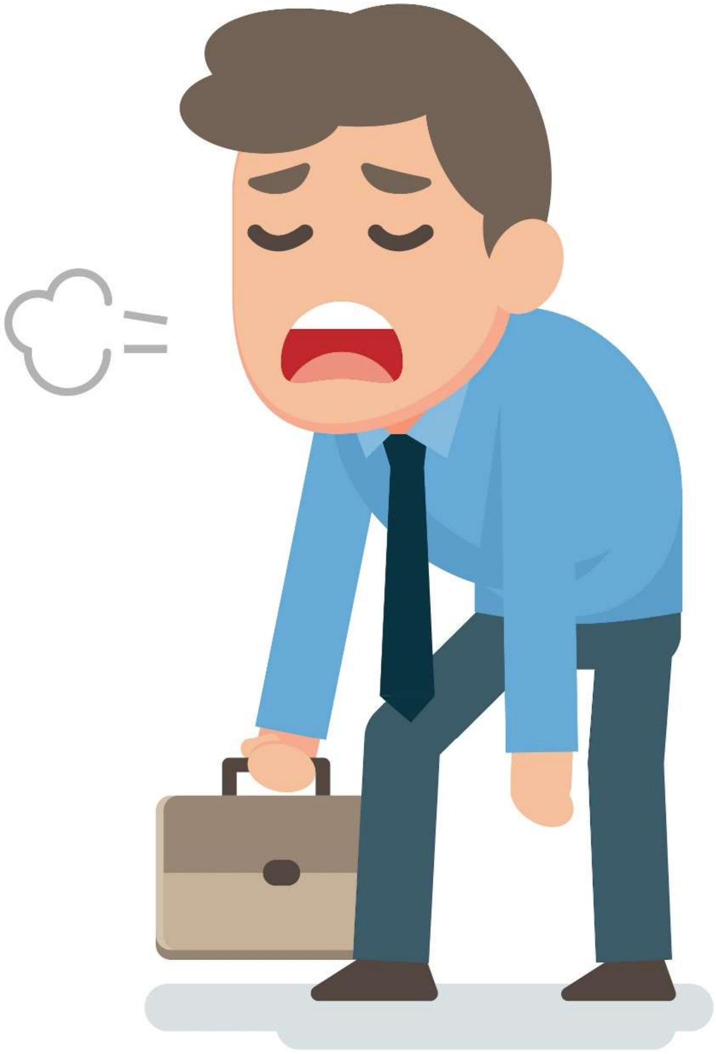


Image source: Medicommi (n.d.)

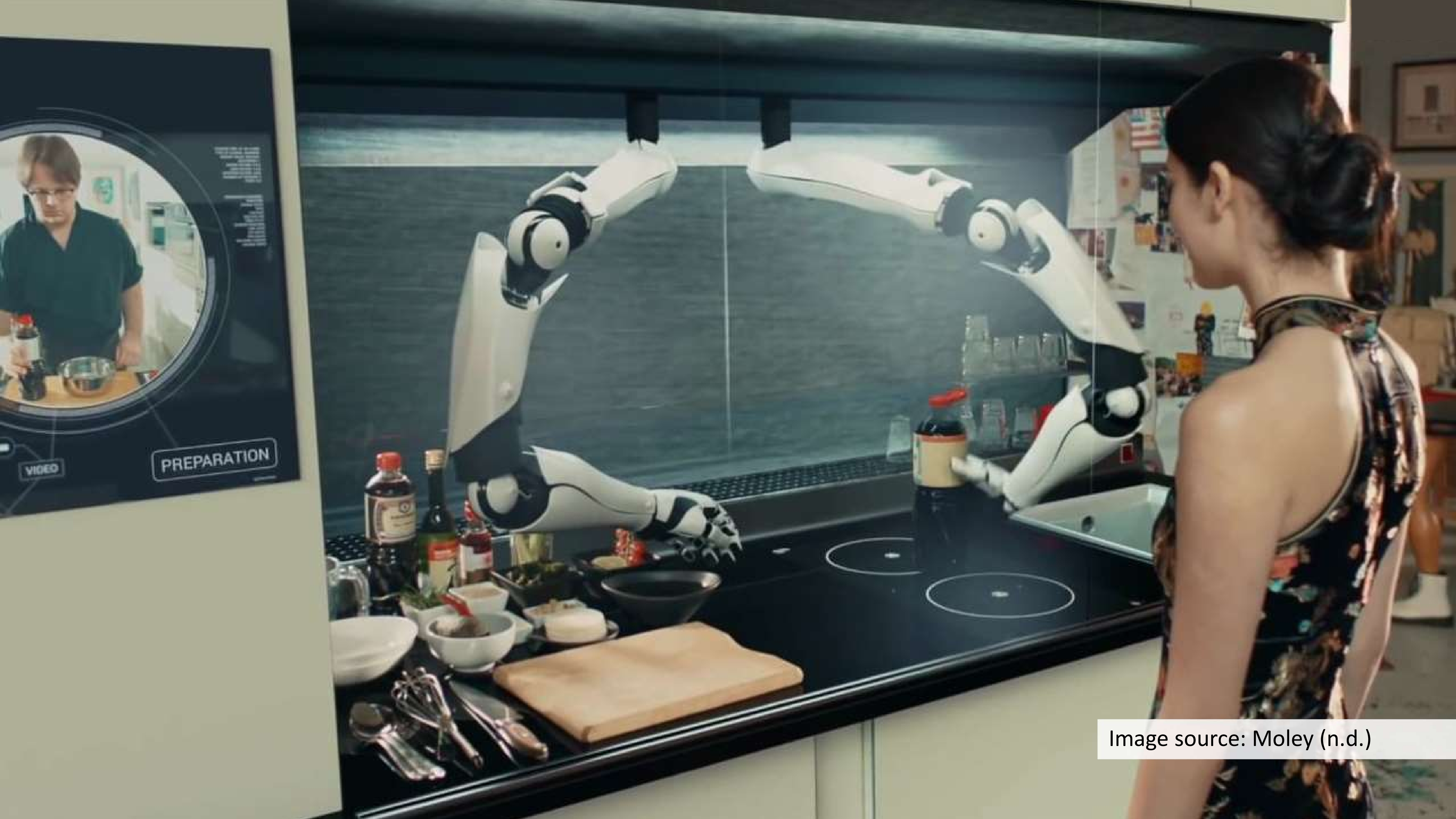


Image source: Moley (n.d.)

Robotic assembly of interlocking CNC-cut sheets into a wall component

Jeroen de Bruijn - 28 June 2019

Robotic assembly of interlocking CNC-cut sheets into a wall component

Jeroen de Bruijn - 28 June 2019

Pressure on Dutch construction industry

- 48.000 labourers shortage

Pressure on Dutch construction industry

- 48.000 labourers shortage
- 1.000.000 new homes (comparable to “wederopbouw”)

Solution? Construction robots!

SAM100

3.000 bricks per day

Image source: Construction Robotics (n.d.)

Solution? Construction robots!

SAM100

3.000 bricks per day

Human

500 bricks per day

Image source: Construction Robotics (n.d.)

Solution? Construction robots!

HRP-5P

Image source: AIST (2018)

Video source: AIST (2018)

Solution? TheNewMakers!

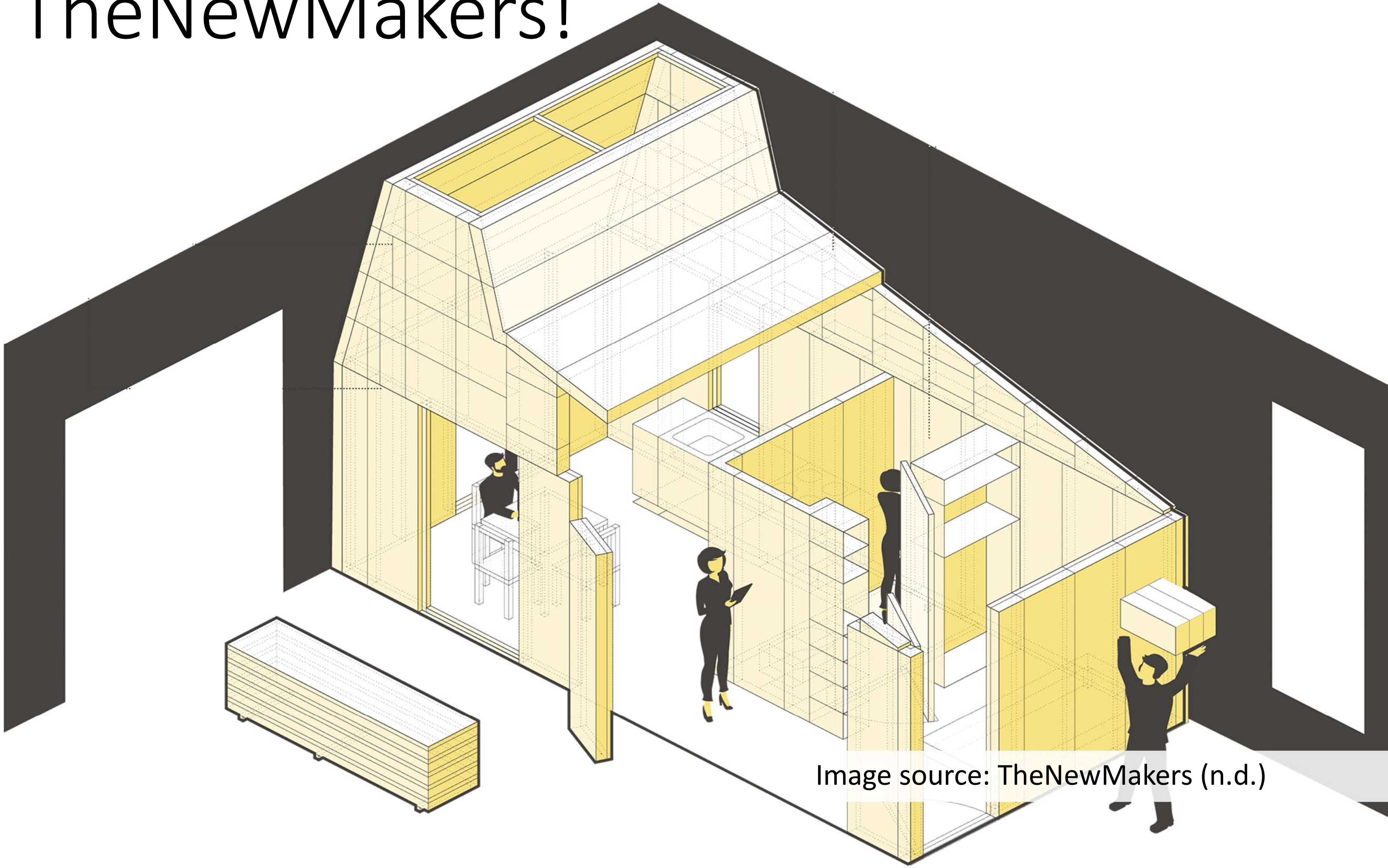


Image source: TheNewMakers (n.d.)

TheNewMakers: Components

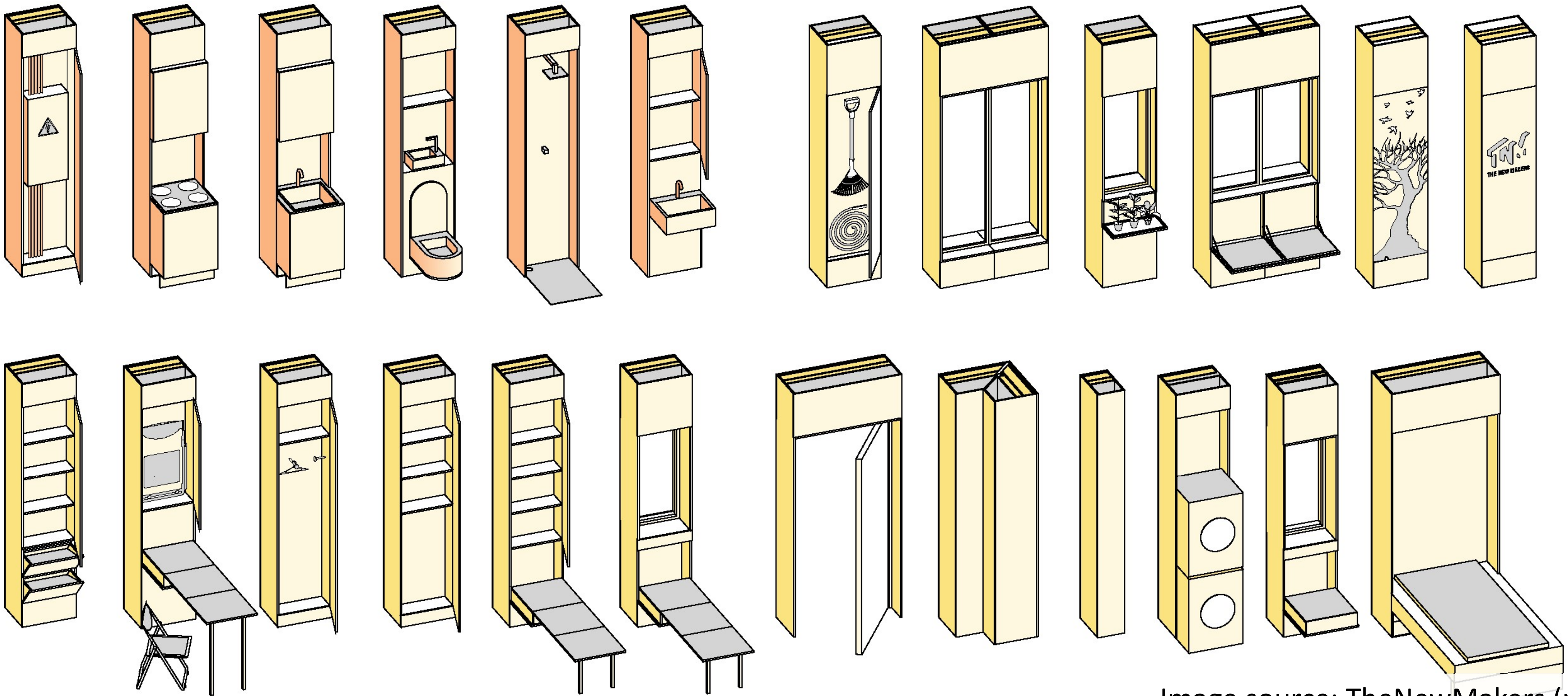
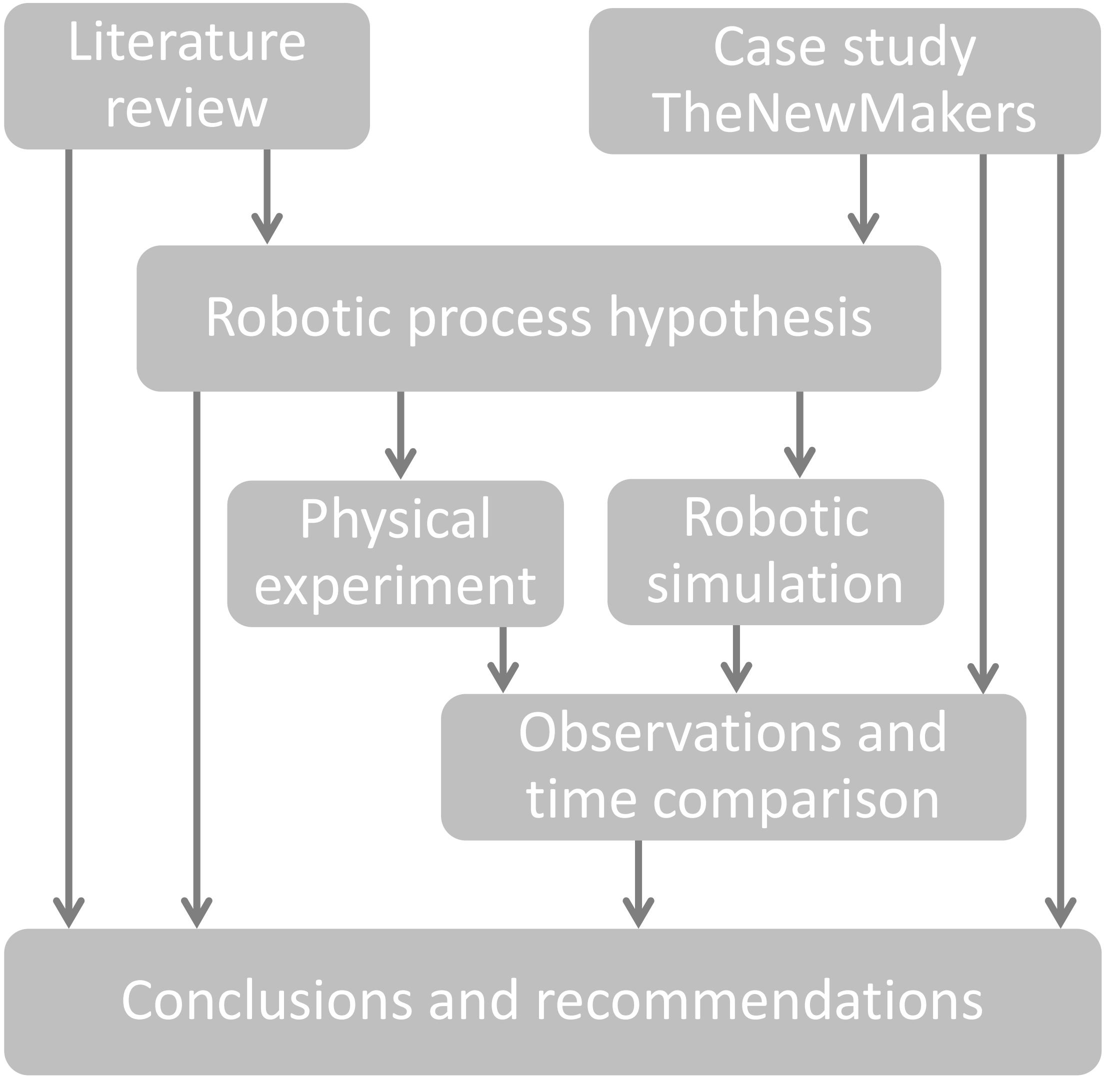


