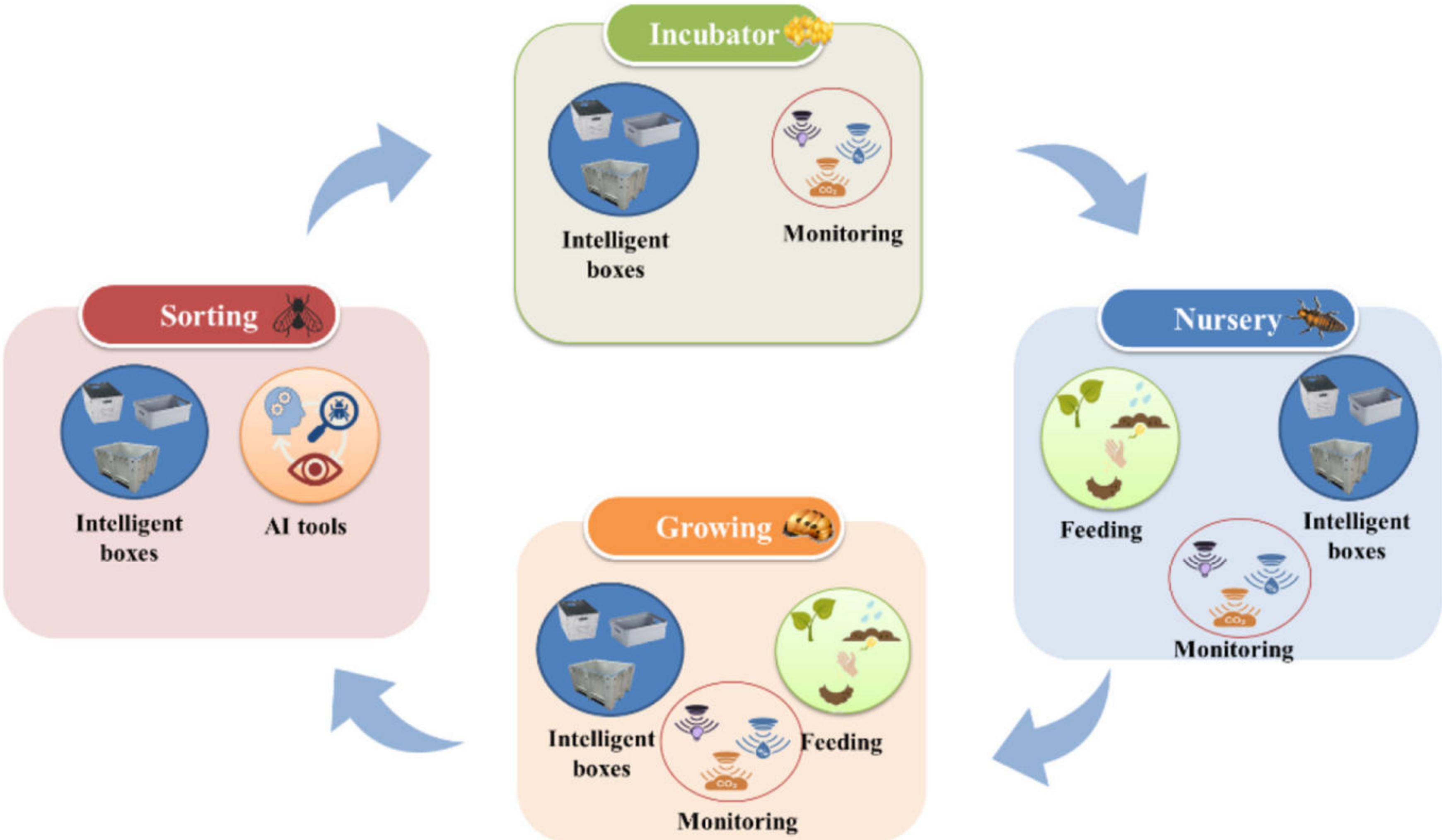
NASEKOMO ENTOCYCLE ICF
NASEKOMO ENTOCYCLE
NASEKOMO ENTOCYCLE ICF INVERTAPRO
SYSTEMS
Human Boxes Transport Containers
Human Boxes Transport Containers
Human Boxes Transport Containers
Human Boxes Transport Containers
Human m-robot ICS d-robot MES/IMS AGV
Human m-robot ICS d-robot MES/IMS AGV
Human m-robot ICS MES/IMS AGV
Human m-robot ICS d-robot MES/IMS AGV
Human m-robot ICS MES/IMS AGV
HUMAN
TRANSPORT
CONTAINERS
BOXES
Operator
Palletizer
Forklifts
Water
Food
Eggs
Cages
Tray
Box
Farm Worker
ICF NASEKOMO ENTOCYCLE
INVERTA.
ICF
ICF INVERTA.
ICF NASEKO. ENTOCY.
NASEKO. ENTOCY.
INVERTA. NASEKO. ENTOCY. ICF
ICF
HUMAN
SOFTWARE
CYBERCOMPONENTS
Operator
MES/IMS
ICs
m-robot
d-robot
Uc-AGV
Visual Inspection
Farm Worker
HSEL ATOS
OAMK
UM TECNOVA
ROBOTNIK
AGVR
CERTH

