NEPTUN

NEW APPROACH TO INNOVATIVE TECHNOLOGIES IN MANUFACTURING

Deliverable 3.3

Pilot Research

Report

Work package No. 3 – Research Project

Prepared by: Marek Chodnicki (GDAŃSK TECH)

Lead participant: TUB

Delivery date: 31 August 2025

Dissemination level: Public

Type: R: Report

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

Revision History

Author Name, Partner short name	Description	Date
Marek Chodnicki (Gdańsk Tech), Felix Unger (TUB),	v. 1.0	30.09.2025

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by
the European Union

“Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them”.

Table of Contents

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

“Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them”.

1. Introduction

This deliverable reports on three pilot research projects executed under WP3 – Research Project of NEPTUN (GA 101079398). The pilots operationalize the WP3 goal to perform joint, application-oriented research with partner expertise clusters and industry-relevant use cases, as envisaged in the NEPTUN proposal and consortium roadmap (AM, HRC, Digital Transformation). Each pilot follows the same logic:

(i) clearly scoped research question aligned with partner strengths;

(ii) shared methods and data;

(iii) measurable outcomes (TRL/KPIs);

(iv) risks and mitigation; and

(v) next steps toward higher TRL or dissemination.

2. Pilots research projects

2.1 Pilot #1 (with TUB)

Title: Strength and stiffness of lattice structures manufactured with Laser Powder Bed Fusion from Ti-6Al-4V titanium alloy: experimental and numerical analysis

Scope and objectives

We study Ti-6Al-4V lattice metamaterials (Kelvin, Octet Truss) fabricated by LPBF, focusing on how mesostructural rounding at nodal junctions affects tensile response (stiffness, strength, failure initiation). Central hypotheses: (i) effective strength depends on local fields at critical meso-sites; (ii) fillets reduce stress/strain concentrations and can improve strength with minimal mass penalty.

Materials and specimen manufacturing

Process: PBF-LB/M on Renishaw RenAM 500Q (250×250×350 mm, 4×500 W lasers), layer 60 µm, platform 200 °C, laser power 320 W, hatch 95 µm, scan speed 1500 mm/s, stripe strategy, multi-laser per part, argon shielding, controlled O_2; $E_v \approx 37$ J/mm³. Build prep: QuantAM 6.0. Post: wire-EDM removal with a 3 mm sacrificial

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

block. Powder: Ti-6Al-4V (Ti64), spherical dp = 20–53 µm; example chemistry (Ti 89.05%, Al 6.37%, V 4.22%, Fe 0.2%, O 0.09%, C/H/N 0.02%, other 0.05%).

Geometric variants (design of experiments)

Unit cell size: u = 2.4 mm; strut diameter d ≈ 0.32–1.10 mm.

Porosity/relative density: p ≈ 33–80% (ρ ≈ 20–67%).

Rounding: fillet radius r up to 0.8 mm; relative fillet $r_{(rel)} = r/r_{(max)}$ from 0% (sharp) to 90% (rounded).

Families: Kelvin (K1–K4 × {a=0%, b=45%, c=90%}) and Octet (O1–O4 × {a~6–16% tech. minimum, b=45%, c=90%}).

Numerical methodology

FE platform: Abaqus/Implicit; geometrical & material nonlinearity; Full-Newton; direct sparse solver; MPI parallel on CI TASK Tryton Plus.

Material model: elastic-plastic Ti-6Al-4V with isotropic hardening from an inverse-calibrated true hardening curve (accounts for post-necking); E = 116.9 GPa, ν = 0.31.

Domain & BCs: RVE = 3×3×3 cells; cubic symmetries → model 1/16 of volume; uniaxial tension via prescribed displacement.

Mesh: 1st-order tets C3D4; 4.5–12+ million elements per model; surface size ≲ 15 µm (below powder dp).

Failure checks: critical σ_1 = 1612 MPa and σ_{vm} = 1242 MPa; macro response from force–displacement; local fields (σ, ε) for initiation mapping.

Experimental campaign (tension)

Setup: MTS 858 Table-Top; axial & transverse extensometry; alignment procedure to remove head torsion; assessed strain-rate sensitivity between 3.6×10^{-4} s^{-1} and 1.0×10^{-3} s^{-1}, adopted 5×10^{-4} s^{-1} for main series.

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03 Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

Specimens: total N = 32 across Diamond (D), Kelvin (K), Octet (O) density/fillet sets; grip pressures per family documented; majority failed in the gauge with mode transition from normal-opening (high porosity) to shear-dominated (higher density).

Key lab observations: (i) rounding improves strength, but measured gains are smaller than pure-geometry FE predicts; (ii) pore size (fitting sphere) is unaffected by fillet—so strength can rise without reducing pore size, relevant for implant design; (iii) for Kelvin, specific edge-cell cutting can trigger stress risers near grips → avoid discontinuities in real parts

Results and analysis (selected highlights)

Kelvin (K1–K4, a/b/c):

- Stiffness: Young's modulus increases with fillet; at low ρ (K1) +15% (b) to +40% (c); at high ρ (K4) modest +2–4%, broadly proportional to small mass gain (Δρ up to ~1–7%).
- Strength & ductility proxies: at the Huber–von Mises criterion, effective stress +3–26% and effective strain +25–70% vs sharp; max principal stress measures are even more sensitive to fillet.
- Example (K1 set, ρ≈19–21%):
- E: 2.22 → 3.11 GPa (a→c); $\varepsilon_e$ff@cHM: 0.10 → 0.17; $\sigma_e$ff@cHM: 67.4 → 84.5 MPa; $\varepsilon_e$ff@cN: 0.005 → 0.060; $\sigma_e$ff@cN: 22.2 → 74.0 MPa.
- Example (K3 set, ρ≈51–53%):
- E: 15.97 → 17.99 GPa; $\varepsilon_e$ff@cHM: 0.13 → 0.18; $\sigma_e$ff@cHM: 294.6 → 315.7 MPa; $\varepsilon_e$ff@cN: 0.005 → 0.100; $\sigma_e$ff@cN: 159.4 → 311.4 MPa.
- Field maps: rounding spreads Huber–von Mises hot-spots over larger volumes, reduces peaks, and delays criterion exceedance; normal-stress fields tend to form continuous bands rather than isolated points.

Octet Truss (O1–O4, a/b/c):

- Similar trends, but mass penalty with high r$_{(}$rel$_{)}$ can grow (e.g., O1c Δρ ~+37%), so optimal fillet exists: moderate rounding enhances properties; excessive rounding may lift ρ too much and reduce net strength advantage.

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

Synthesis vs experiments: Numerical improvements from filleting are qualitatively confirmed by lab tests; magnitude is lower in practice due to manufacturing imperfections (surface roughness, off-nominal strut geometry) and boundary effects. This supports using image-based or imperfection-aware models in the next iteration.

KPIs (status)

KPI-R1: Correlation (FE vs test) for stiffness (target $R^2 \geq$ […]) — on track; K-series shows strong monotonic gains with r_{rel}.

KPI-R2: MAPE for peak force ≤ […%] — partially achieved (sensitive to grip effects and imperfection levels noted in lab log).

KPI-R3: Hot-spot localization vs fracture origin ≥ […%] match — ongoing; high-speed imaging series initiated.

Risks & mitigation

µCT resolution vs specimen size: use ROI scans at nodes; validate notch radii.

Mesh cost: sub-modeling of hot-spots; far-field homogenization.

Process-induced deviations: include imperfection fields (surface roughness, strut waviness) in next-step models; update hardening with batch-specific data.

Next steps

Imperfection-aware FE: introduce µCT-derived geometry for a subset to reconcile magnitude gaps (FE vs test).