Image source: TheNewMakers (n.d.)

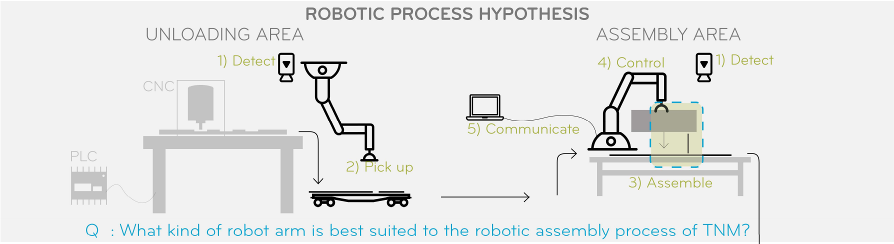
Research framework

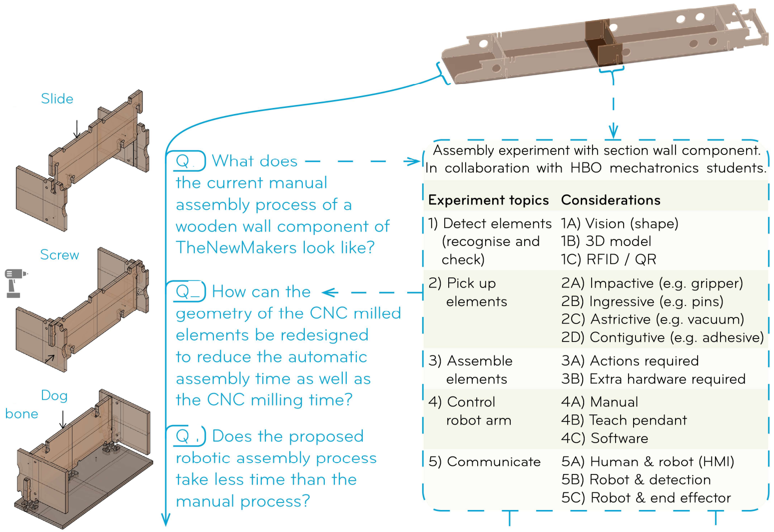
Research design: Conceptual



Research design: Detail

Main research Q: How could the elements of a wall component of TheNewMakers be redesigned for automatic assembly while taking less time to assemble than the manual process?





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Q Does the proposed robotic assembly process take less time than the manual process?

Assembly experiment with section wall component.
In collaboration with HBO mechatronics students.

Experiment topics	Considerations
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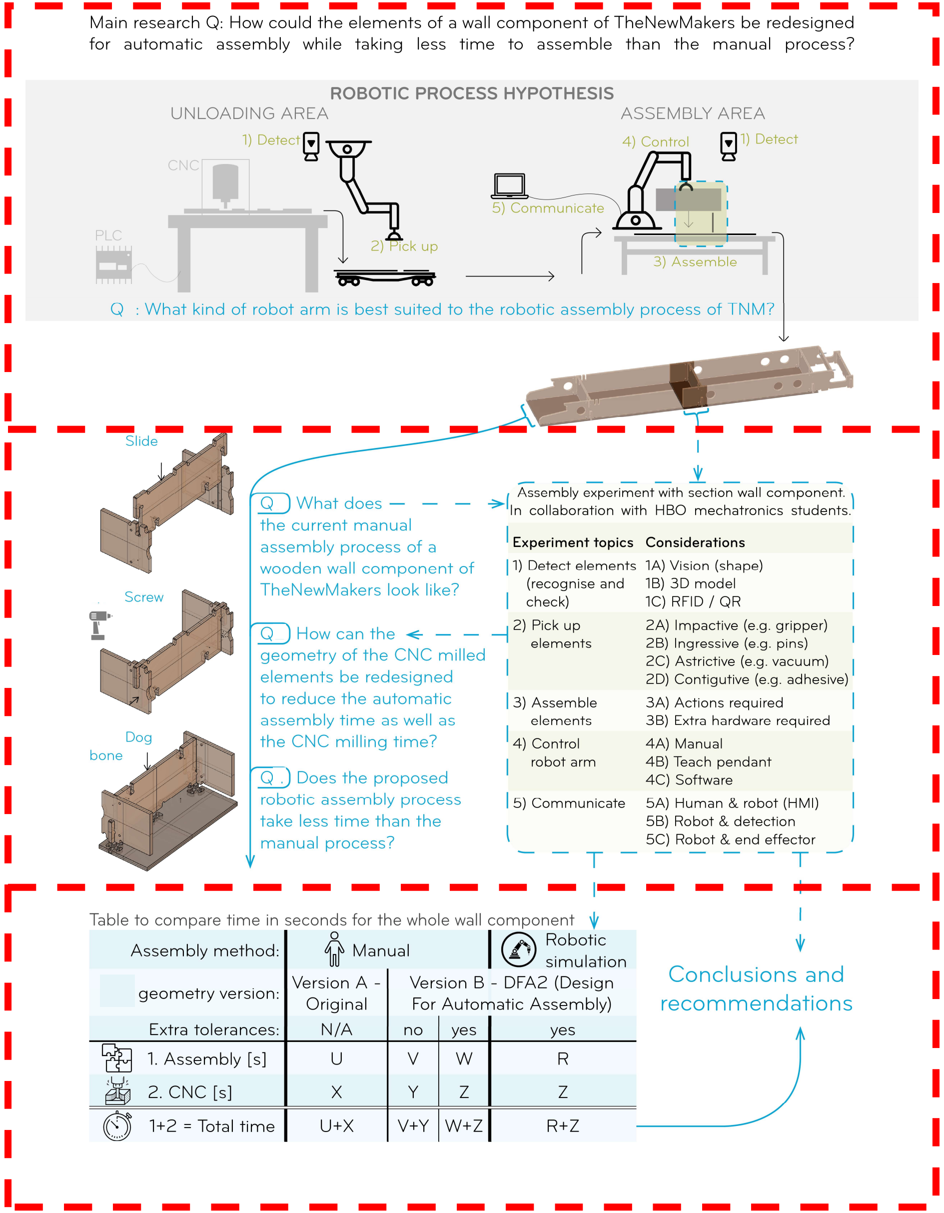
Table to compare time in seconds for the whole wall component

Assembly method:	Manual			Robotic simulation
geometry version:	Version A - Original	Version B - DFA2 (Design For Automatic Assembly)		
Extra tolerances:	N/A	no	yes	yes
1. Assembly [s]	U	V	W	R
2. CNC [s]	X	Y	Z	Z
1+2 = Total time	U+X	V+Y	W+Z	R+Z

Conclusions and recommendations

Research design: Detail



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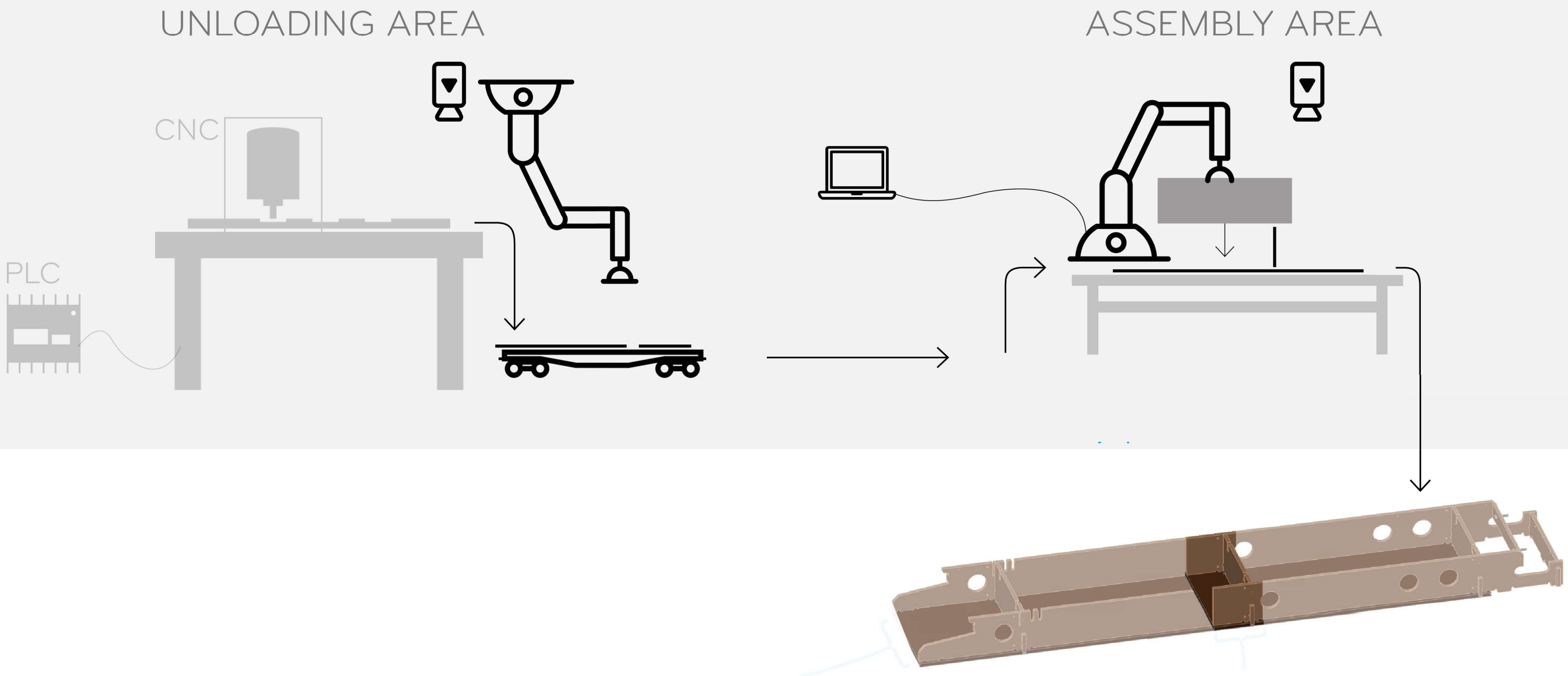
ROBOTIC PROCESS HYPOTHESIS



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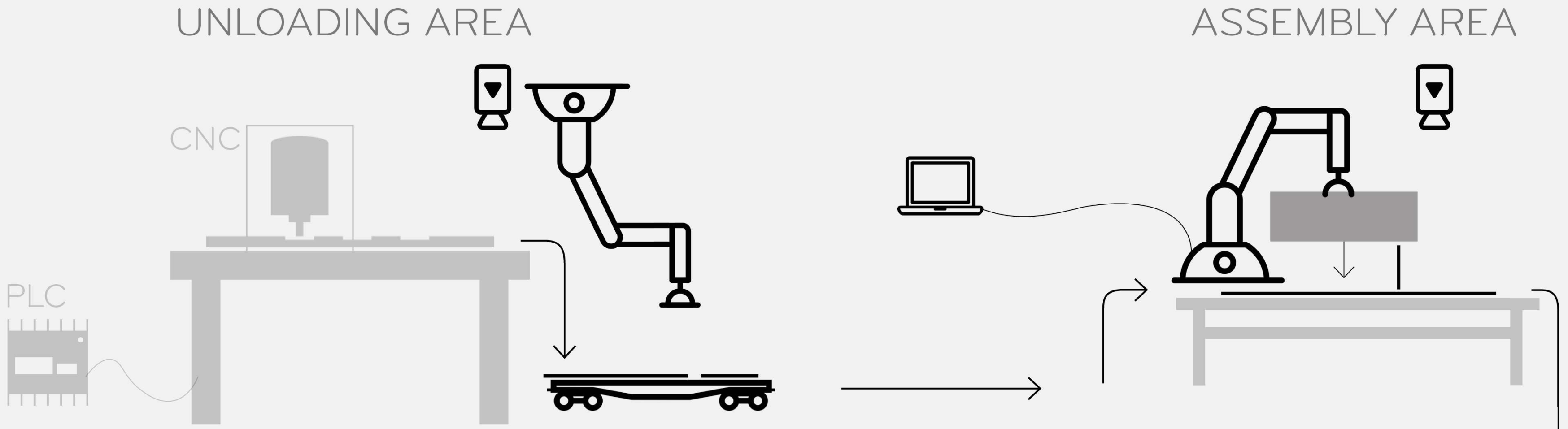
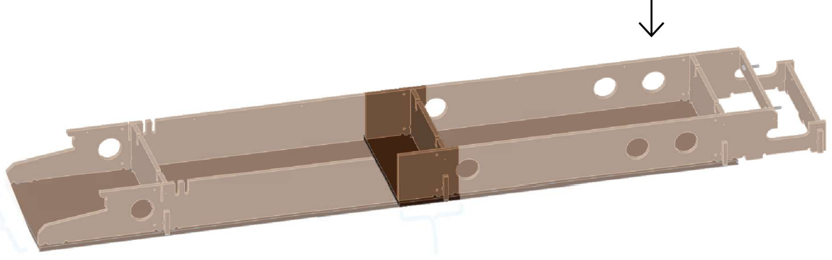


Q : What kind of robot arm is best suited to the robotic assembly process of TNM?