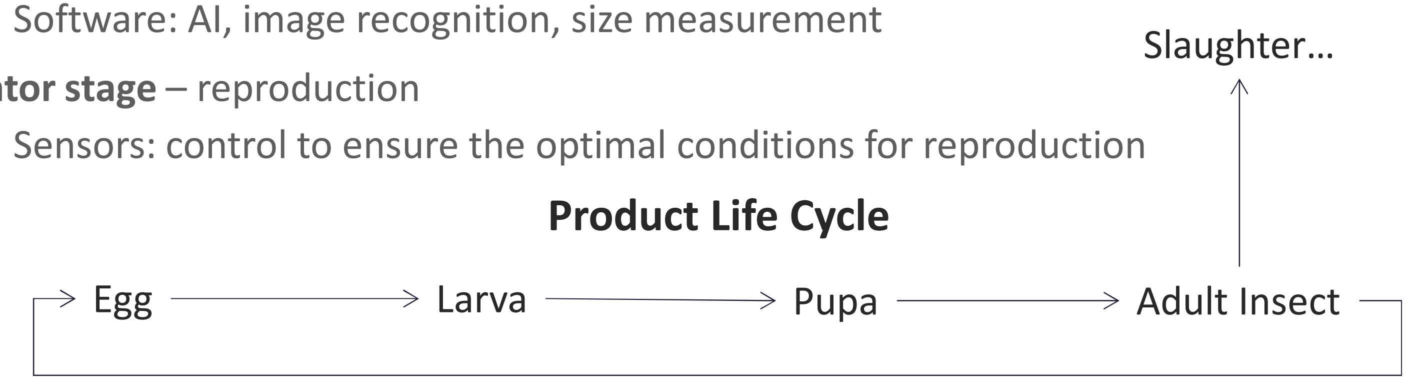
The functional architecture – physical and cyber components