Fatigue-relevant metrics: extend to low-cycle/fatigue indicators using local strain-based criteria.

Design rule: propose optimal r_{rel} windows per density band (Kelvin/Octet) balancing $\Delta\rho$ vs σ, ε gains; link to post-processing routes from the TUB chain (e.g., light brushing) to further reduce notch severity prior to use.

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03
Funded by the European Union

“Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them”.

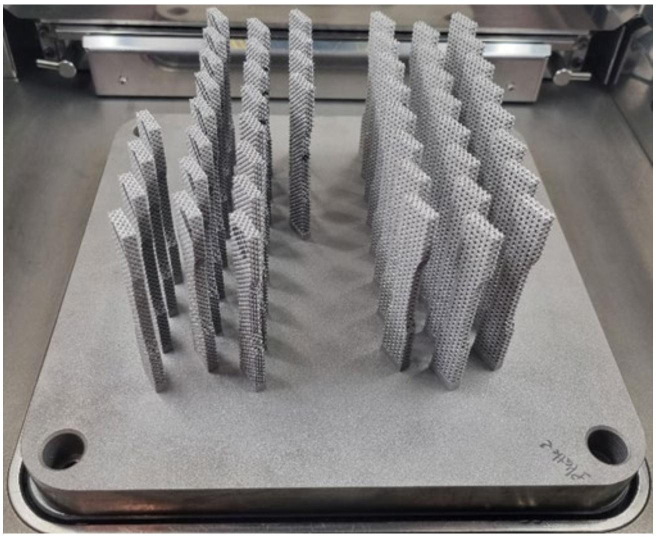


Figure 1. Additively manufactured tensile test specimens with TPMS-structures on the build plate

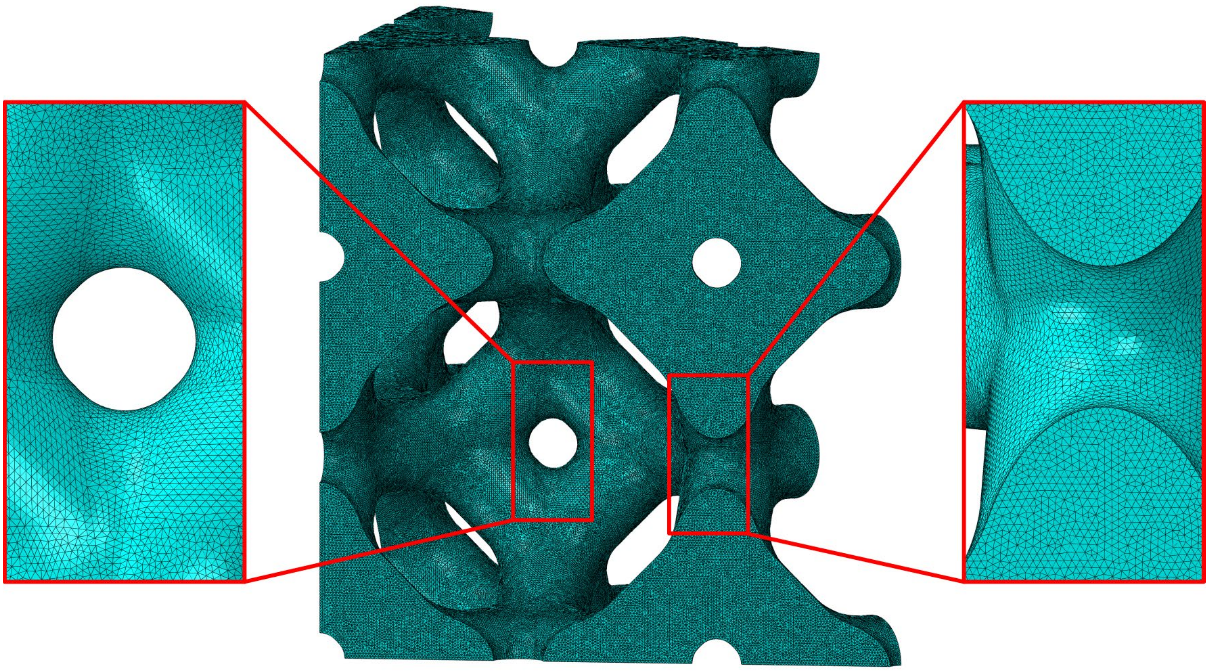


Figure 2. Example mesh of Kelvin-type structure (K2c): 1.13M nodes, 6.14M C3D4 elements

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03
Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

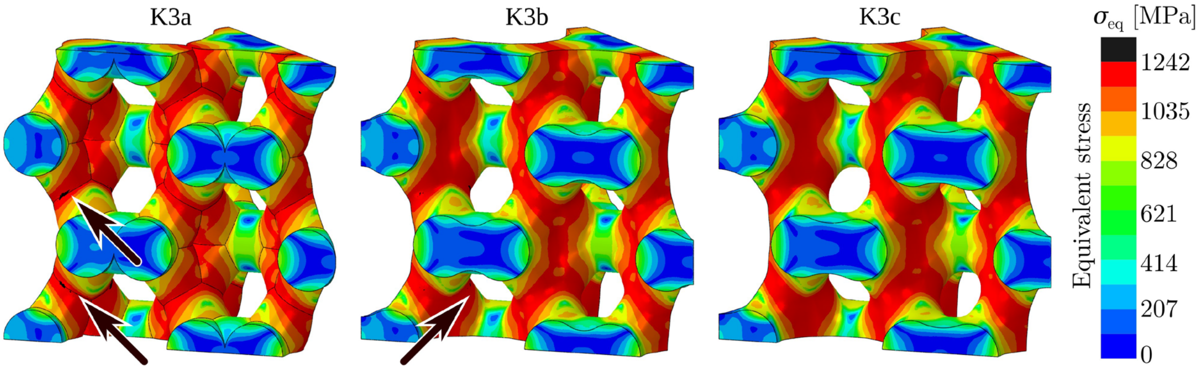


Figure 3. K3 Huber–von Mises equivalent stress fields (cHM met for K3b at εeff = 0.14)

2.2. Pilot #2 (with NTUA, with support of KTH)

Title: Human–Robot Collaboration in disassembly of wooden doors hinges

<u>Scope and objectives</u>

The aim of the pilot was to design and test an actively cooperating HRC cell for dismantling door hinges (A–E: two hooks, pin, pin screw, half of the hinge in the door leaf), with an emphasis on:

(i) safe human-robot interaction (SSM/force limits),

(ii) visual perception of steps and objects,

(iii) robust pick-and-assist (holding the pin, removing components, sorting),

(iv) operator ergonomics and cycle time reduction.

The project is part of the closed-loop (re-use/remanufacturing) path and serves as a model for small disassembly operations in EoL/service.

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

Cell, equipment and baseline

The station uses a Hanwha HCR-3 cobot with a 3D + top 2D camera, force/torque sensor, gripper with replaceable fingers (modification + rubber linings), magnetic pick-up tool for collecting items from the door surface, and sorting baskets. Communication and vision integration with the controller is implemented via ROS2 (transfer of object position/class data; movements performed natively in the robot controller), which minimizes the risk of delays in real-time control. The workspace layout meets the requirements for operator access and a straight-line mandrel removal trajectory (~15 cm), with limited reach and a long flange-gripper section.

Process design (disassembly tree & HRC allocation)

The procedure is defined as a disassembly tree from the Door+ABCDE state to Door, broken down into steps, role allocation, and recognizable intermediate states. Key steps (abridged):

1R. positioning the robot to recognize pin C; 2R. visual recognition of the pin head (YOLO-seg); 3R. grasp C; 4H+R. human unscrews bolt D with the robot actively pressing down on C; 5H. remove D; 6R+H. robot pulls out C, human supports E; 7R/8H. put C aside and remove E; 9–10H. disassembly of hooks A/B and sorting. Variants allow for assisted manual TCP feeding in teach mode and the inclusion of additional human event classifiers (detection of completion 4/grasping E).