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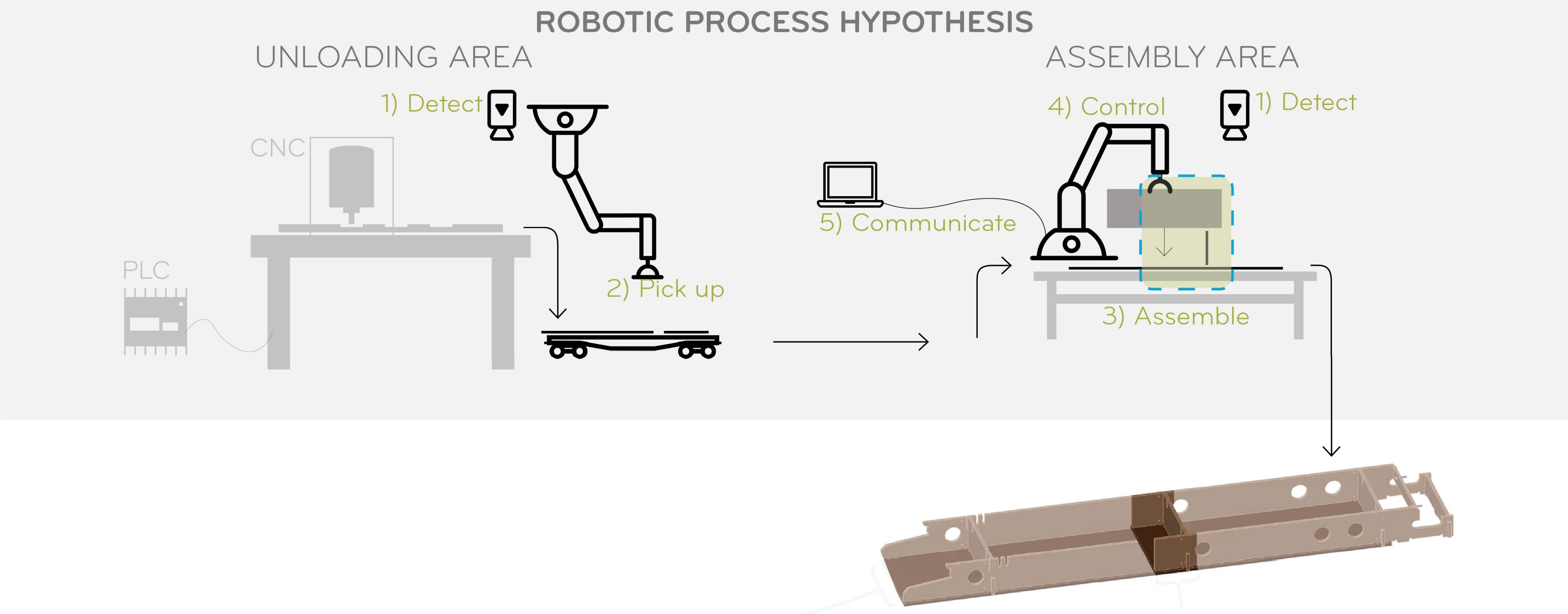

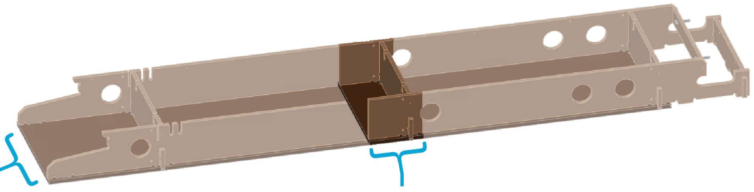

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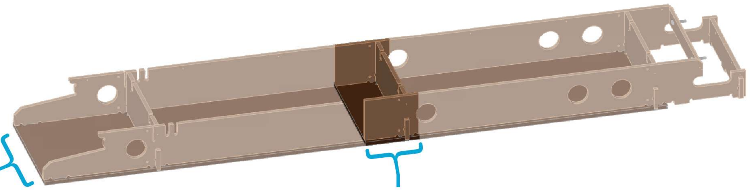
Q4 Does the proposed robotic assembly process take less time than the manual process?

Section experiment:
HBO students, small UR5 robot

Experiment topics

1) Detect elements
2) Pick up elements
3) Assemble elements
4) Control robot arm
5) Communicate



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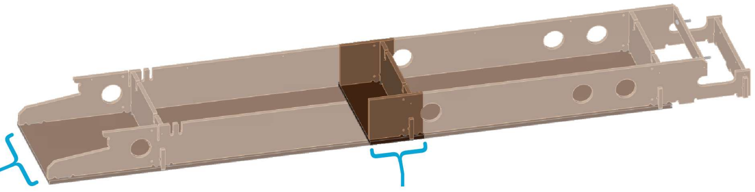
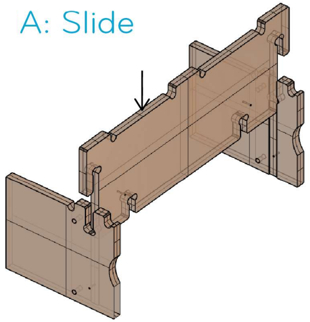
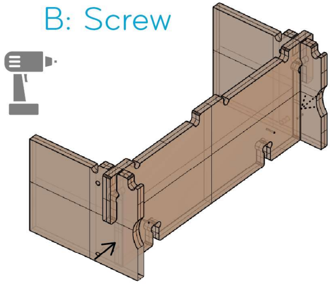


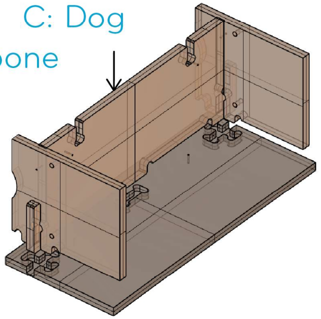
A: Slide



B: Screw



C: Dog bone



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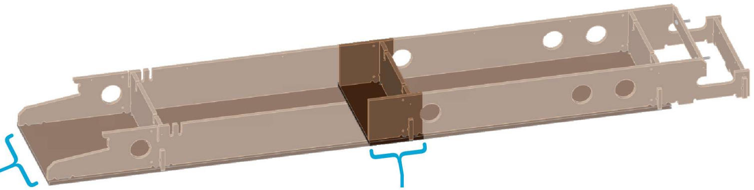

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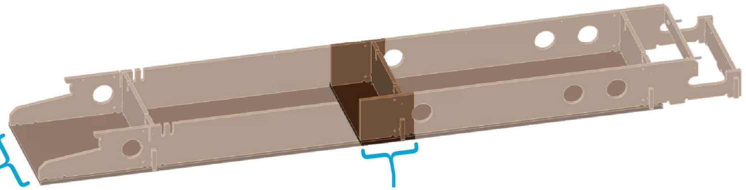

Q1A: Slide

Q1B: Screw

Q1C: Dog bone

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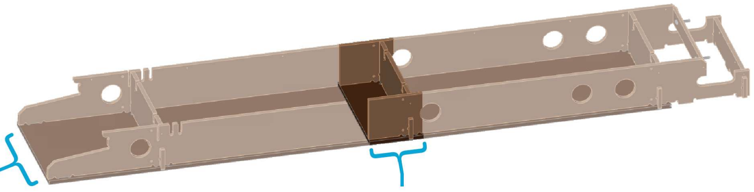
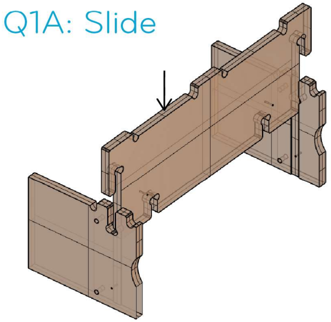
Extra gap tolerances:	N/A	no	yes	yes
1. Assembly [s]				
2. CNC [s]				
1+2 = Total time				

Conclusions and recommendations

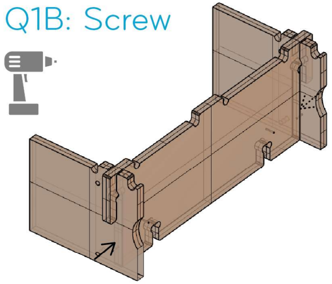
Research results



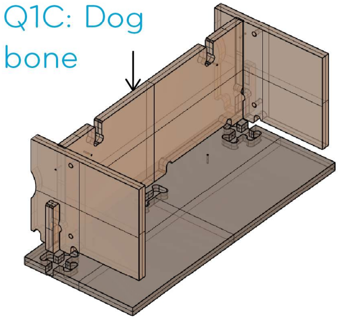
Q1A: Slide



Q1B: Screw



Q1C: Dog bone



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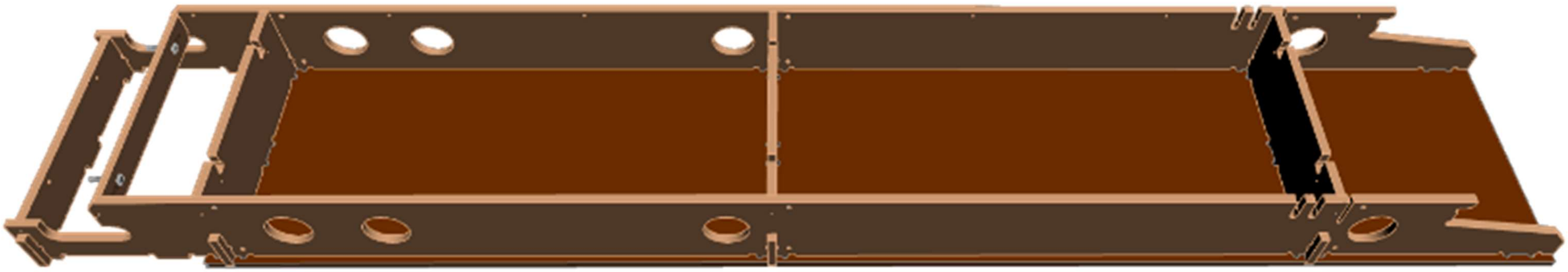
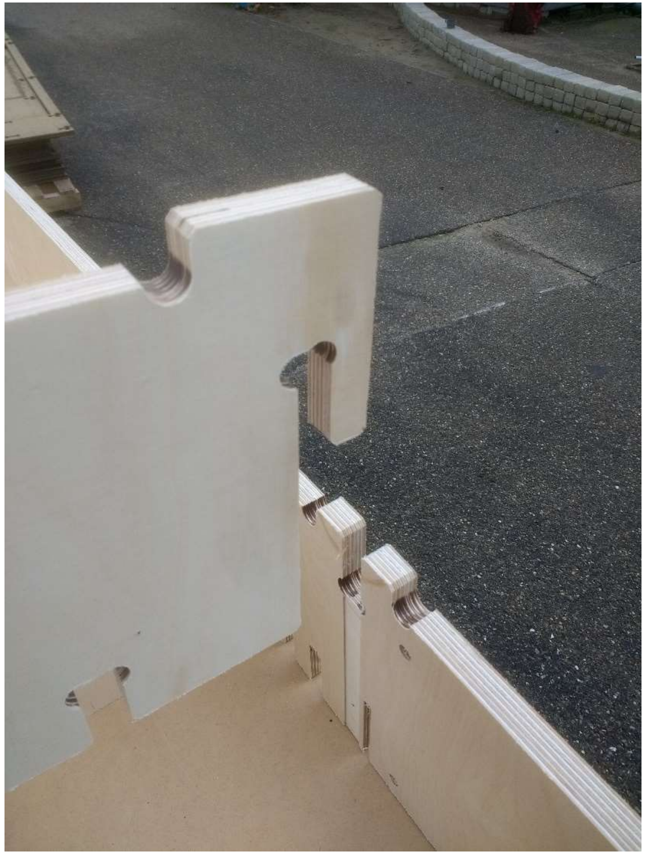
Case study: Exterior wall component