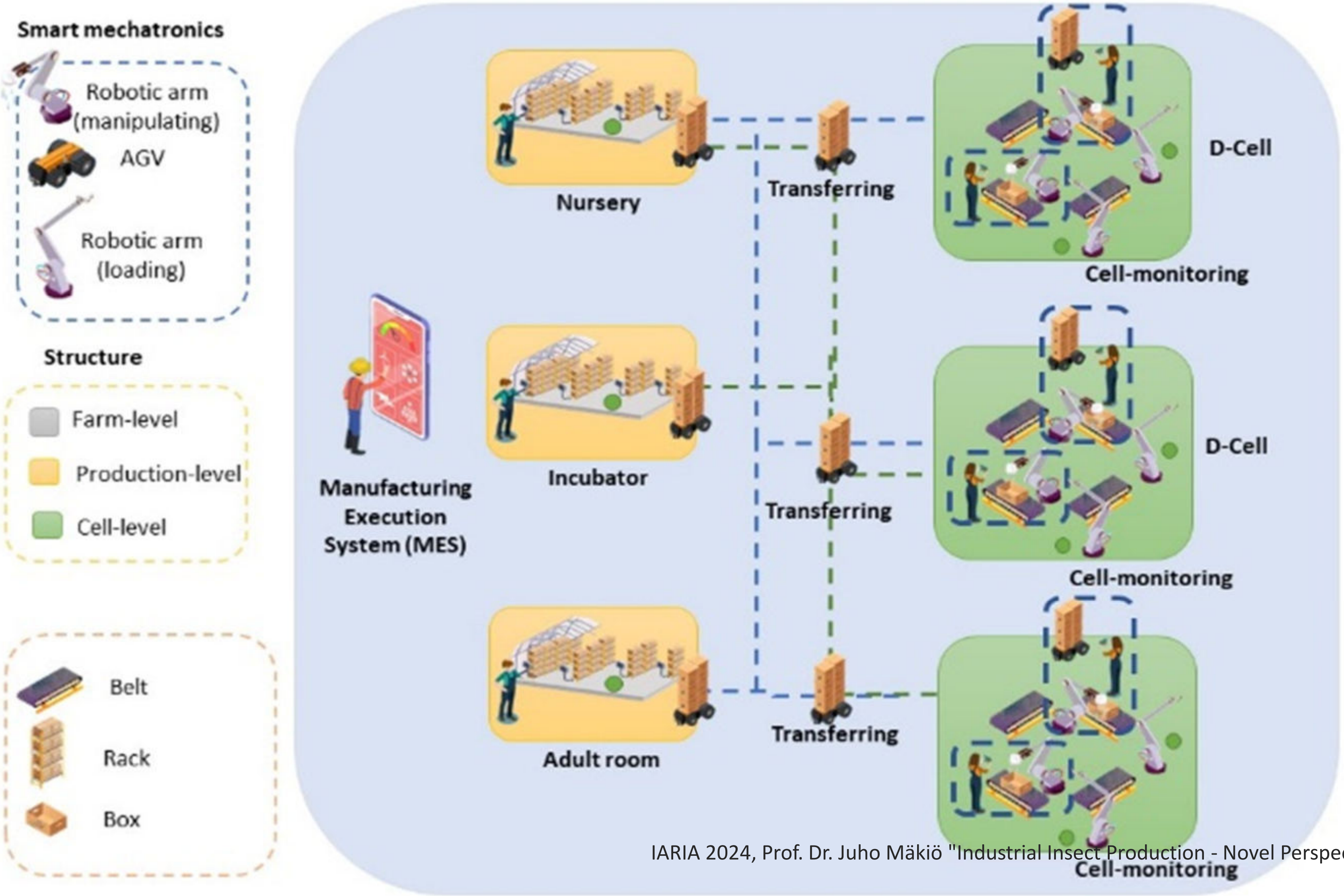
Stages

- **Nursery stage** – counting larvae, feeding, size checking → next stage
  - Robotic are special designed to avoid stress and mortality
  - Robotic functionalities : machine vision; AGVs for transportation
  - Software: AI, Image recognition for counting larvae and size measurement
- **Growing stage** – control of the growing process + feeding, larvae size
  - Sensors to measure temperature, metabolic gases production, food consumption, vibration
  - Robotic functionalities: machine vision; AGVs for transportation
  - Software: AI, Image recognition machine vision for counting larvae and size measurement
- **Sorting stage** –selecting for reproduction (right balance males-females!)/ slaughter
  - Robotic functionalities: picking, transportation, machine vision
  - Software: AI, image recognition, size measurement
- **Incubator stage** – reproduction
  - Sensors: control to ensure the optimal conditions for reproduction

Product Life Cycle



CoRoSect – Approach



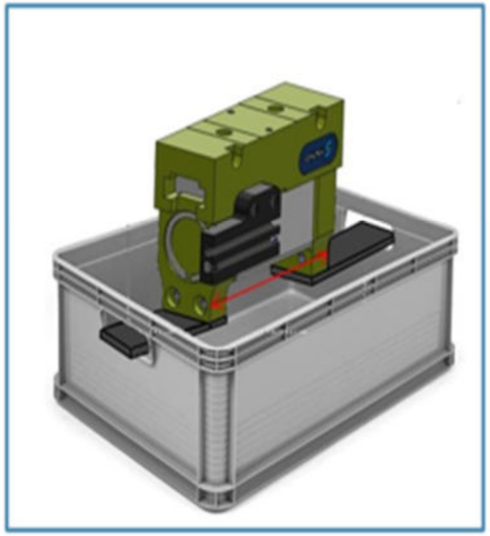
- Cognitive robotics and smart mechatronics
- AI-based perception
- Human-robot collaboration
- Farm level modelling and orchestration – RAMI 4.0
- Decision Support System