Perception, planning and control

Vision: YOLO11s-seg for detecting the head of the pin (any background/position, operator presence) and the YOLOv11-OBB model (9 classes) for recognizing the position and orientation of elements on the door panel; various approach/grip points defined for each class/orientation. The tests achieved nearly 100% accuracy in real-world conditions.

Integration: two RODI-X plugins for ROS2 (vision results transfer; robot monitoring). Due to <5 Hz effective exchange, trajectory control remains on the controller side, and ROS provides target data—a simple, sufficiently fast, and safe solution.

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

Grip/removal C: slippage problem → new fingers + rubber; for misalignment of elements, trajectory correction from the force loop (2D online) was used. The "step-stretching" mode shortens the phases by up to ~50% when the forces are small.

Pick-and-place & sorting: an experimentally selected magnetic tool (magnet type/size) allows reaching beyond the normal range; basket design optimized for self-collisions and long/short element orientation variants.

Safety and HRC framing

Active cooperation has been adopted (the robot assists and periodically leads), with roles divided according to the leader/supportive classification and a shared workspace; some local decisions remain with the operator (zero-programming/gestures—optional). The architecture is consistent with the symbiotic HRC approach (cyber-physical, digital twin in the background, mobile interfaces), and heavy/non-time-critical tasks can be moved to a private cloud (planning, supervisory cockpit). This ensures compatibility with the KTH framework (Wang et al., CIRP Annals 2017).

Results (interim)

Process stability: sequence 1–10 performed stably and repetitively; element recognition errors ≈0% in working tests.

Cycle time: force correction mode slower in a single step, but thanks to "step-stretching," this phase was shortened by up to 50% at low forces; total time/lock depends on hinge variant and coaxiality.

Ergonomics and safety: no SSM zone violations in tests; the robot takes over the axial forces during unscrewing D and removal C, which limits unfavorable wrist positions for the operator. E-stops triggered only in forced intrusion tests.

Technical limits: HCR-3 may reach its force limit with large component clearances—in these cases, cooperation with the operator or pre-conditioning (alignment) is necessary.

KPIs (status)

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

“Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them”.

KPI-H1 (Throughput): ≥ [..]% improvement vs. manual baseline for "nominal" (axial) hinges – achieved/nearing completion.

KPI-H2 (Ergonomics): [..–..]% reduction in load (RULA: −1 class) – measurements in progress.

KPI-H3 (Safety): 0 recordable incidents; no SSM violations – achieved.

KPI-H4 (Vision): detection effectiveness >98% (pin head; OBB elements) – achieved.

Risks & mitigation

Misalignment / high extraction forces C: correction from the force loop; variant with operator assistance; ultimately a higher cobot class (≥5 kg) / shorter flange-gripper section.

Gripper slippage: fingers with rubber + larger contact area; selection of contact forces.

Vision integration–control: leaving motion control in the robot controller; ROS2 only as a data bus (safer degradation in case of delays).

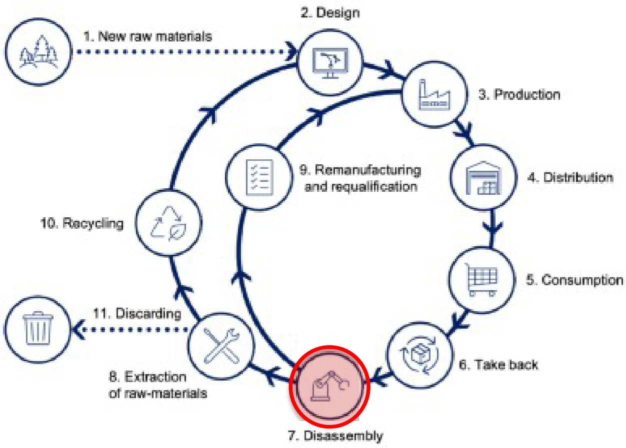
Next steps

Automatic detection of H events (end of 4, grasp E) → switching cooperation states without voice commands; 2) Refinement of baskets and paths (avoiding singularities, planning with consideration of vertical movement after grasping); 3) Ergonomic metrics and full cycle times on a population [N] of doors/hinges; 4) HRC reference package: BOM, layout, YOLO recipes, ROS2 plugins, SSM checklist; 5) Integration with symbiotic HRC/digital twin framework according to KTH (planning tasks in a private cloud; supervisory cockpit).

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

Product disassembly



- Becomes more and more important stage of the product lifecycle especially in terms of ecology, zero-waste economy, remanufacturing, etc.
- Thus – it will be profitable to perform this process automatically or with (robot) assistance

Figure from:

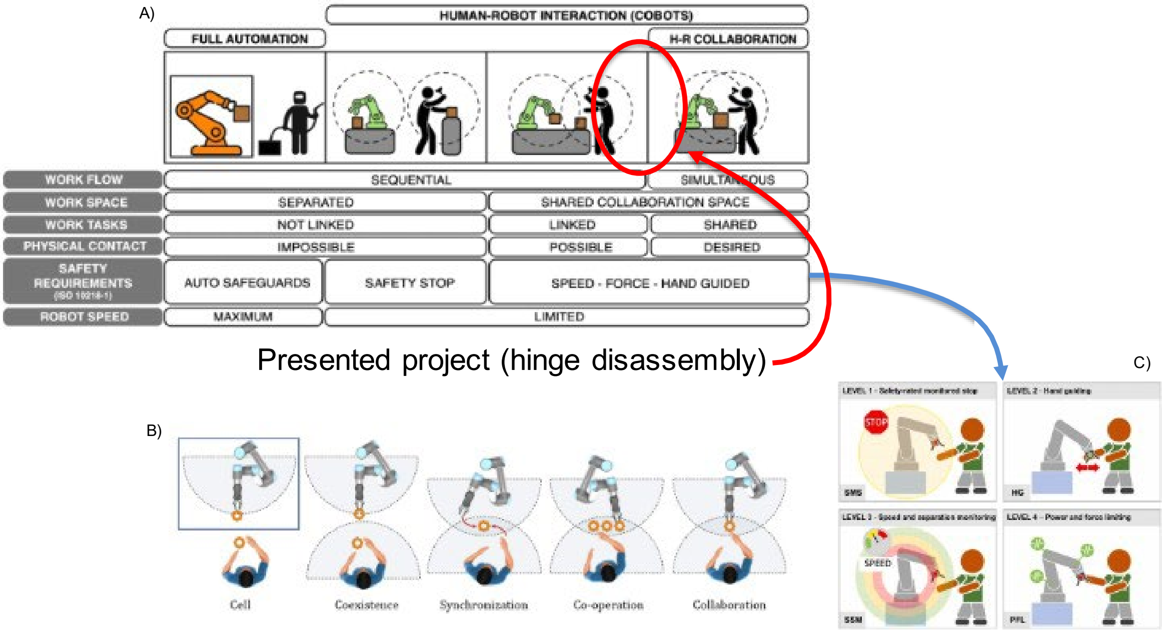
- Hjorth S., Chrysostomou D., Human–robot collaboration in industrial environments: A literature review on non-destructive disassembly, Robotics and Computer-Integrated Manufacturing, 2022, 73:102208, https://doi.org/10.1016/j.rcim.2021.102208.