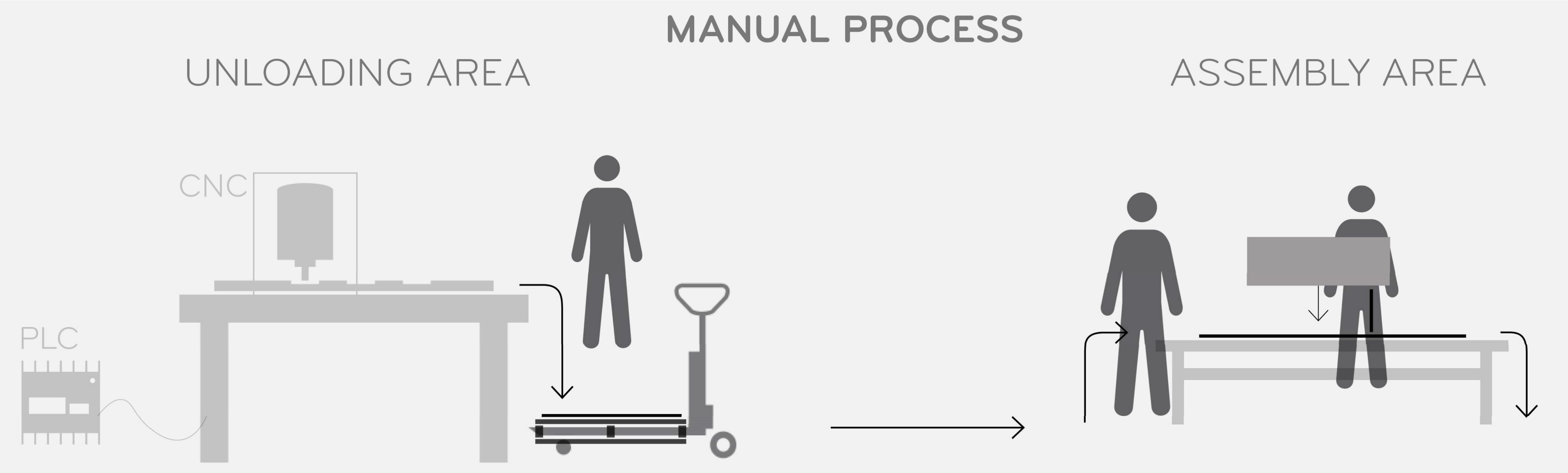


Case study: On-site

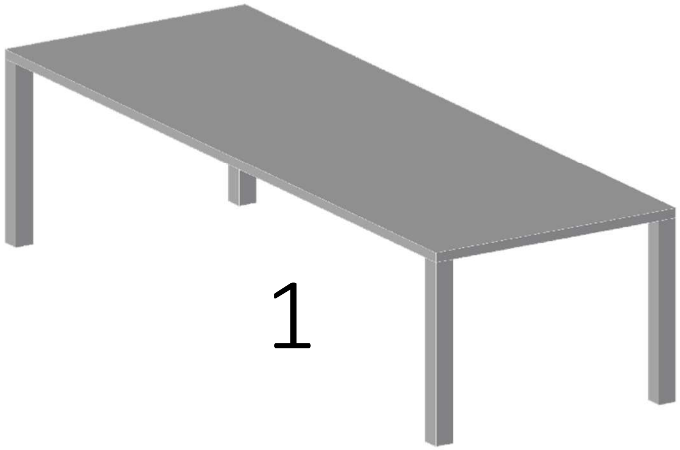
Case study: On-site

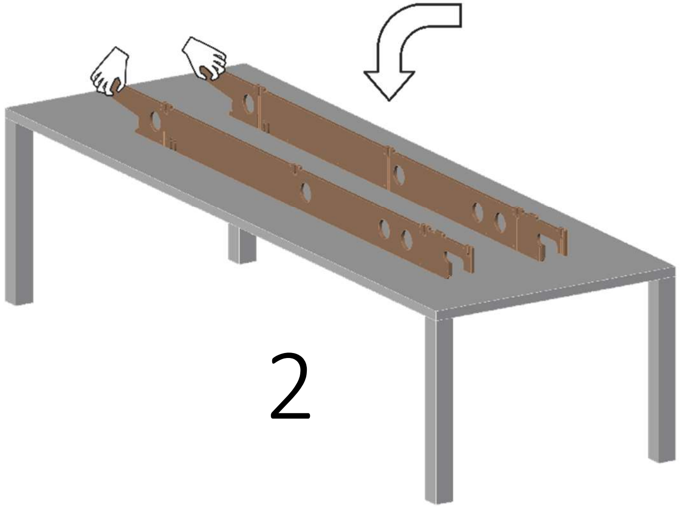


Manual process



Manual assembly





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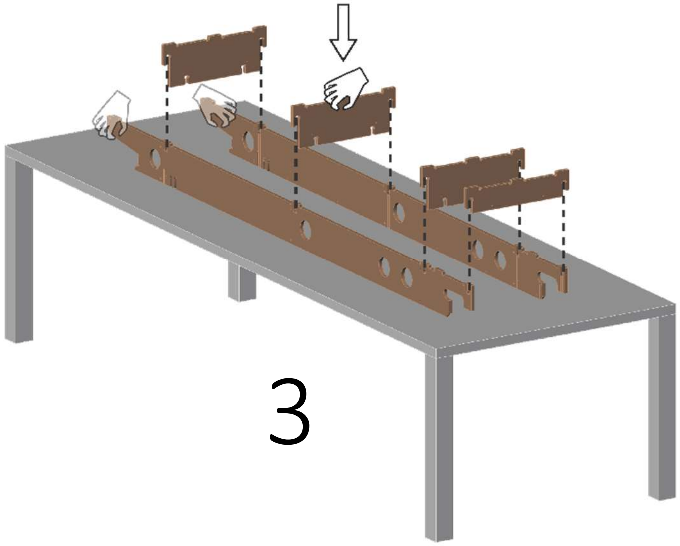

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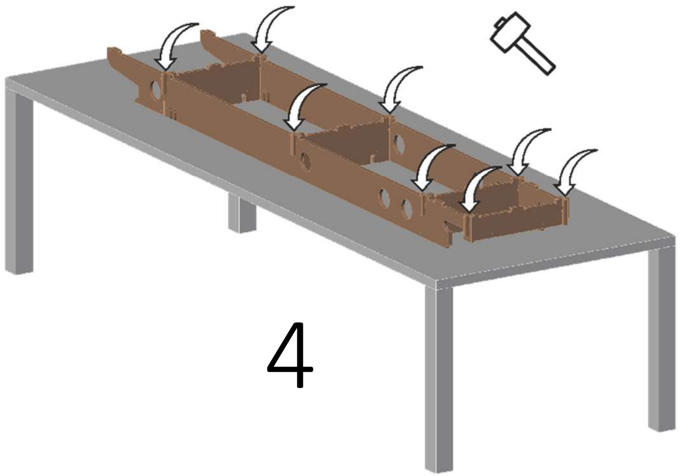

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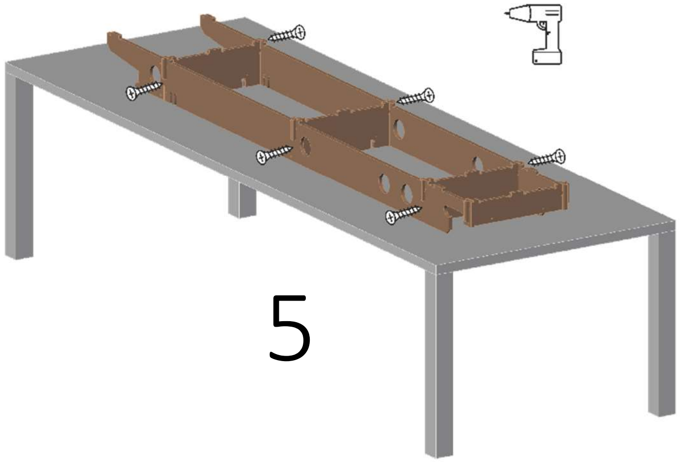
Manual assembly



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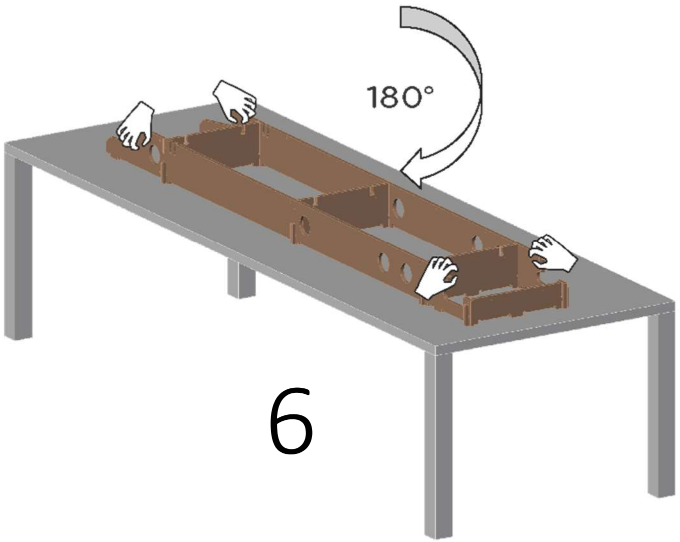

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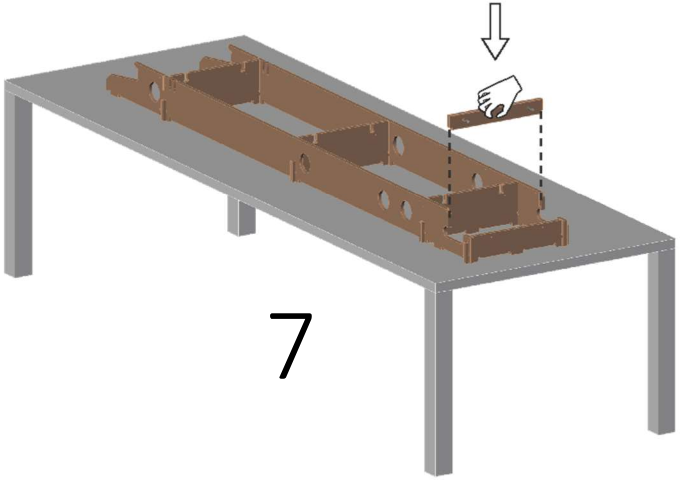
Manual assembly



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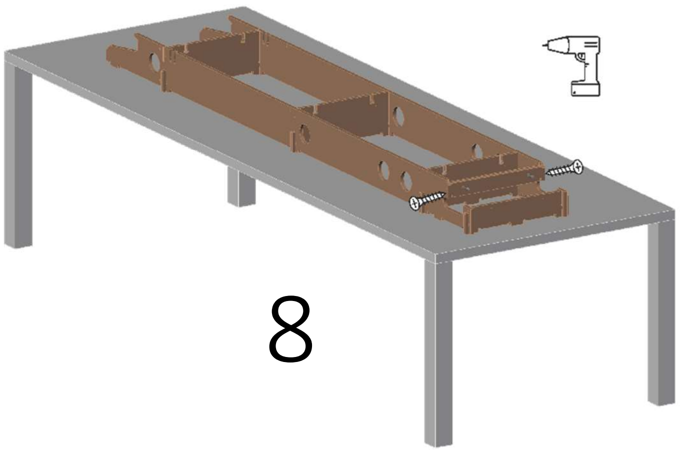

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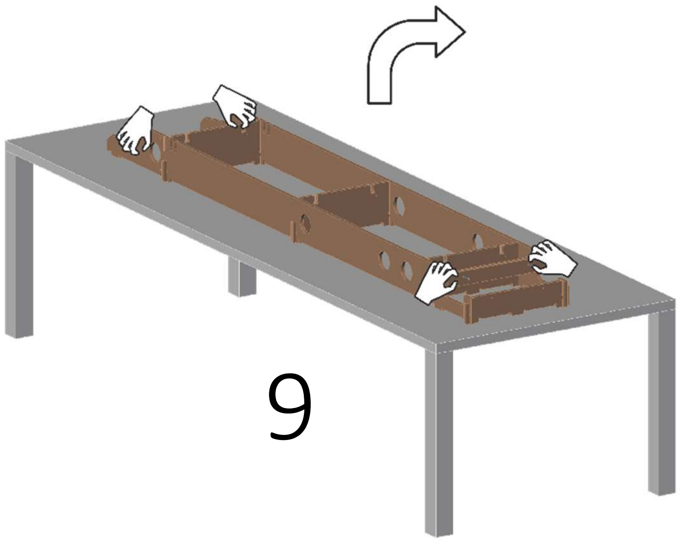
Manual assembly



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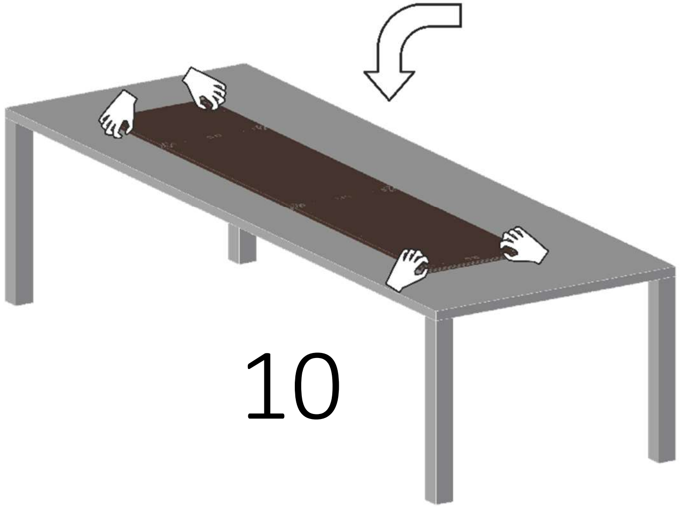

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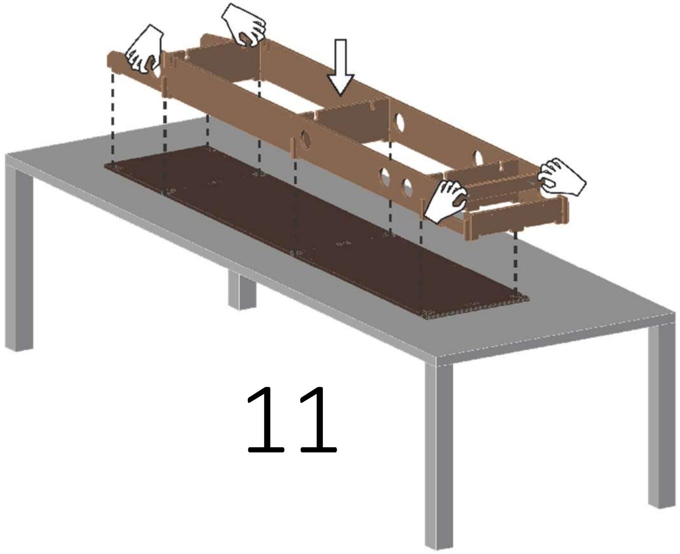

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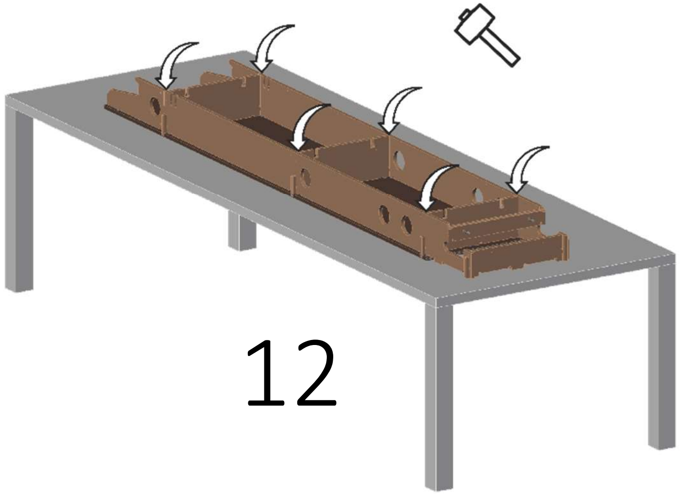
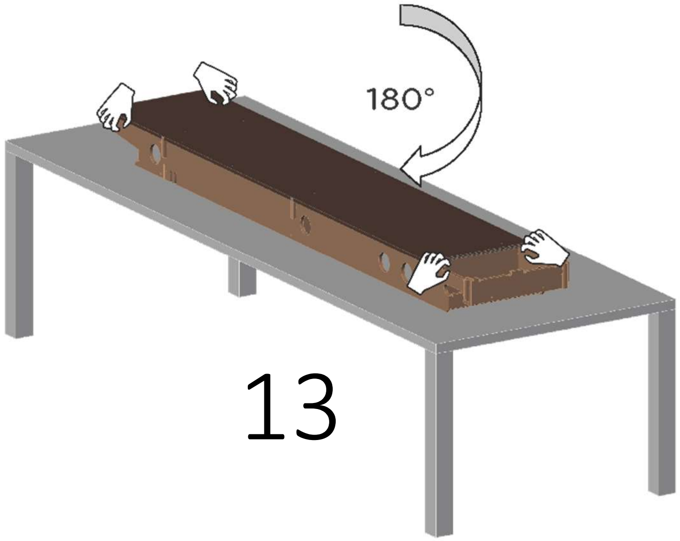