Farm Process Modelling

Components of the CoRoSect Factory Floor

D-Robot – de-stacking robot
M-Robot – manipulator robot
I-Crate – sensor devices for the intelligent box

CoRoSect's Environment

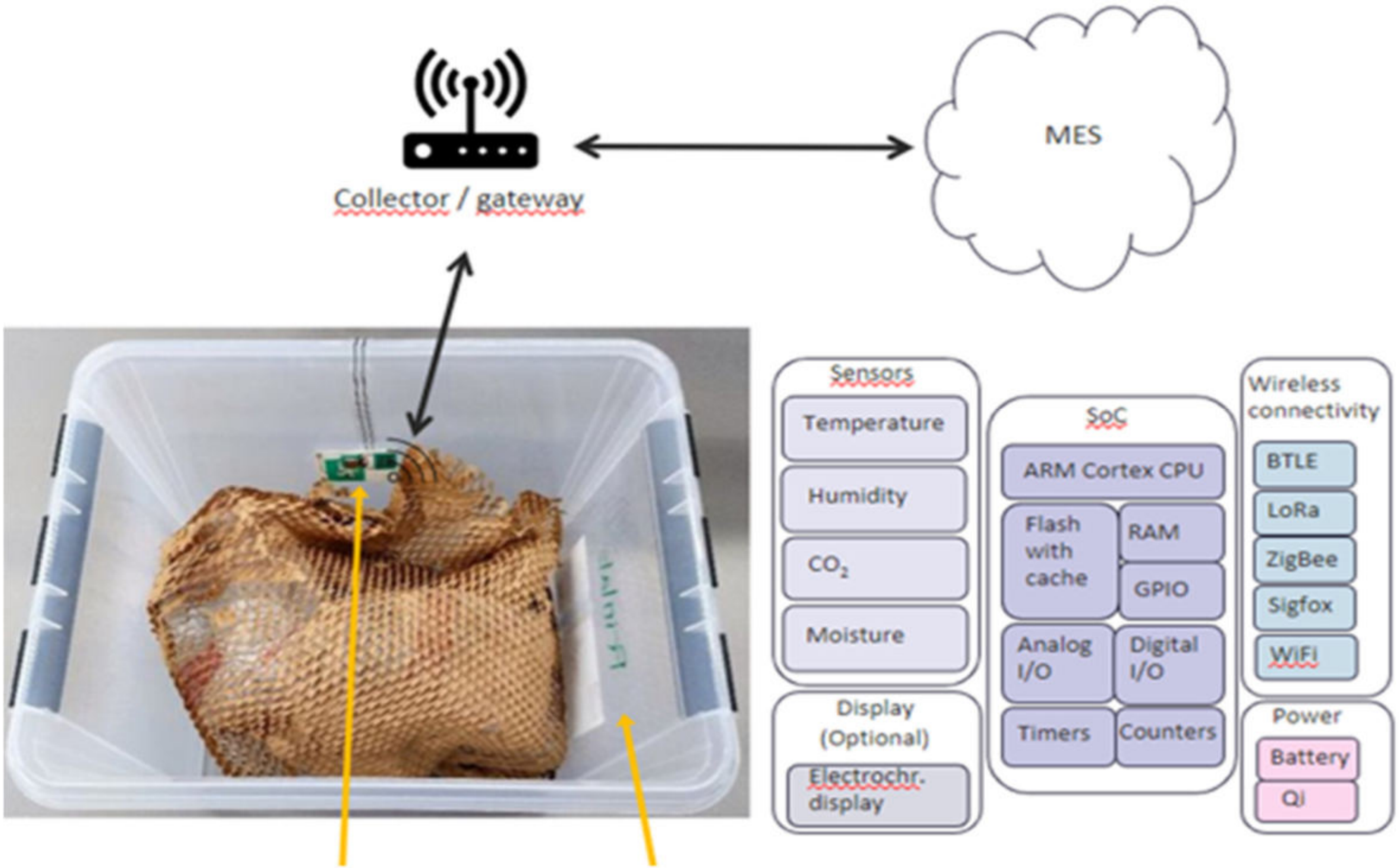


COMPONENT	LIMITATIONS AND CONSIDERATIONS
UR10e 	• Can manipulate crates with up to **8 kg**.
KUKA KR 16 R1610-2 	• Can manipulate crates with up to **14 kg.** • Requires safety system + fence -> Integration with agv is required. • Space requirements safety system + fence. • Installation of the robot requires heavy machinery.
Gripper 	• The selected gripper + manipulation method requires all crates to have handles. • Compressed air system installation (compressor can be provided).
Installation	• Electrical connection. • Network connection. • Good illumination for visual servoing of crates.

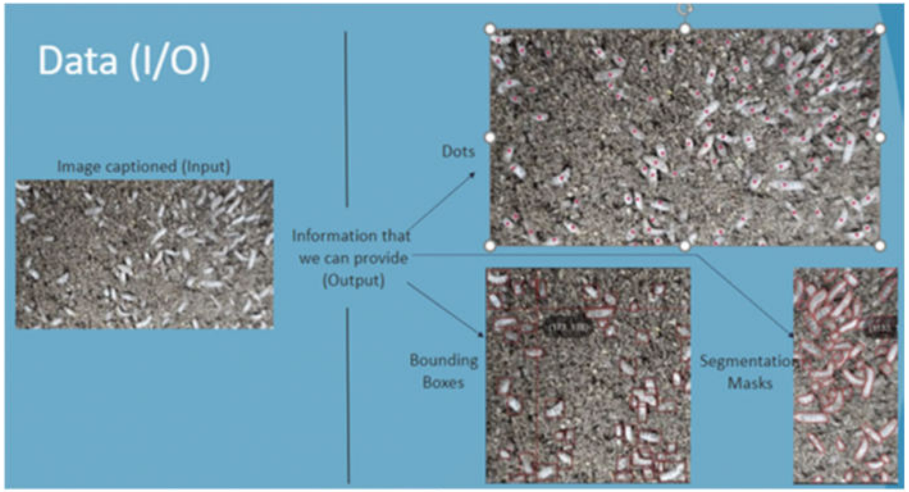