2

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

Human-robot collaboration



Figures from:

- A - Liu, Y.; Caldwell, G.; Rittenbruch , M.; Belek Fialho Teixeira, M.; Burden , A.; Guertler, M. What Affects Human Decision Making in Human–Robot Collaboration?: A Scoping Review. Robotics 2024, 13, 30. https://doi.org/10.3390/robotics13020030
- B - Malik, A.A., Bilberg, A. Developing a reference model for human –robot interaction. Int J Interact Des Manuf 13, 1541 –1547 (2019) . https://doi.org/10.1007/s12008-019-00591- 6
- C - Hjorth S., Chrysostomou D., Human– robot collaboration in industrial environments: A literature review on non -destructive disassembly, Robotics and Computer-Integrated Manufacturing, 2022, 73:102208, https://doi.org/10.1016/j.rcim.2021.102208.

3

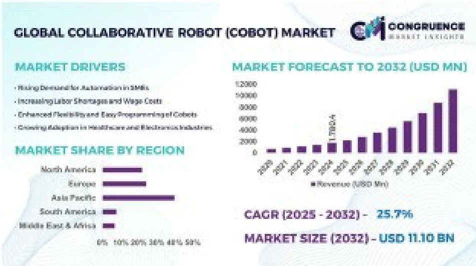
Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

“Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them”.

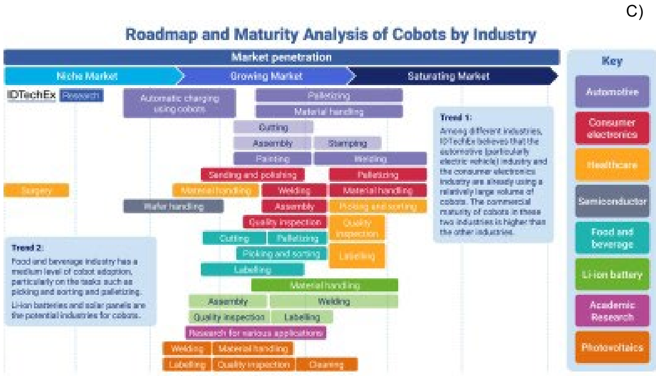
Collaborative robots trends

A)



B)

C)



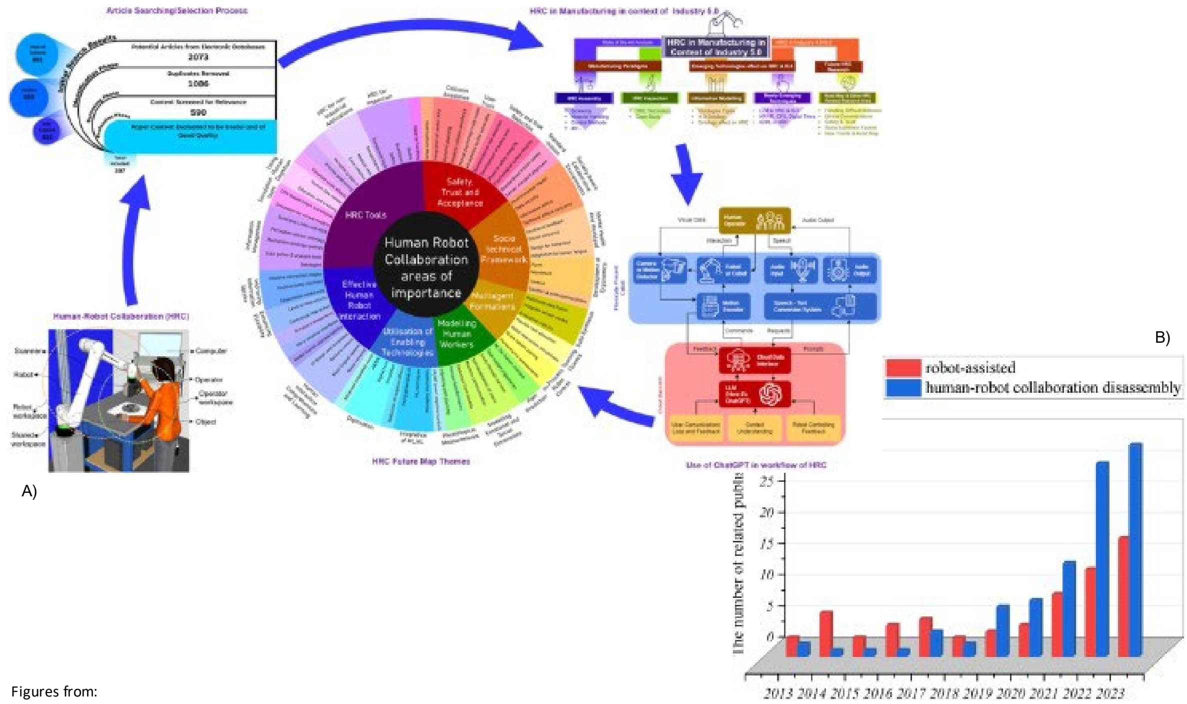
Figures from:

- A - https://www.congruencemarketinsights.com/report/collaborative -robot -cobot -market , last accessed 12/9/2025
- B - https://www.interactanalysis.com/wp -content/uploads/2019/06/Cobot -Market-Outlook -Infographic-press -release.pdf, last accessed 12/9/2025
- C - https://www.idtechex.com/en/research -article/the -rise-of-collaborative -robots -technical -and -commercial -insights/33439, last accessed 12/9/2025 4

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

Collaborative robots research



Figures from:

- A – Dhanda, M.; Rogers, B.A.; Hall, S.; Dekoninck, E.; Dhokia, V. Reviewing human-robot collaboration in manufacturing: Opportunities and challenges in the context of industry 5.0. Robotics and Computer-Integrated Manufacturing. 2025, 93, 102937. https://doi.org/10.1016/j.rcim.2024.102937
- B – Xiao, J.; Huang, K. A comprehensive review on human–robot collaboration remanufacturing towards uncertain and dynamic disassembly. Manufacturing Review. 2024, 11, 17. https://doi.org/10.1051/mfreview/2024015

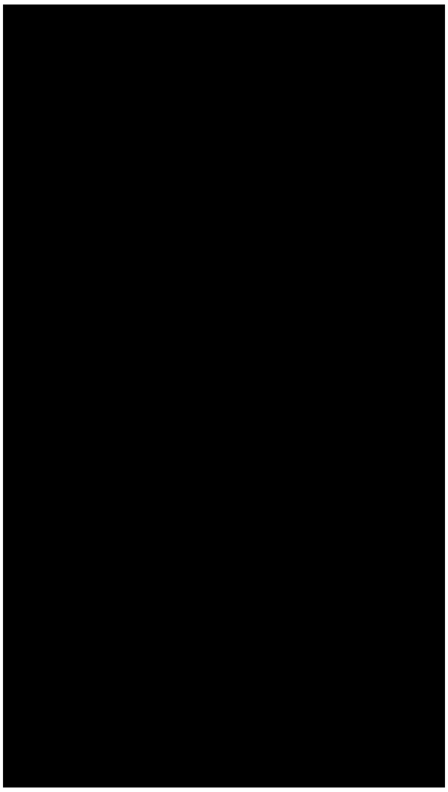
5

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

Task to do – hinge disassembly

- **Manual hinge disassembly**
  Courtesy of Porta KMI Poland s.a.