12

Manual assembly



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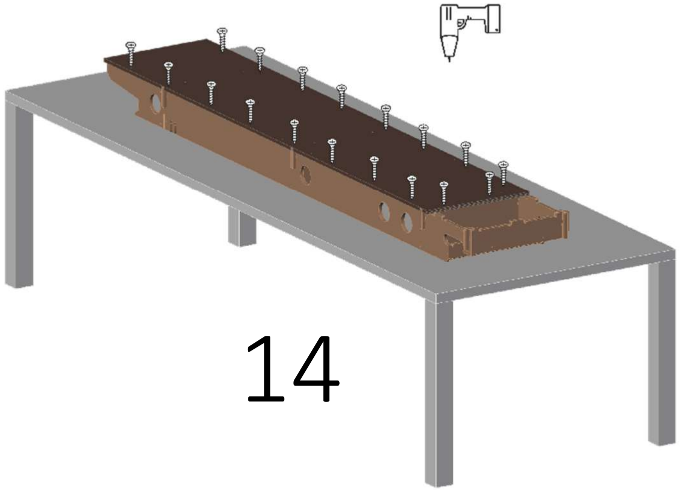

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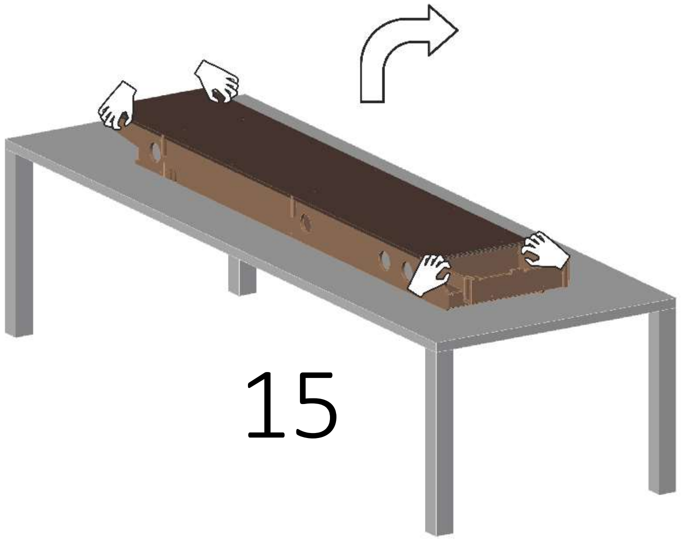
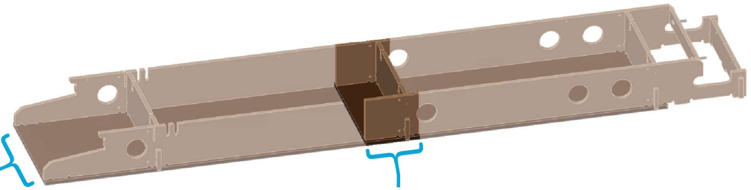
Manual assembly





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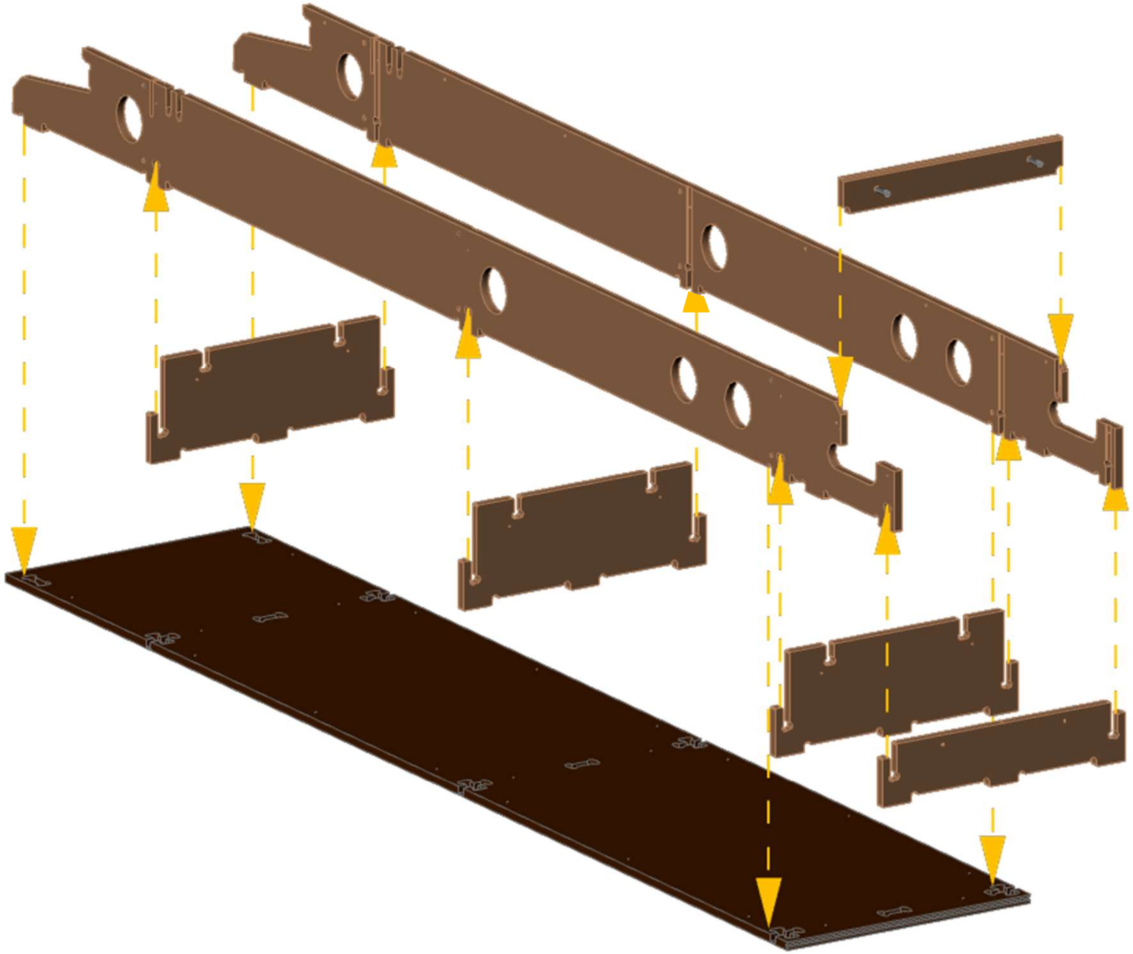
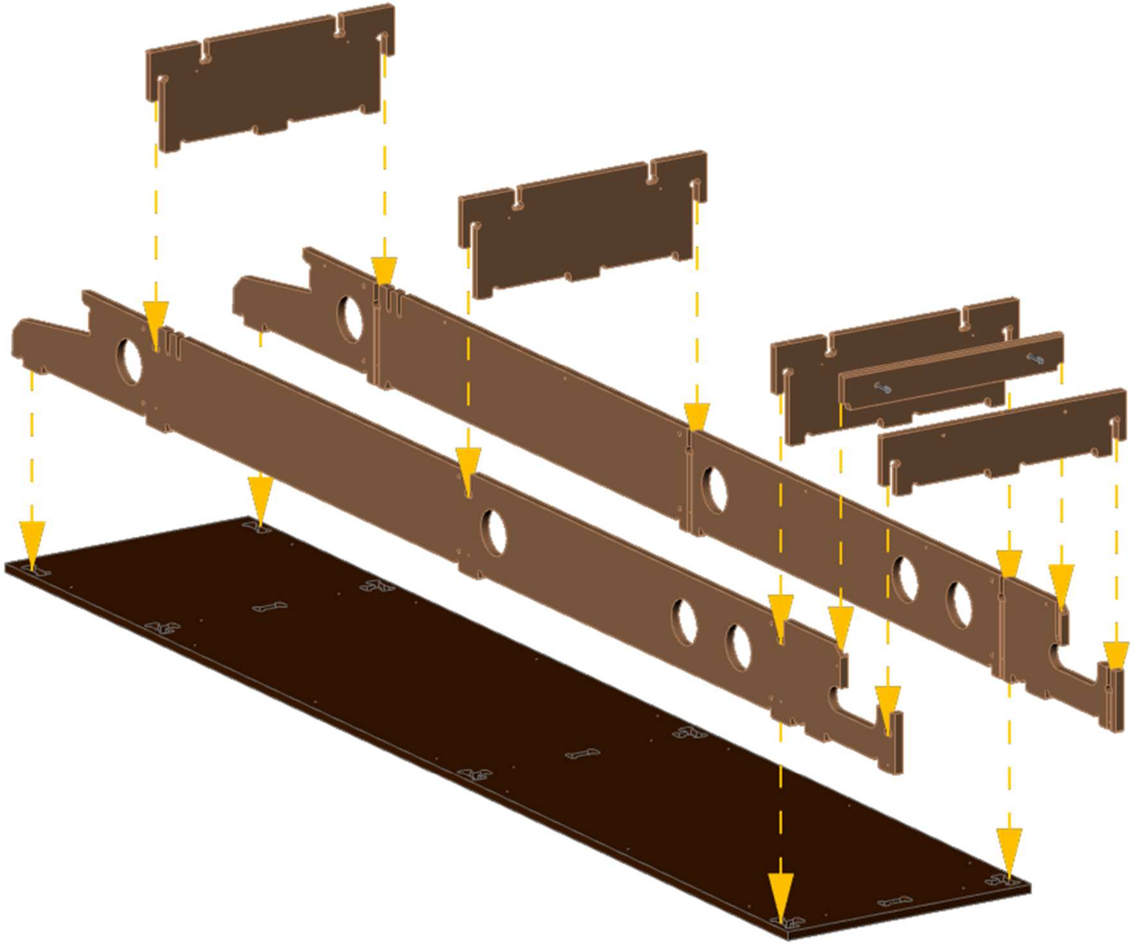
Geometry version A - Original



Geometry version B - DFA2



DFA2 Method

DFA2 = Design For Automatic Assembly

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DFA2 main goal:

Design a component "*that is as simple (non-complex) as possible, which, in turn, means that the simplest possible assembly process can be used*" (Eskilander, 2001, p. 154)

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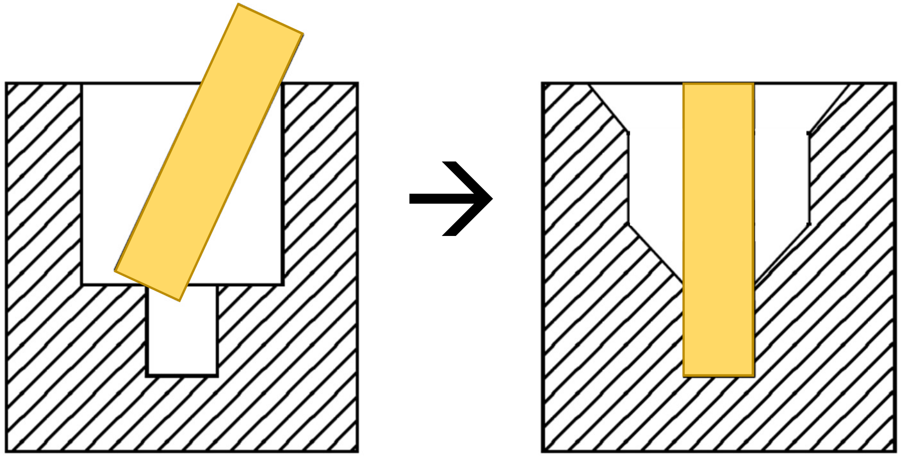
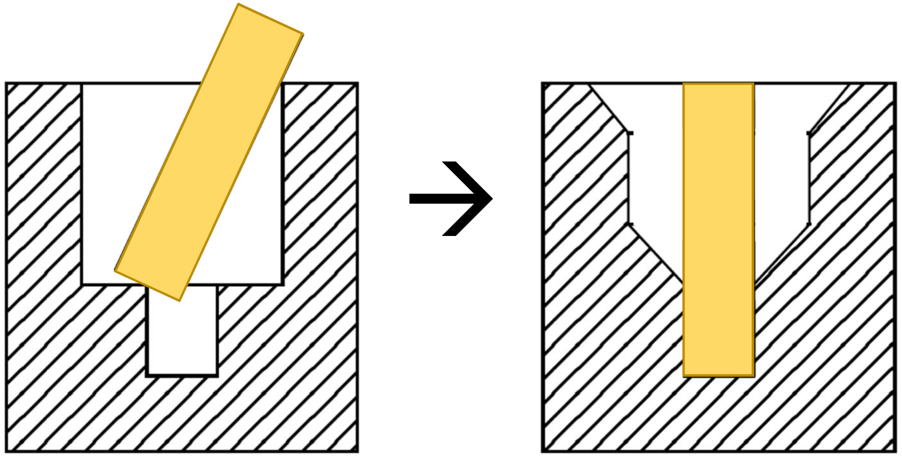
DFA2 (re)design guidelines

DFA2 Redesign guideline: Insertion



Source: Eskilander (2001)

DFA2 Redesign guideline: Insertion



Chamfer?	Points
Yes	9
No, but guiding surfaces	3
No and no guiding surfaces	1

Source: Eskilander (2001)

DFA2

Component level

- Reduce number of elements
- Unique elements
- Base object
- Design base object
- Assembly directions
- Parallel operations
- Chain of tolerances
- Disassembly
- Packaging

Element level

- Need to assemble element?
- Level of defects
- Orientation
- Non-fragile elements
- Hooking
- Center of gravity
- Shape
- Weight
- Length
- Gripping
- Assembly motions
- Reachability
- Insertion
- Tolerances
- Hold assembled elements
- Fastening method
- Joining
- Check/adjust

DFA2

Component level

- Reduce number of elements
- Unique elements
- Base object
- Design base object
- Assembly directions
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- Chain of tolerances
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- Packaging

Element level

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DFA2

Component level

- Reduce number of elements
- Unique elements
- Base object
- Design base object
- Assembly directions
- Parallel operations
- Chain of tolerances
- Disassembly
- Packaging

+

Assembly score

Element level

- Need to assemble element?
- Level of defects
- Orientation
- Non-fragile elements
- Hooking
- Center of gravity
- Shape
- Weight
- Length
- Gripping
- Assembly motions
- Reachability
- Insertion
- Tolerances
- Hold assembled elements
- Fastening method
- Joining
- Check/adjust

+

Assembly score

DFA2: Assembly score

	Assembly score	
Geometry	**Component level**	**Element level**
Version A - Original	36,5%	48,4%
Version B - DFA2	55,6%	51,9%
Improvement of version B compared to version A	**1,5**	**1,1**