CoRoSect's Environment

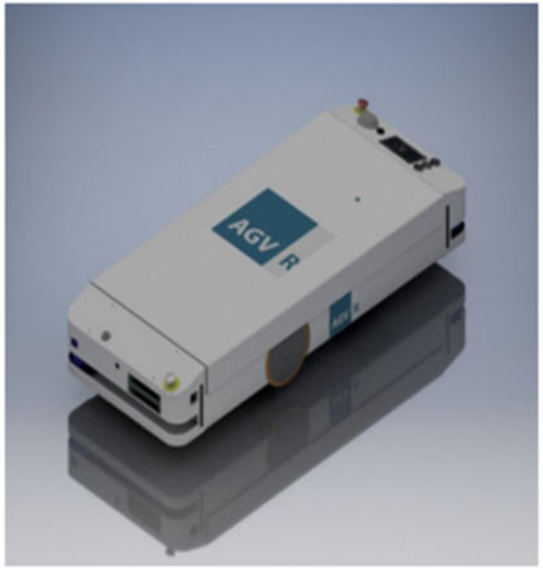
- Visual feedback required for control of robot --> requires sufficient light
- Possible use of laser scanner for 3D object recognition --> problematic for insects?
- In-stack operations (manipulations, inspections, taking samples) might be impossible due to small openings between crates --> requires tests; challenge of high and deep stacking --> we can only operate on crates we can reach
- Robots are slower than humans (but can work 24/7)
- Friendly competition dynamic cell and classical conveyor belt system (CoRoSect allows for integration of both concepts)
- Human-robot collaboration for the 20% of tasks that are too difficult for robot --> we see humans and robots as co-workers
  - Environmental conditions, robot is IP 54
  - Disinfection --> avoid spreading parasites
  - Escaping insects