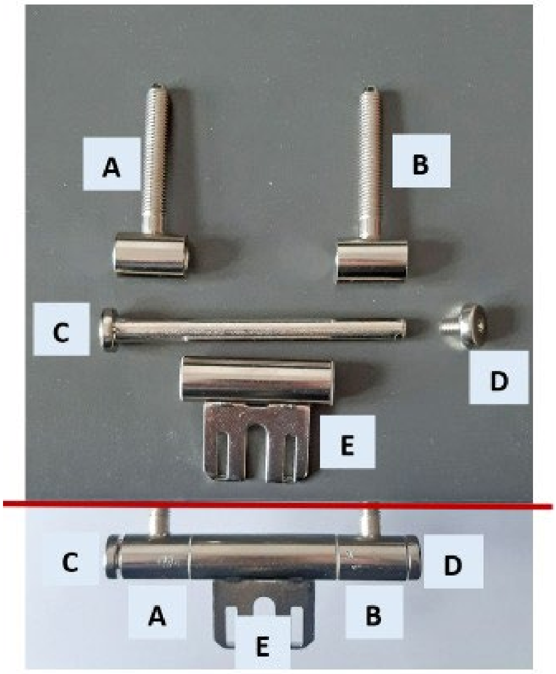
6

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

Task to do – hinge disassembly



A, B – door side hinge hooks

C – hinge pin

D – hinge pin screw

E – port side hinge

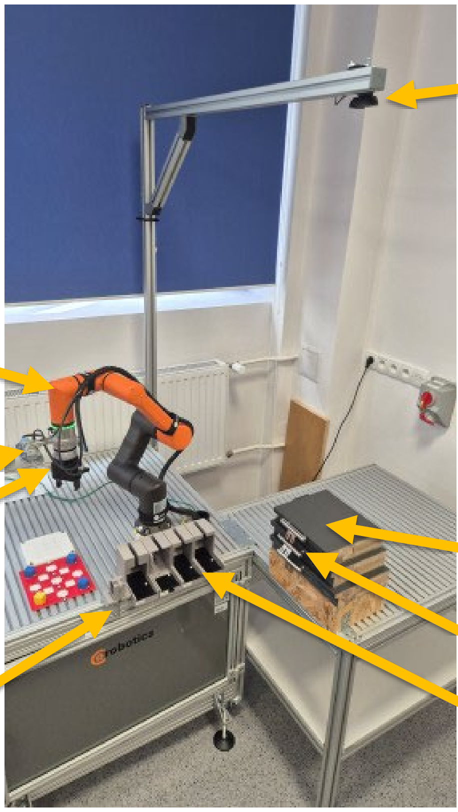
7

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

“Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them”.

Hinge disassembly – stand and equipment



8

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03
Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

Hinge disassembly steps

Initial state: Door+ABCDE

1R – Move Robot arm to the side of the work area for visual pin location recognition

2R – Visual pin location recognition – YOLO AAN

3R – Grip hinge pin (C) head

4H+R – Human unscrews hinge pin screw (D) while R holds the hinge pin (C)

5H – H removes hinge pin screw (D)

State: Door+ABCE, removed D

9

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

Hinge disassembly steps

6R+H – R removes hinge pin (C) while H holds port side hinge (E)

State: Door+ABE, removed C

7R – R puts the hinge pin (C) away
and places in an appropriate basket

10

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

GDAŃSK UNIVERSITY OF TECHNOLOGY

Hinge disassembly steps

8H – (In parallel with **7**) H removes port side hinge (E)
State: Door+AB, removed E

9H – H changes the tool in handheld drill driver to hook driving tool and unscrews door side hinge hooks (A and B)
State: Door, removed A and B

11

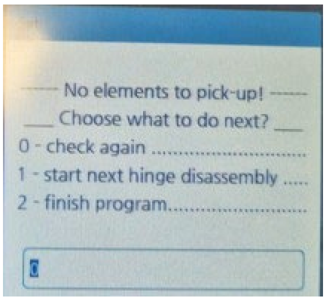
Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03
Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

Hinge disassembly steps

10H and/or R – Recognition of elements placed at the door top,
R picks up elements from door top plane and puts them in the appropriate baskets (elements sorting)
Elements may be placed in the baskets by H as well

11R – When no more elements on door top plane, R asks what to do next:
- re-check for elements,
- start next hinge disassembly
- finish program



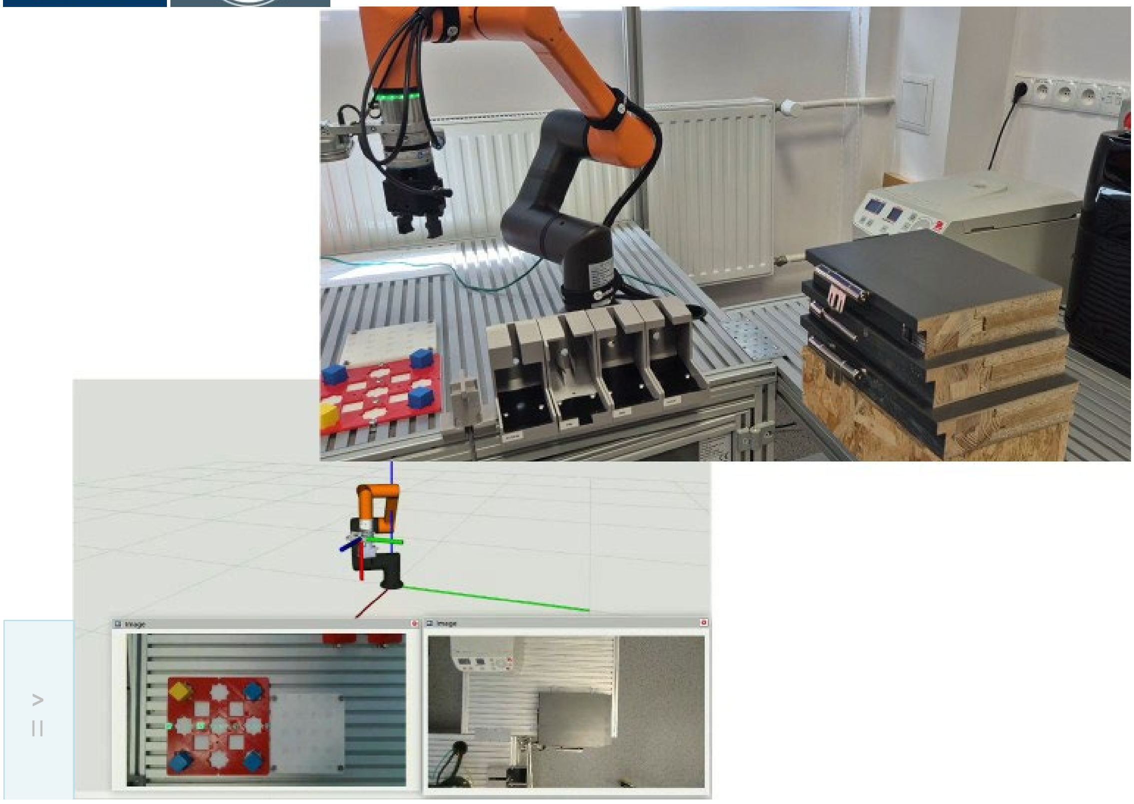
12

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03
Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

GDAŃSK UNIVERSITY OF TECHNOLOGY

Robot assisted hinge disassembly



13

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

“Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them”.