Simplest possible assembly process

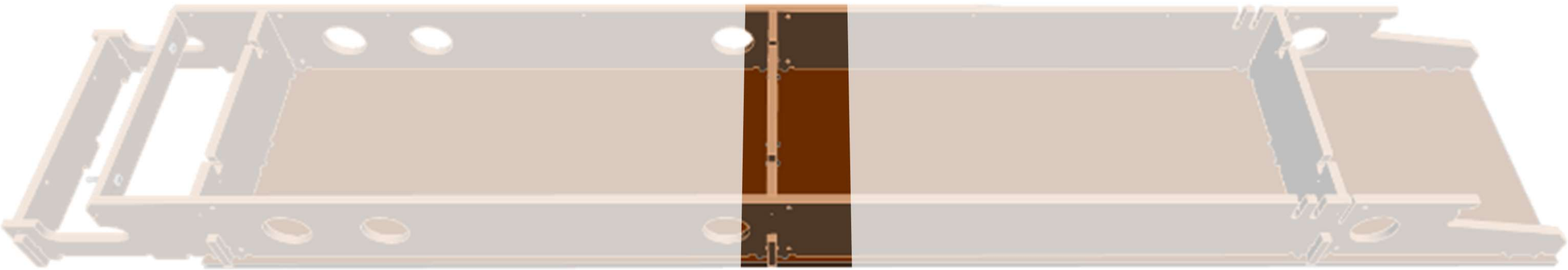
- No hammer

Simplest possible assembly process

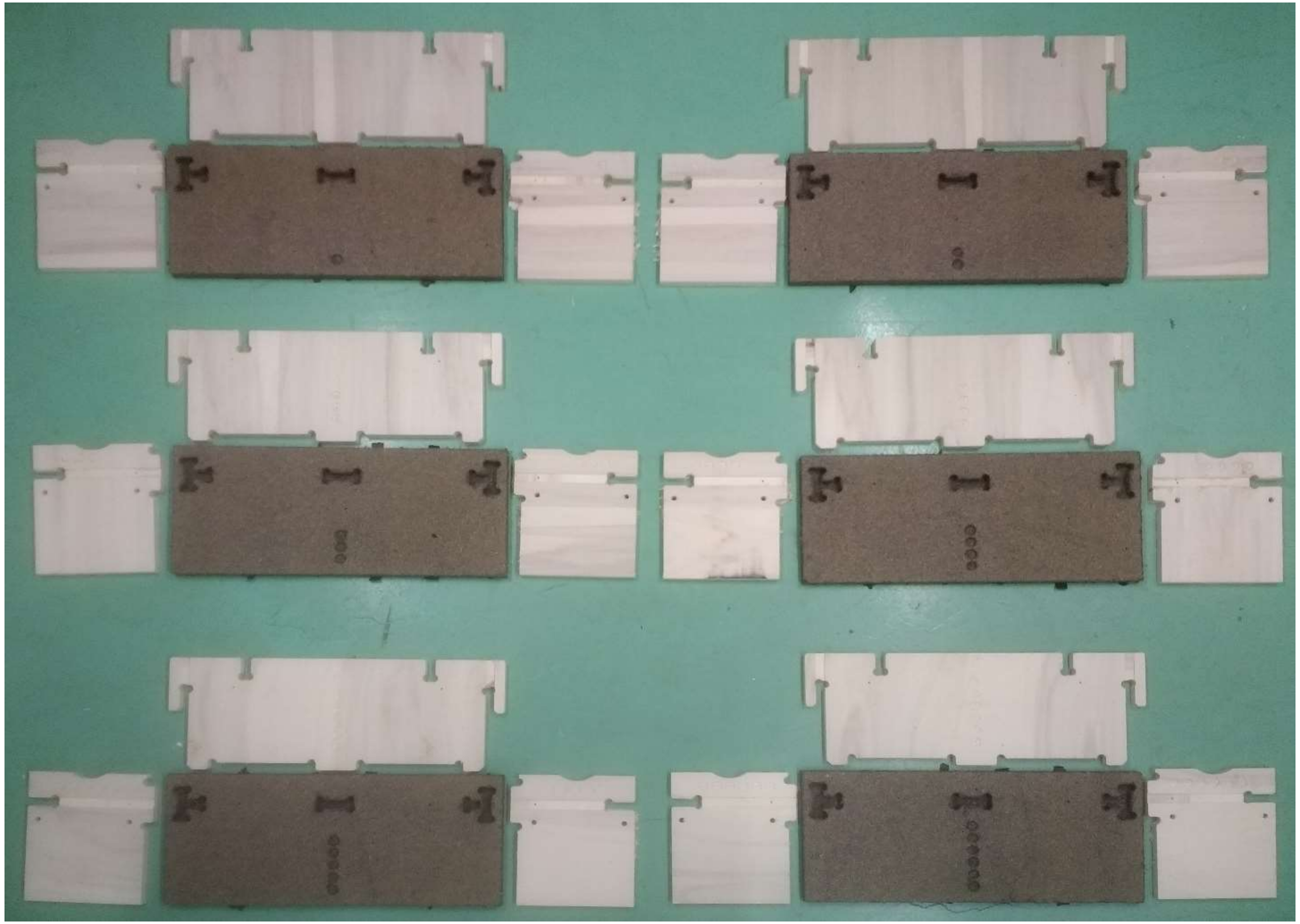
- No hammer → Extra gap tolerances

- Robotic experiment
  - Physically try and test
  - Geometry version B - DFA2

Robotic assembly experiment: Section



Robotic assembly experiment: Extra gap tolerances



Robotic assembly experiment: UR5 cobot

Payload [kg]	Reach [mm]	Mass [kg]
5	850	18,4

Image source: Universal Robots (n.d.)

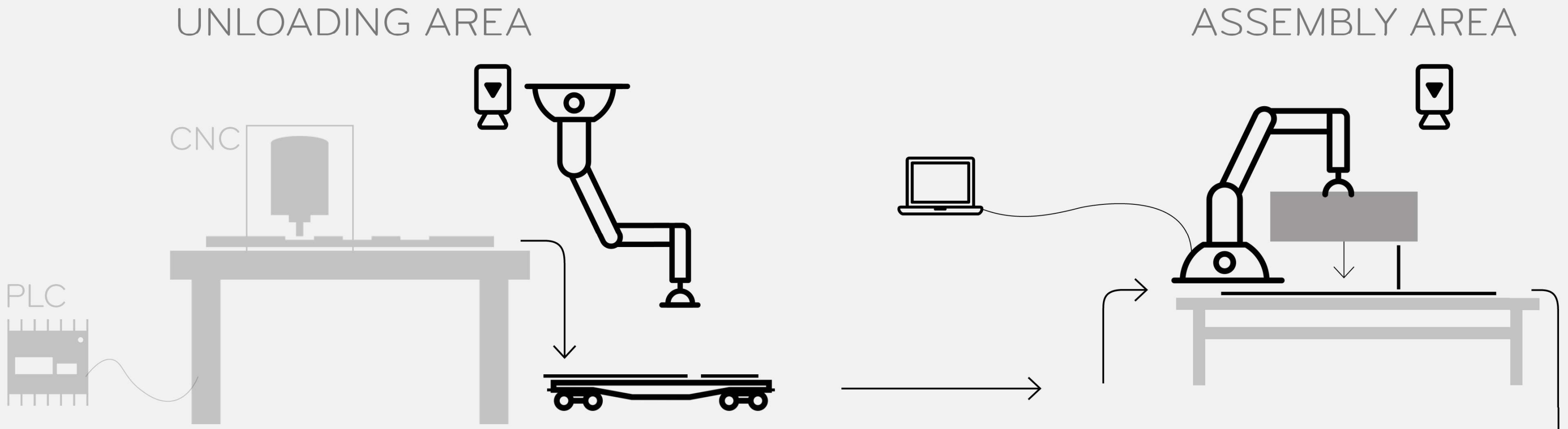
Video sources: TheNewMakers, HBO students (2019)

Geometry versions

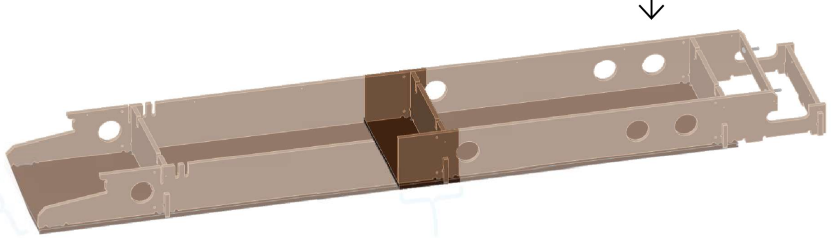
- Geometry version A - Original
- Geometry version B - DFA2 without extra gap tolerances
- Geometry version B - DFA2 with extra gap tolerances

Main research Q: How could the elements of a wall component of TheNewMakers be redesigned for automatic assembly while taking less time to assemble than the manual process?

ROBOTIC PROCESS HYPOTHESIS



Q3: What kind of robot arm is best suited to the robotic assembly process of TNM?

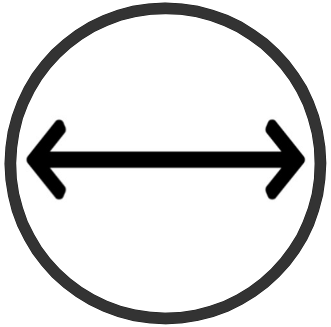


Robot arm choice

- Limitations
  - 1 robot arm
  - Fixed to the floor

Robot arm choice

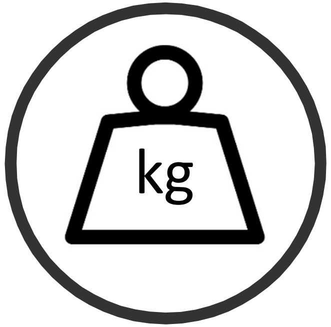
Payload [kg]



Reach [mm]

Velocity [m/s]

Repeatability [mm]



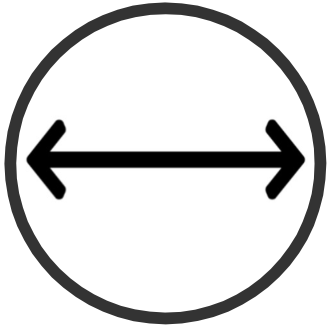
Mass [kg]

Estimated TCO (Total Cost of Ownership) [€]

Icons source: Noun Project (n.d.)

Robot arm choice: constraints

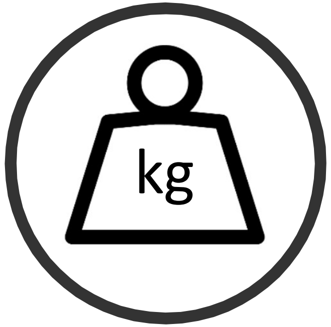
Payload [kg]
≥ 100 kg



Reach [mm]
≥ 2.500 mm

Velocity [m/s]

Repeatability [mm]



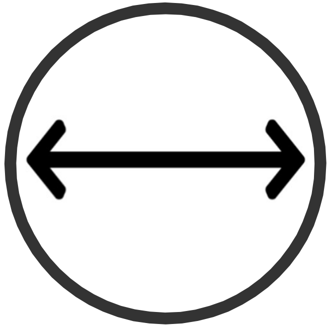
Mass [kg]

Estimated TCO (Total Cost of Ownership) [€]

Icons source: Noun Project (n.d.)

Robot arm choice: weighted priority (1=min, 5=max)

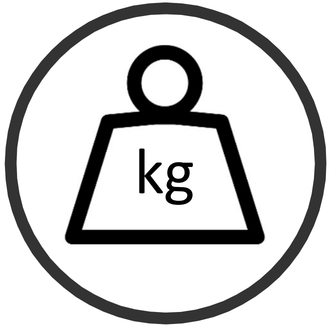
Payload [kg]
≥ 100 kg
5



Reach [mm]
≥ 2.500 mm
5

Velocity [m/s]
4

Repeatability [mm]
3



Mass [kg]
1

Estimated TCO (Total Cost of Ownership) [€]
1

Icons source: Noun Project (n.d.)

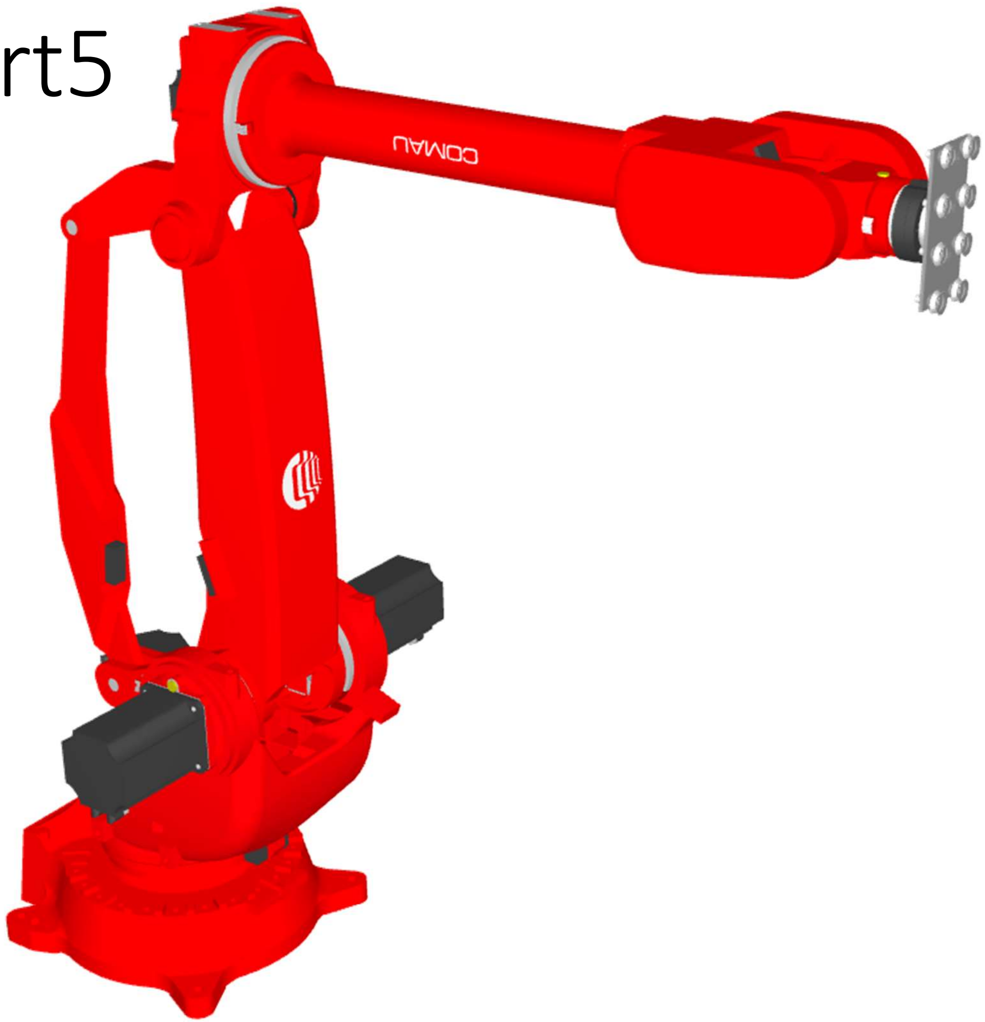
Robot arm choice: RoboDK library

Robot arm	Company	Payload [kg]	Reach [mm]	Repeatability ± [mm]	Velocity [°/s]	Mass [kg]	Base type [mm]	Base area [m2]
Smart5 NJ 110-3.0	Comau	110	2.980	0,07	110-230	1.070	Ø 700	0,385
KR 120 R2500 pro	KUKA	120	2.500	0,06	120-292	1.049	830x830	0,689
KR 120 R2700 HA	KUKA	120	2.696	0,05	101-292	1.104	830x830	0,689
IRB 6400 2.8 120	ABB	120	2.800	0,10	90-190	2.230	Ø 800	0,503
KR 150 L120/2	KUKA	120	2.810	0,20		1.140		
KR 120 R2900 extra	KUKA	120	2.896	0,06	115-292	1.084	830x830	0,689
Smart5 NJ 130-2.6	Comau	130	2.616	0,07	110-230	1.050	Ø 700	0,385
S-430iW	FANUC	135	2.643	0,30	105-210	1.300	610x771	0,470
KR 150 R2700 extra	KUKA	150	2.696	0,06	115-219	1.068	830x830	0,689
KR 150-2	KUKA	150	2.700	0,06	100-238	1.245	830x830	0,689
RX260	Stäubli	150	2.831	0,07	104-230	1.900	?	?