CoRoSect's Environment – Intelligent Crate



CoRoSect's Environment





- **SLAM**

The initial map is created with SLAM

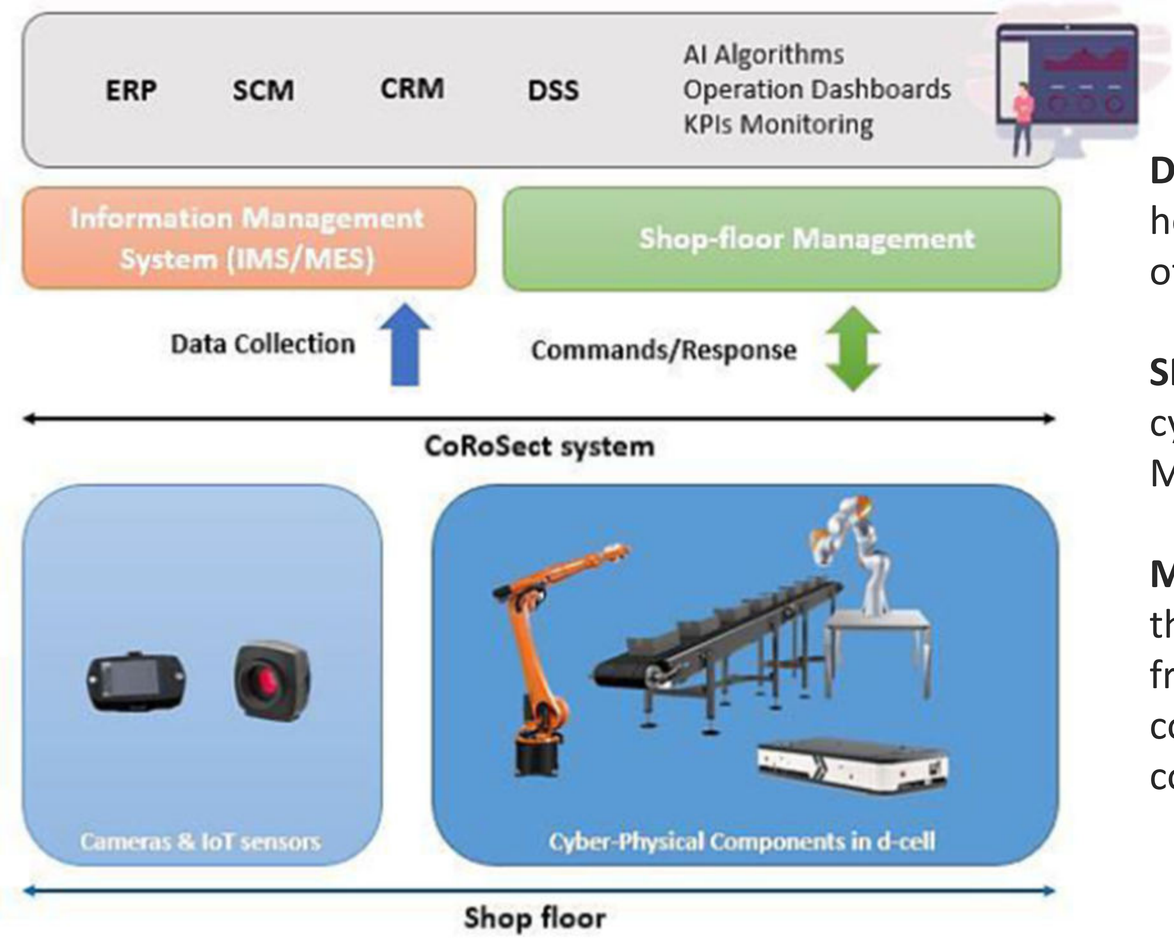
- **Contour navigation**

Map + LiDAR

- **Transport loads from source to destination**

Load: Pallet, box, manipulation robot
Breeding rooms, robot cell, empty crate storage