GDAŃSK UNIVERSITY OF TECHNOLOGY

Main challenges

- **Main challenges**
  - Proper arrangement of the robot and the doors that allows visual recognition of the pin location and removing the pin
  - Pin location recognition
  - Data transfer between visual recognition system and the robot controller
  - Pin removal
  - Picking up hinge elements from the door top plane
  - Elements sorting

14

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

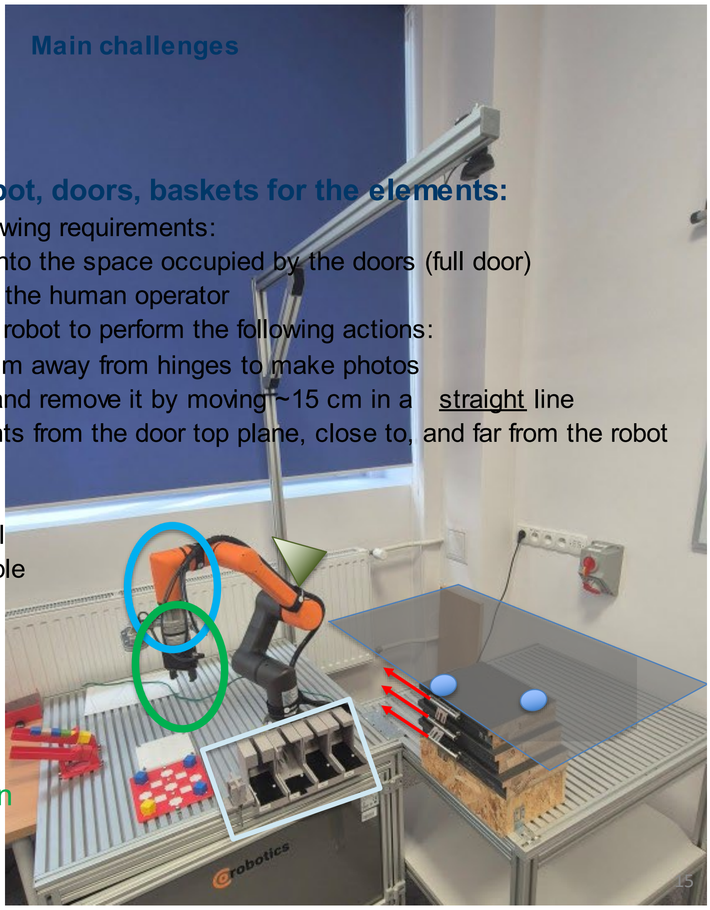
Funded by the European Union

“Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them”.

GDAŃSK UNIVERSITY OF TECHNOLOGY

Main challenges

- **Proper arrangement of the robot, doors, baskets for the elements:**
  - Arrangement must fulfil the following requirements:
    - No robot part can intrude into the space occupied by the doors (full door)
    - There must be a space for the human operator
    - It must be possible for the robot to perform the following actions:
      - Reach position ~40 cm away from hinges to make photos
      - Grasp the hinge pin and remove it by moving ~15 cm in a straight line
      - Pick-up hinge elements from the door top plane, close to, and far from the robot
      - Reach positions of each of the baskets and the magnetic tool
    - Baskets must be accessible for the operator too



Not easy!
Mostly due to the :

- „twisted" robot's 5-th link
- long flange-gripper section
- limited robot reach

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

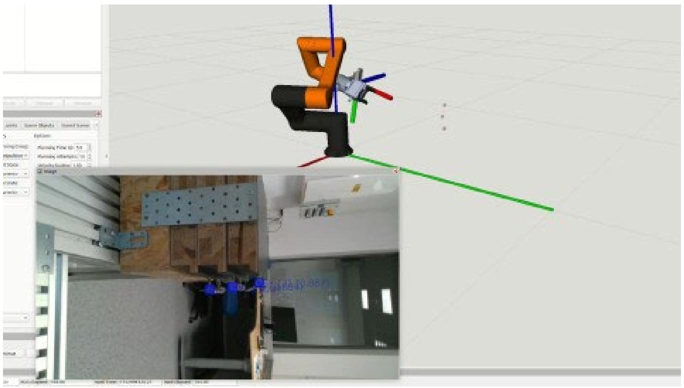
Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

Main challenges

- **Pin location recognition:**
  - Pin must be located :
    - in any place of the image space
    - for varius angles of the camera
    - for various backgrounds , inlcuding people (operator) - conditions closer to the real, factory-like ones
  - Solution: **YOLO** ANN (yolo11s-seg.pt model) + transfer learning

Results test



Sample training images

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

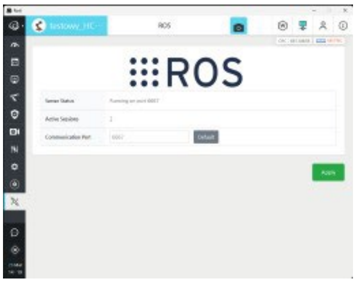
GDAŃSK UNIVERSITY OF TECHNOLOGY

Main challenges

Data transfer and robot monitoring

- ROS2 (Robot Operating System) used for:
  - communication and integration environment
  - on robot camera position calculation for pin recognition
- 2 RODI-X plugins developed
  - Visual recognition results data transfer
  - Robot control and monitoring

- Due to low communication frequency (<5Hz) robot moves are not controlled externally (i.e. form ROS).
  Only data required for robot moves are transferred to the robot controller, and then movement is controlled internally, by the robot itself
    - Simple, efficient enough, safer (?)
    - Keeps all the control on the robot side



17

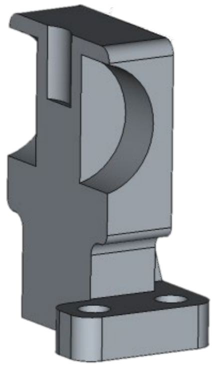
Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

Main challenges

- **Pin removal**
  - Not enough grip between gripper fingers and the pin
    - Solved by redesign of gripper fingers and adding rubber pads



… however , …

  - If the elements of the hinge are not well centred, in -line, there is a high force needed to remove pin (C), and:
    - The pin may slip off from the gripper
    - The robot may be unable to provide enough force, and stop due to overload (it's a CoBot anyway – safety first! ☺)

18

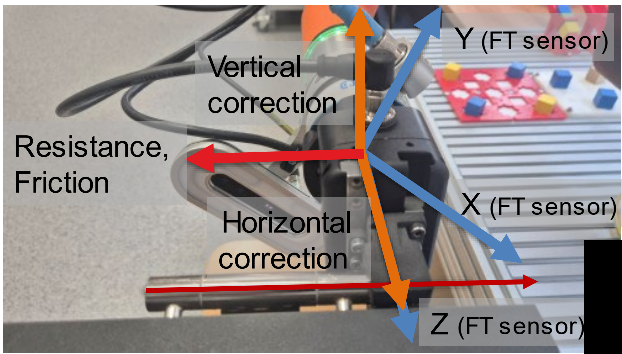
Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

Main challenges

- **Solution – force-feedback assisted pin removal**
  - On-line, 2D correction of removal trajectory based on force measurements
    - Drawback – must be made step-by-step – slow…
    - … but „step stretching” when forces are low allows for up to 50% time reduction



Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

“Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them”.

Main challenges

- **Elements pick-up**
  - Magnetic tool
    - Neodymium magnet tip
      (Magnet type and size had to be carefully selected)
    - Passive
      (no control signals and power needed)
    - Long enough to reach elements lying far from the robot
      (beyond normal reach)
    - Works surprisingly well!

20

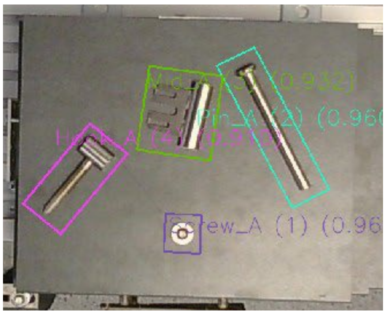
Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

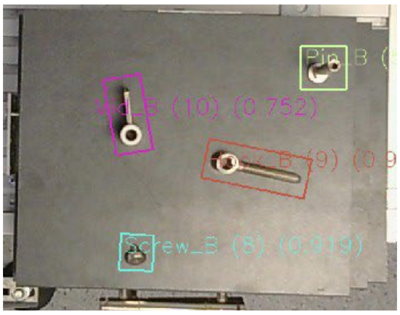
Funded by
the European Union

GDAŃSK UNIVERSITY OF TECHNOLOGY

Main challenges

- **Elements pick-up**
  - Element position and angle recognition
    - YOLOv11-obb ANN model retrained for 9 classes (transfer learning)
      - 4 elements x 2 vertical orientations (lying, standing)
      - 1 „empty" / „no elements" class
      - High performance in real-life application (proper recognitions in almost 100% of test)
    - Different pick-up points defined for each element class and orientation
    - No problems with proper element picking (!)