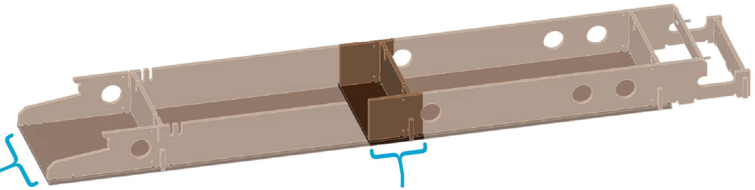
Robot arm choice: RoboDK library

	Criterion:	Maximum payload	Maximum reach	Maximum velocity	Repeatability	Mass	TCO	TOTAL weighted score
	Weighted priority:	5	5	4	3	1	1	
Robot arm	Company							
Smart5 NJ 110-3.0	**Comau**	**3**	**3**	**2**	**3**	**2**	**3**	52
KR 120 R2500 pro	KUKA	2	1	3	3	2	2	40
KR 120 R2700 HA	KUKA	2	1	3	2	3	2	38
IRB 6400 2.8 120	ABB	2	2	1	1	2	2	31
KR 150 L120/2	KUKA	2	2	3	2	1	2	41
KR 120 R2900 extra	KUKA	2	3	3	3	2	2	50
Smart5 NJ 130-2.6	Comau	1	1	2	3	2	1	30
S-430iW	FANUC	1	1	1	1	1	1	19
KR 150 R2700 extra	KUKA	1	1	1	3	2	1	26
KR 150-2	KUKA	1	1	1	2	2	1	23
RX260	Stäubli	1	3	1	1	2	1	30

Robot arm choice: Smart5



Payload [kg]	Reach [mm]	Repeat-ability ± [mm]	Velocity [°/s]	Mass [kg]
110	2.980	0,07	110-230	1.070



Q1A: Slide

Q1B: Screw

Q1C: Dog bone

Q1 What does the current manual assembly process of a wooden wall component of TheNewMakers look like?

Q2 How can the geometry of the CNC milled elements be redesigned to reduce the automatic assembly time as well as the CNC milling time?

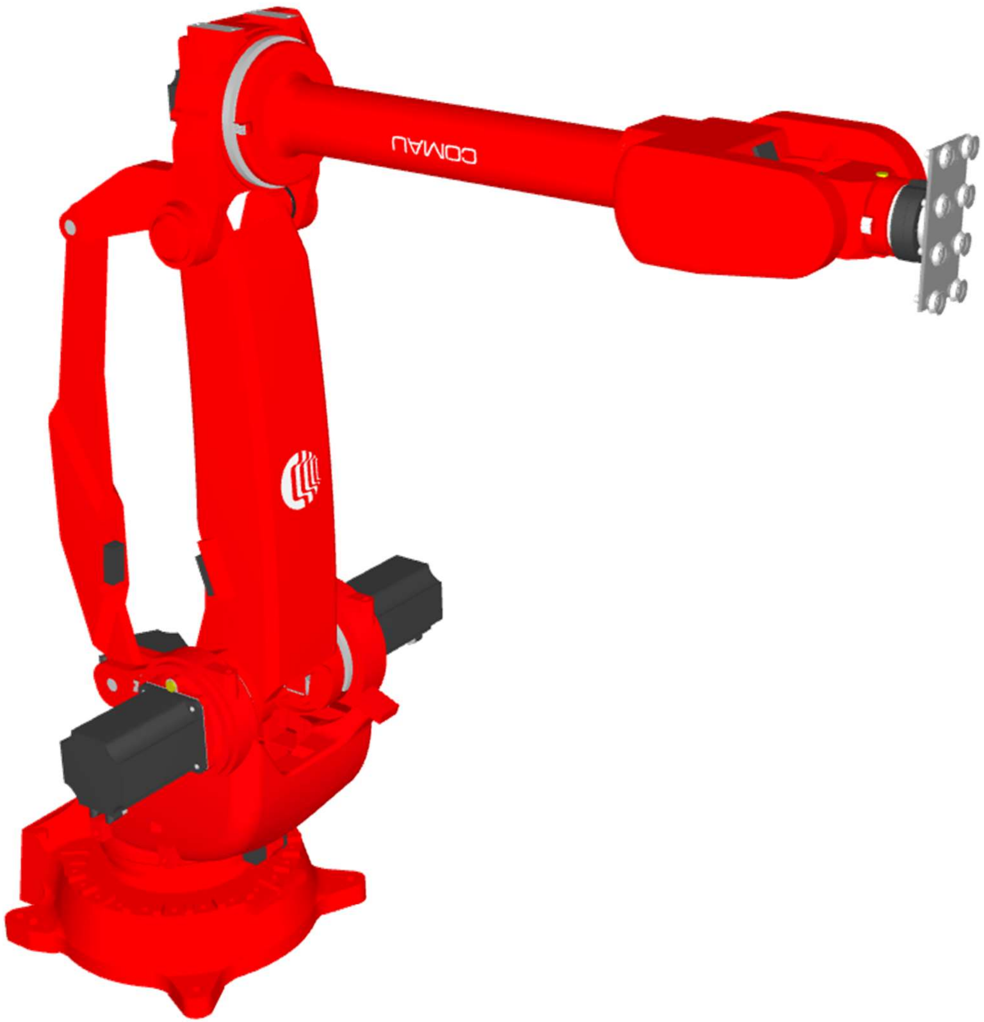
Q4 Does the proposed robotic assembly process take less time than the manual process?

Assembly experiment with section wall component. In collaboration with HBO mechatronics students.

Experiment topics	Considerations
1) Detect elements (recognise and check)	1A) Vision (shape) 1B) 3D model 1C) RFID / QR
2) Pick up elements	2A) Impactive (e.g. gripper) 2B) Ingressive (e.g. pins) 2C) Astrictive (e.g. vacuum) 2D) Contigutive (e.g. adhesive)
3) Assemble elements	3A) Actions required 3B) Extra hardware required
4) Control robot arm	4A) Manual 4B) Teach pendant 4C) Software
5) Communicate	5A) Human & robot (HMI) 5B) Robot & detection 5C) Robot & end effector

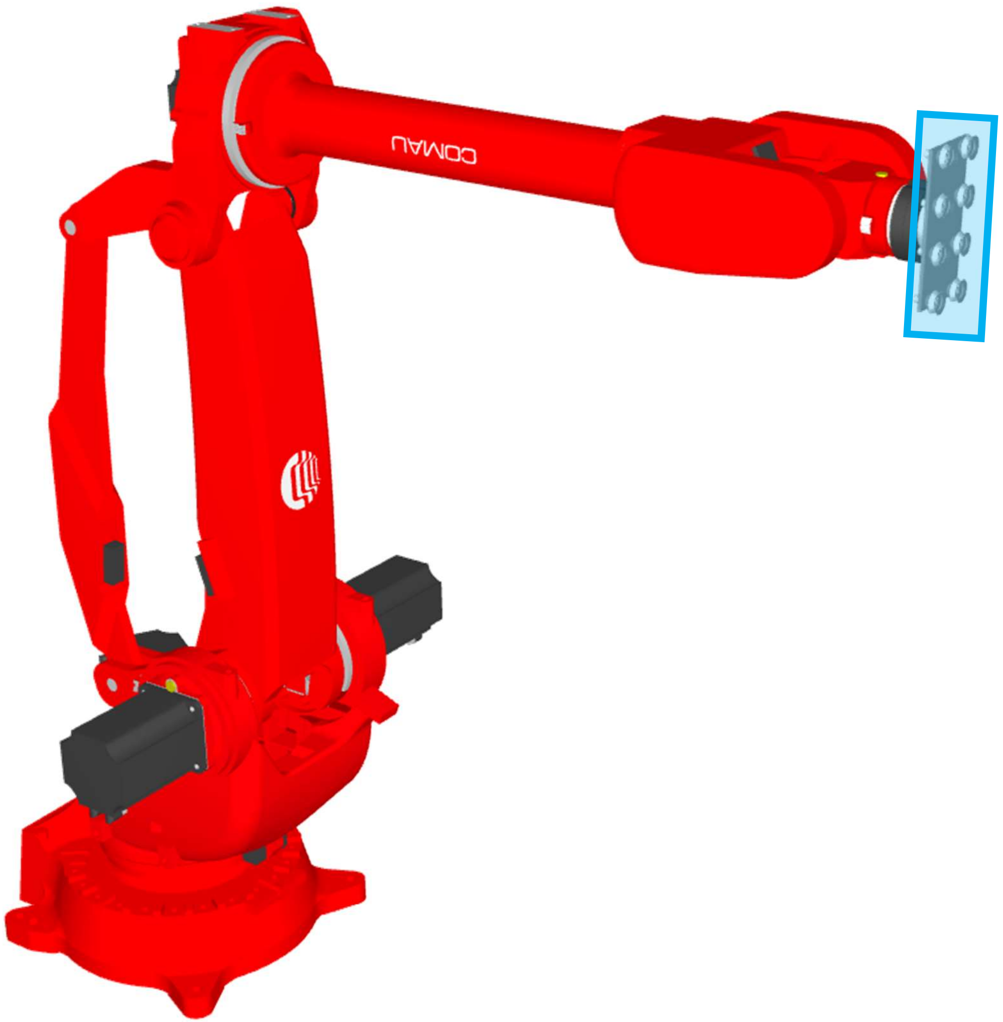
Robotic simulation

- RoboDK and Python
- Robot Smart5



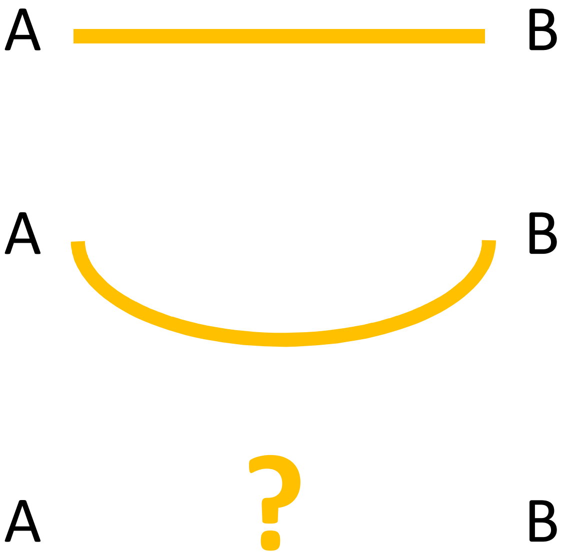
Robotic simulation

End effector



Robotic simulation: Movements

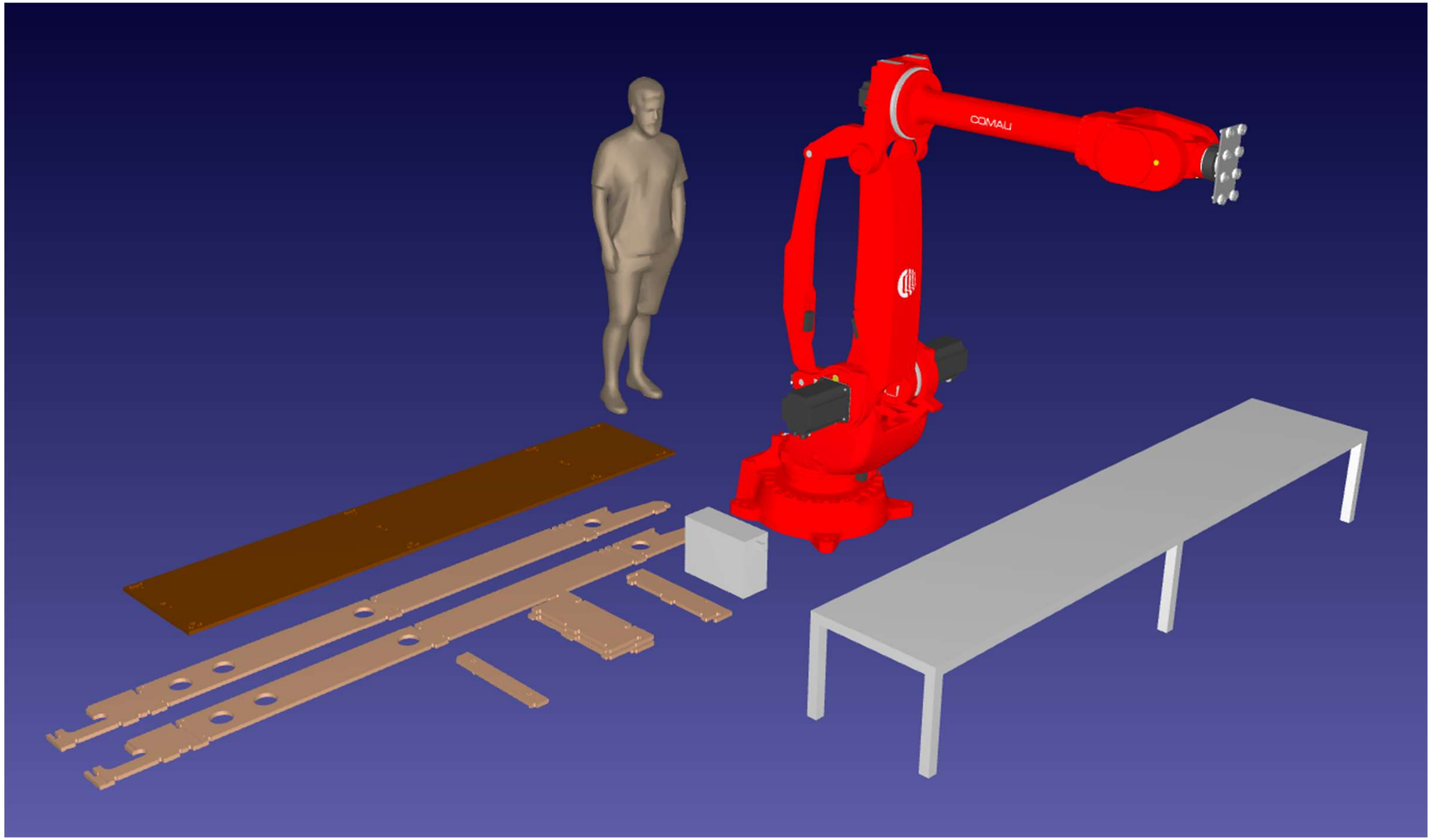
- Linear movement
- Circular movement
- Joint movement (fastest)



Robotic simulation: Screws

Image source: Festool (2019)

Robotic simulation



Human arm 7 DOF (Degrees Of Freedom)