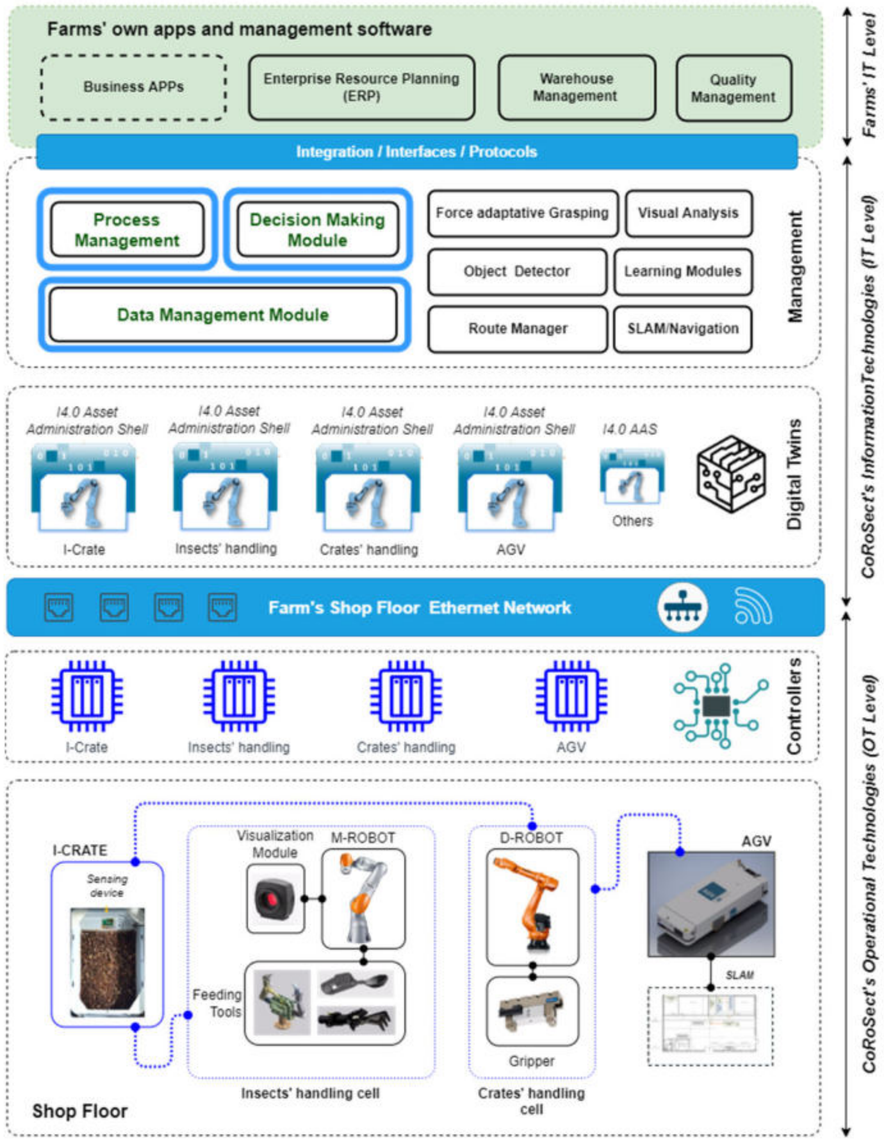
Orchestration model



DSS: Supports the decisions making of the actions, to help with a specific task, to decide what to do in case of an action that does not know what to do.

SFM: Management of the orders (commands) of the cyber components to send the information to the MES.

MES: Receive and articulate all the information from the components and systems, obtain information from the cyber components, from the vision and will communicate it in a standard format to each component that requires it for something.



RAMI 4.0 Architecture layer

Business

Functional

MES = Management Execution System

Information

Communication

Integration

Asset

Assets on the shop floor:

I-crate = intelligent crate

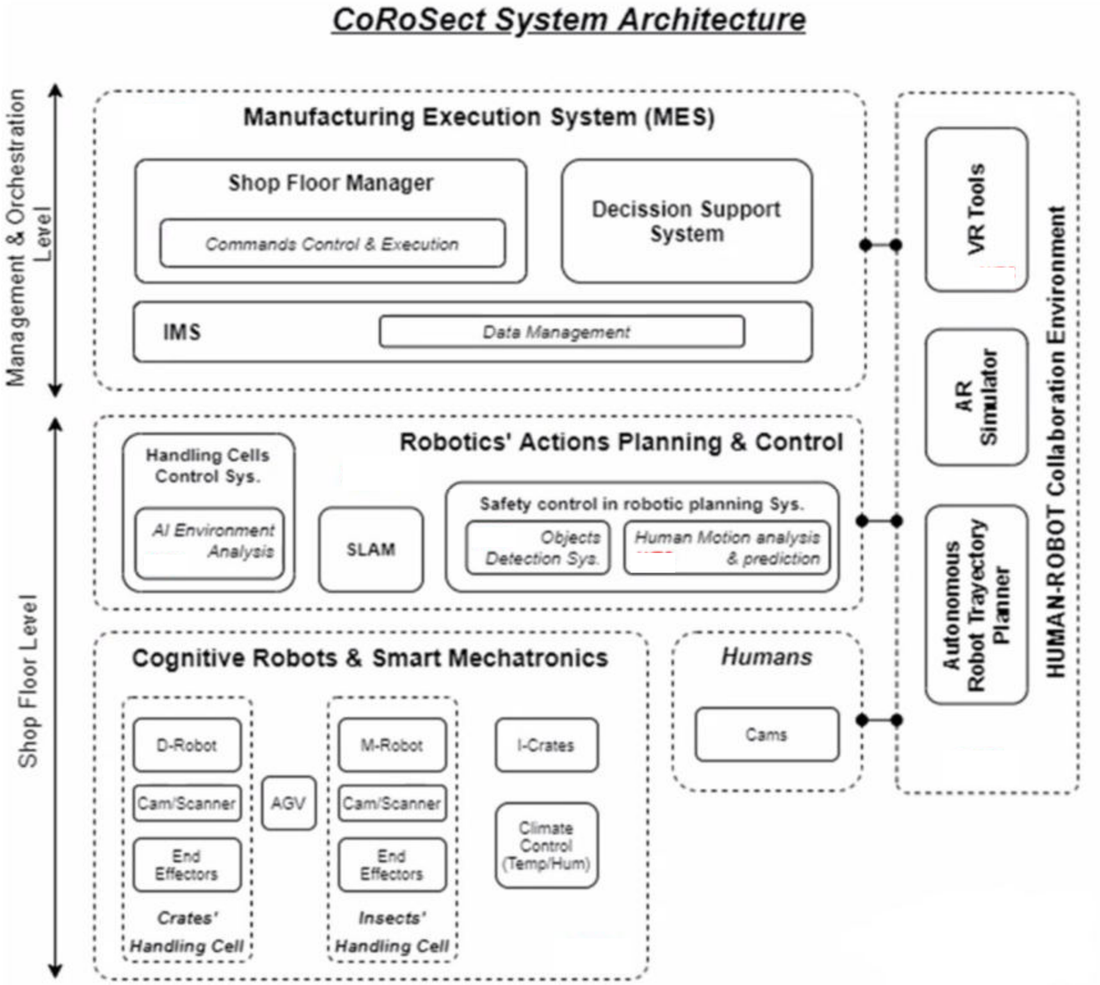
M-robot = manipulation robot

D-robot = stacking-destacking robot

AGV = automated guided vehicle

SLAM = simultaneous localisation and mapping

CoRoSect's Cognitive Robotic System for Digitalized and Networked (Automated) Insect Farms



Integrated Robotic Solution Based on RAMI4.0 → support all phases of the insects' lifecycle inside **insect farms**

Robots' Actions: e.g. feeding, watering, transportation...

CoRoSect – Impact

CoRoSect makes a vital contribution to securing a sustainable, environmentally friendly food production for humans and animals from insects at large scale and in an automated way.

Thereby CoRoSect has the potential to reduce the risk of international conflicts, to help protecting the environment, and to protect and increase the quality of life of many people worldwide.

By producing food from insects, greenhouse gas emission and organic waste during food production will be reduced, while land and water can be used more efficiently.

CoRoSect advances the state-of-the-art in robotics, artificial intelligence, and digitalization for industry and agriculture thereby improving working conditions of workers and boosting the competitiveness of the EU in robotics and AI.

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