21

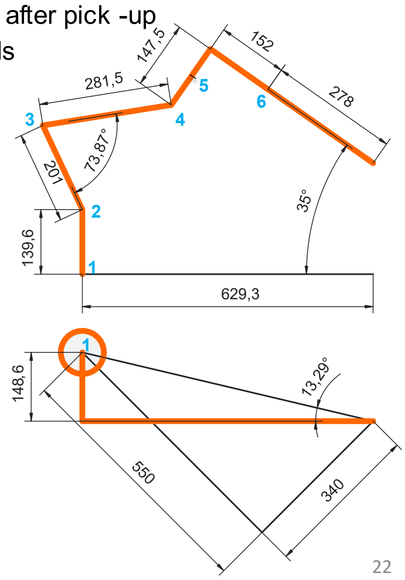
Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

Main challenges

- **Elements pick-up**
  - Element approach
    - Robot controller inverse kinematics solver…
      - Does not take into account geometrical constraints around the robot
      - Does not take into account, that the next move after pick-up must be, and will be performed straight upwards
        - Pick-up and post pick-up positions must be reachable
        - Possible singularities or out of robot reach configurations must be avoided
      - Does not allow to mix joints angles and cartesian positions constraints in one solution
    - Analytical solution was developed
      - 3 out of 6 joints constrains are well specified or can be easily calculated.
      - The problem may be reduced to planar one
      - Simple trigonometry
      - Possible to be programmed directly in the robot
      - Fast calculations
      - No „full-scale" IK solver needed



Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03
Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

GDAŃSK UNIVERSITY OF TECHNOLOGY

Main challenges

- **Elements sorting**
  - Sorting and element drop -off
    - Very limited space around the robot
    - Some position very close to self -collision
    - Due to long flange-gripper-tool robot section, limited space for vertical move during element drop -off
    - Diverse elements (long, short, square, round, light, „heavy")
    - Quite sophisticated design of baskets for elements was needed to handle all possible tool-part-basket mutual orientation cases
      (espacially the basket design for the long hinge pin was demanding)

23

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03
Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

GDAŃSK UNIVERSITY OF TECHNOLOGY

Summary

- **It works! ☺**
  - Stable, repeatable, very low error rate
- **Visual recognition using YOLO models**
  - Relatively easy to implement
  - Good results
- **ROS**
  - Good environment for integrating vision systems with AI and robot controller
    - However, ROS control capabilities were not used because fast and reliable ROS↔robot controller communication is needed
      - (Works under way – for future projects)
      - All robot control was performed by the robot controller (i.e. not externally)

24

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

NEPTUN

NEW APPROACH TO INNOVATIVE TECHNOLOGIES
IN MANUFACTURING

GDAŃSK UNIVERSITY OF TECHNOLOGY

Conclusion and Thoughts for the future

- **The robot itslef**
  - Slightly larger (5kg class?) robot would have facilitate many operations
    - Longer arm / reach
    - Higher payload (especially close to full arm reach)
  - Long flange-gripper-tool section caused various problems
  - More room around the robot would make elements manipulation easier during sorting
- **Robot speed**
  - In some cases, it's not the robot speed that limits the performance but accelerations . Top speed is not important if the robot can't reach it during its move (accelerates to slow). And some operatins must be performed with low accelerations…

25

2.3. Pilot #3 (with KTH)

Title: Digital Transformation of Manufacturing Companies: Mapping Cross-Domain Interactions – Case Studies

<u>Scope and objective.</u>

The pilot with KTH developed and tested a cross-domain interaction (CDI) framework for sustainable digital transformation (SDT) in manufacturing. The aim was to move beyond checklist approaches (TBL/ESG) and capture how decisions in technology, management, people, and environment trigger sequences and feedback loops that shape outcomes.

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03 Funded by the European Union

“Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them”.

Methodology (mixed-methods).

Two manufacturing companies were studied using (i) an anonymous 5-point Likert survey of employees and managers, and (ii) semi-structured interviews with transformation leaders. Interview data were deductively coded into 24 SDT areas; flows were visualised via Sankey/chord diagrams to expose driver→effect paths.

Sample & baseline.

Company 1 (medium) and Company 2 (large) both had >10 years of operation and >PLN 50M budgets; DT spending ranged from PLN 200k–1M (Co.1) to >PLN 1M (Co.2). Employees rated overall digital maturity 2.78 (Co.1) vs 3.45 (Co.2). Resistance to change was low overall but higher in Co.2.

Key results.

We identified 86 CDIs. Drivers clustered in Technological, Operational, and Business sophistication; effects concentrated in Economical, Human/Psychological, Knowledge & support, and Organisational areas. The most frequent links were Business sophistication → Economical, Business sophistication → Environmental, Business sophistication → Psychological, and Technological → Knowledge & support. Practically, this means that strategy launches and tech roll-outs immediately reverberate into costs/benefits, energy and waste footprints, employee well-being, and training needs.

Interpretation.

DT initiatives start in Technology/Management but their strongest impacts land in People/Management, confirming that success hinges on governance, capability building, and ergonomics of change, not only on tooling. Leaders systematically overrate outcomes vs employees (gap up to 1.36 points), signalling communication/ownership gaps.

KPIs (pilot-level).

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

CDI coverage: ≥80% of the 24 areas represented in maps (met).

Decision support: actionable sequencing checklist derived from top CDIs (delivered).

Alignment metric: maturity/awareness gap dashboard (employees vs leaders) for both firms (delivered).

<u>Implications for NEPTUN.</u>

The CDI lens links Industry 4.0 tooling to Industry 5.0 principles, explaining why process-level interactions are the real levers. Recommended: pair every tech deployment with a co-owned governance action, an upskilling package, and an impact check on human and environmental dimensions—measured not only by outputs but by interaction flows.

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them".

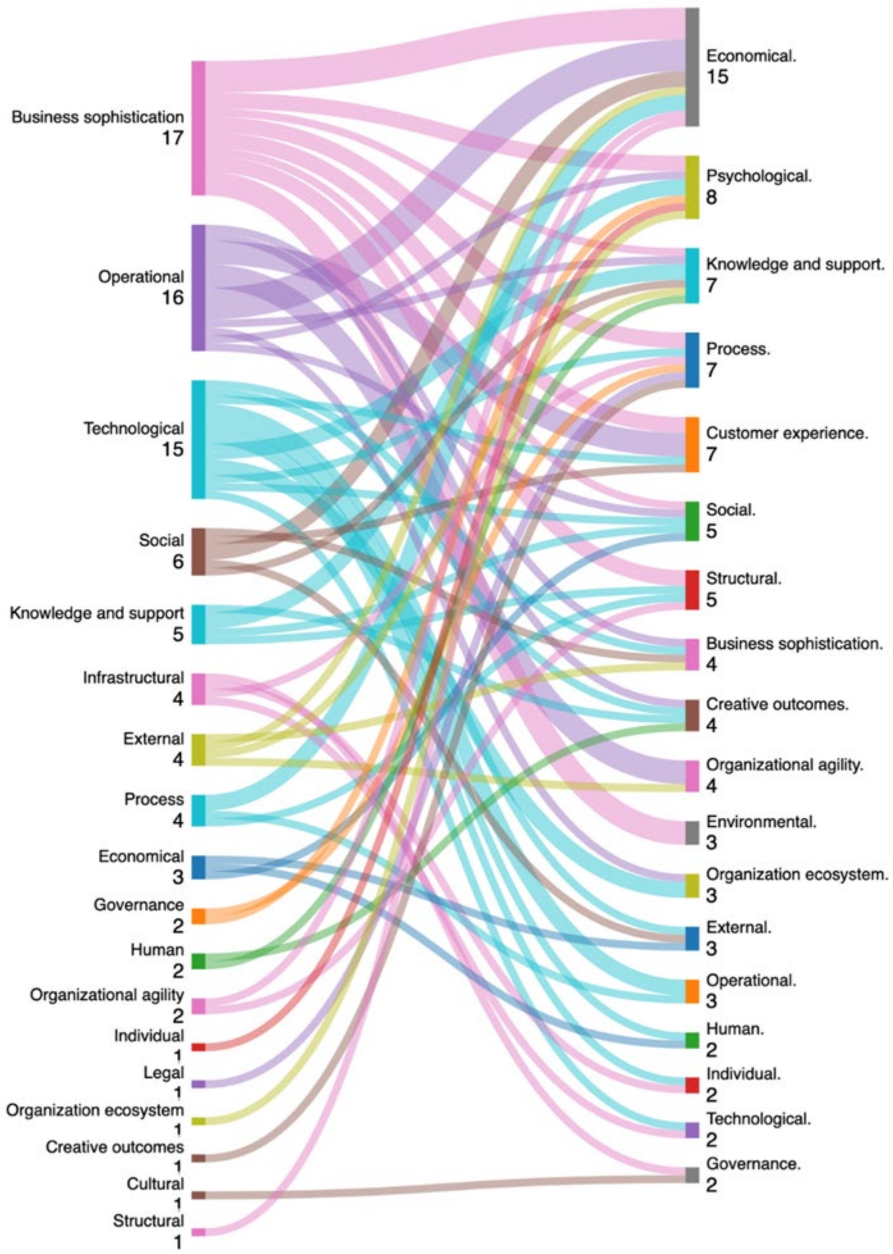


Figure 4. All identified cross-domain interactions

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by
the European Union

“Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them”.

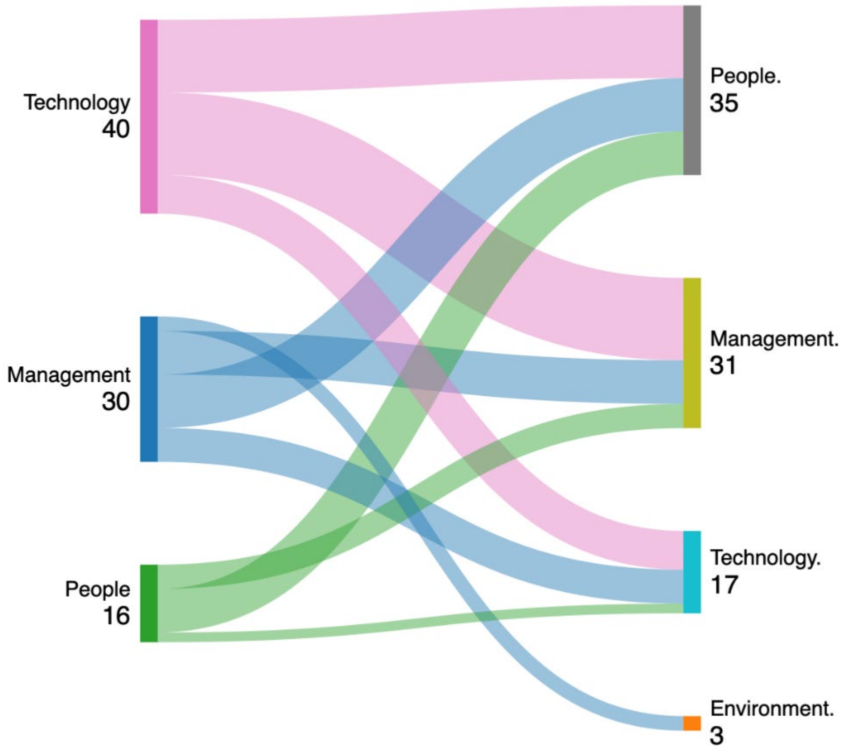


Figure 5. Flow of interactions between fields

3. Conclusions

The three pilots executed under WP3 demonstrate a coherent lab-to-factory pathway fully aligned with NEPTUN's objectives: build capacity with partners, validate methods on realistic use cases, and extract actionable, transferable practices for industry.

1. **AM lattices (with TUB)**

   We showed that imperfection-aware design choices especially controlled nodal rounding produce measurable gains in stiffness and strength of LPBF Ti-6Al-4V lattices. Image-based/physics-based models track test trends and locate failure hot-spots with engineering accuracy, creating a rational basis for

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03
Funded by the European Union

tolerance budgeting, post-processing selection, and fatigue-oriented follow-up. The pilot matured our capability to couple µCT, FE and test rigs, and sets up direct collaboration with TUB on finishing strategies that reduce notch severity before assembly.

2. **Human–Robot Collaboration (with NTUA, supported by KTH)**

   We designed and validated a safe, repeatable HRC cell for hinge disassembly, combining robust perception (YOLO-seg/OBB), controller-resident motion with ROS2 data exchange, and force-assisted cooperation. The result is a transferable HRC pattern for fine disassembly tasks: improved throughput on nominal parts, lower ergonomic load, and zero safety incidents in trials. The architecture is compatible with KTH's symbiotic HRC/digital-twin framing, enabling gradual scaling (richer event detection, higher-class cobot, private-cloud planning).

3. **Digital Transformation mapping (with KTH).**

   A cross-domain interaction (CDI) framework made transformation dynamics visible: tech/management decisions reverberate first into people, knowledge, and organisation, not just cost or OEE. The pilot delivered case playbooks, sequencing checklists, and gap dashboards (leaders vs employees), giving SMEs a pragmatic route to Industry 5.0-consistent change small, interoperable steps with measurable effects.

Cross-pilot takeaways

- Data + models beat heuristics. Whether in lattices (µCT→FE) or HRC (vision→force logic), decisions improved when grounded in measured states.
- Integration over invention. The wins came from linking existing assets—scanners, controllers, ROS2, DEM/FE, XR—into lean pipelines, not from monolithic rebuilds.
- People are the multiplier. Training, ergonomics, and governance determine whether technical gains persist; the CDI lens should accompany every deployment.

KPIs and impact

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03
Funded by the European Union

All pilots produced the intended methods, datasets, and demonstrators, with KPIs either achieved or on track (model/test correlation; HRC safety and detection accuracy; CDI coverage and decision support). Collectively, they raise TRL for targeted capabilities (AM design-for-performance, HRC disassembly, SME digitalisation) and furnish reusable templates for partners and regional firms.

Risks and mitigation

Known constraints (μCT resolution vs size, cobot force limits, data-access in SMEs) are addressed by ROI scans & sub-modelling**,** assisted modes or higher-class robots, and anonymised data contracts with minimal, interoperable tooling.

Next steps

- Pilot-1: incorporate μCT-derived geometries and extend to fatigue; benchmark effect of light post-processing on life.
- Pilot-2: add automatic human-event detection, complete ergonomics/time studies on larger part sets; package a reference HRC cell (BOM, code, safety dossier).
- Pilot-3: publish the CDI method & case results, scale to additional SMEs, and embed the checklists in partner training.

NEPTUN's WP3 thus delivers both scientific advances and deployable know-how**,** validating the consortium model: targeted pilots with TUB, NTUA and KTH convert research into repeatable, industry-ready practices that support greener, safer and more resilient manufacturing.

Project: 101079398 — NEPTUN — HORIZON-WIDERA-2021-ACCESS-03

Funded by the European Union