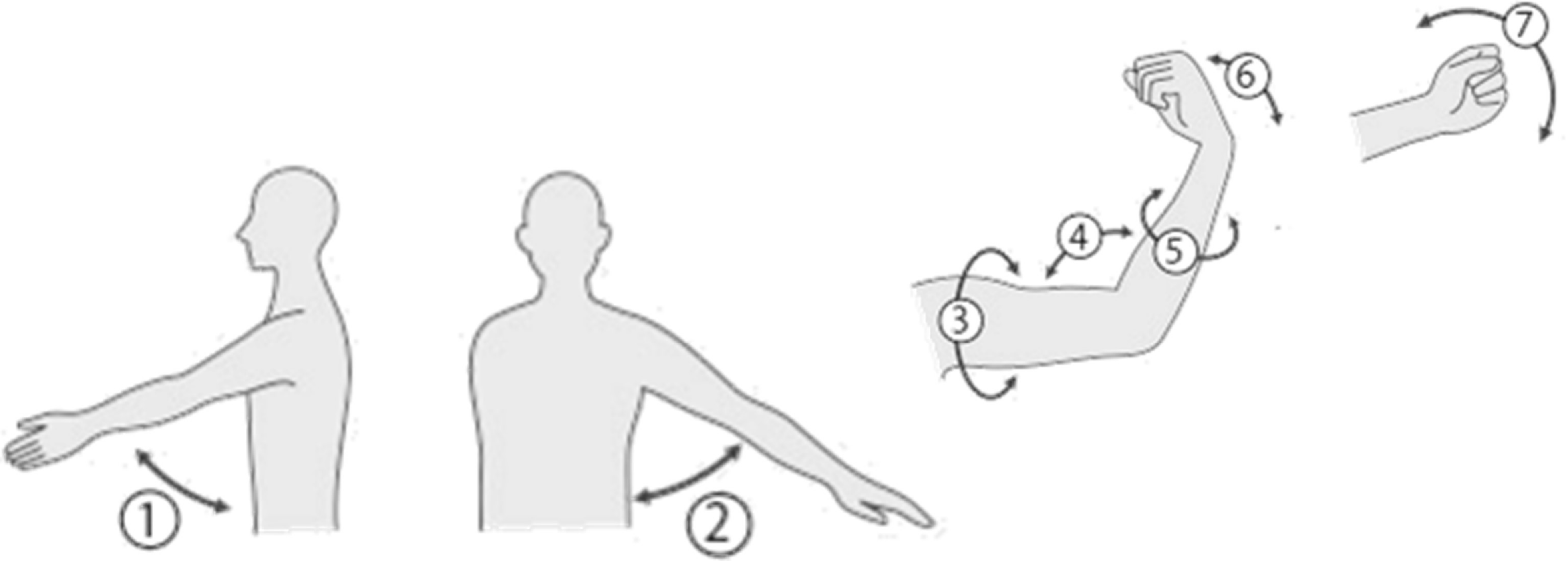
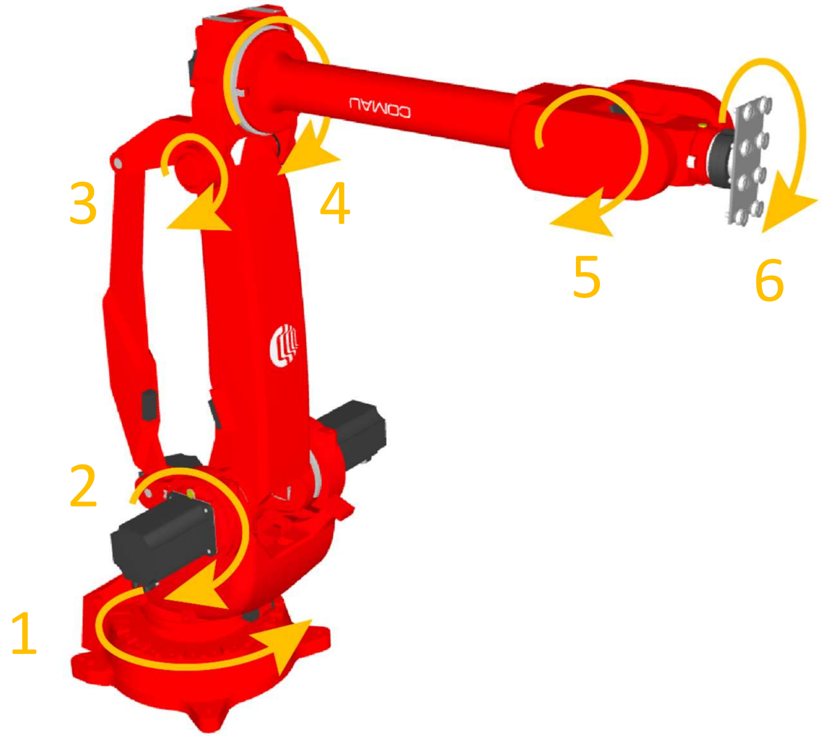


Image source: Yaskawa global (2019)

Robotic simulation: Joints

6 DOF

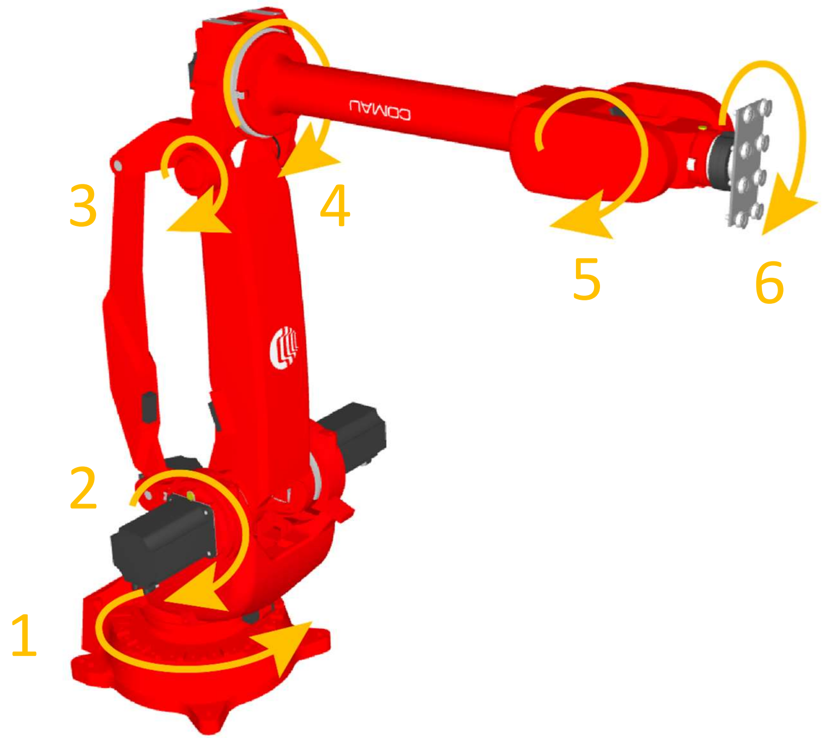
(Degrees Of Freedom)

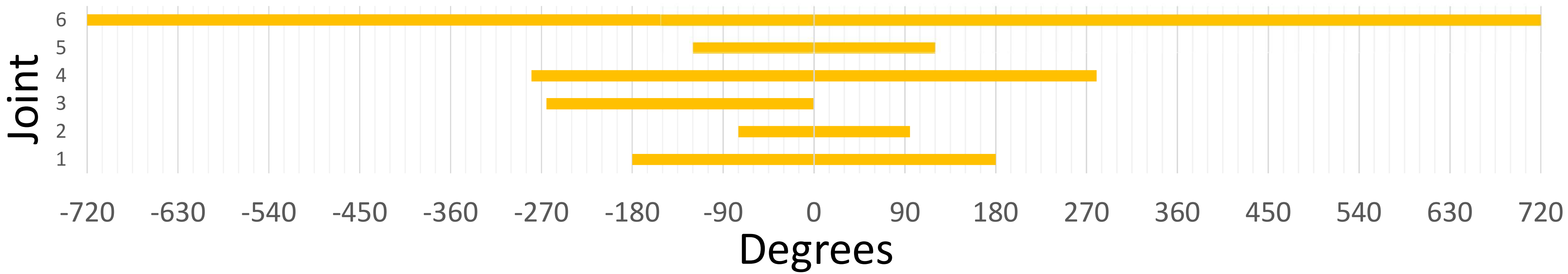


Robotic simulation: Joints

6 DOF

(Degrees Of Freedom)

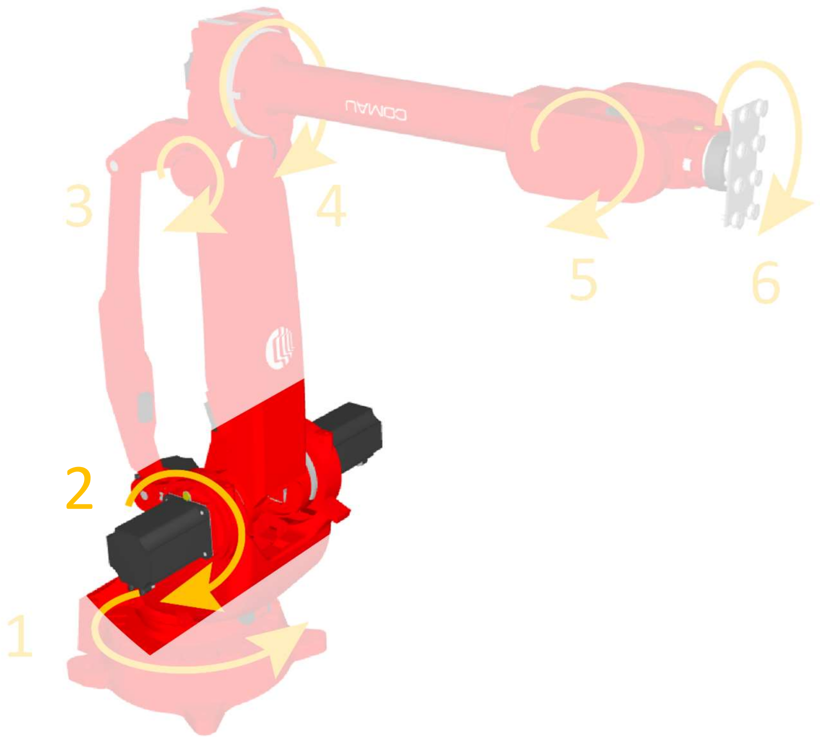


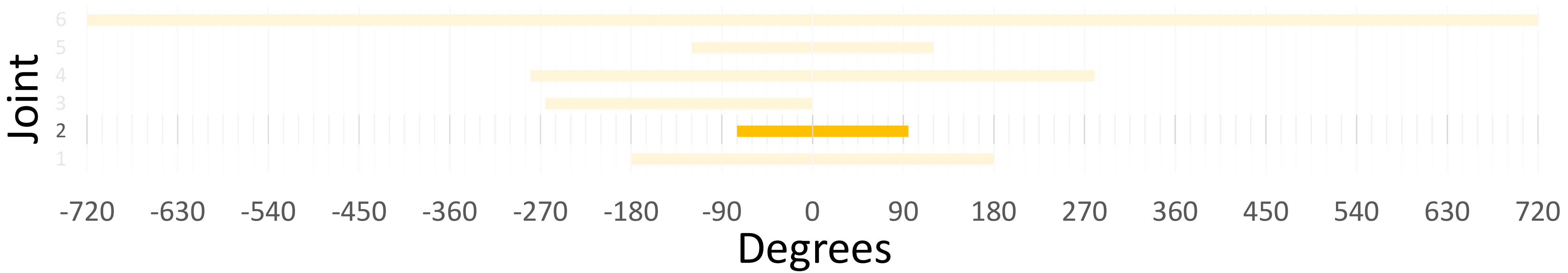


Robotic simulation: Joints

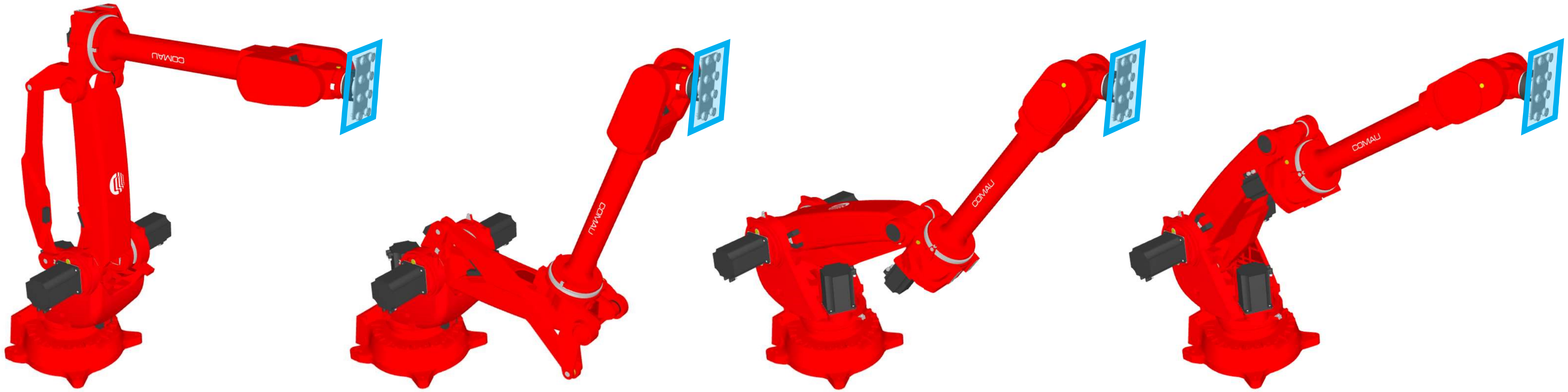
6 DOF

(Degrees Of Freedom)

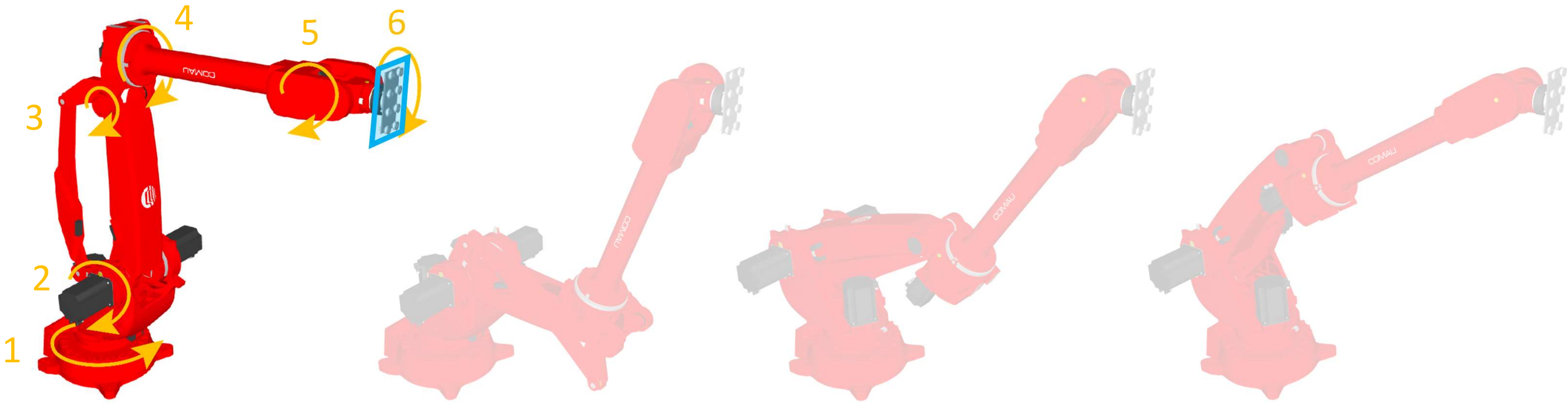


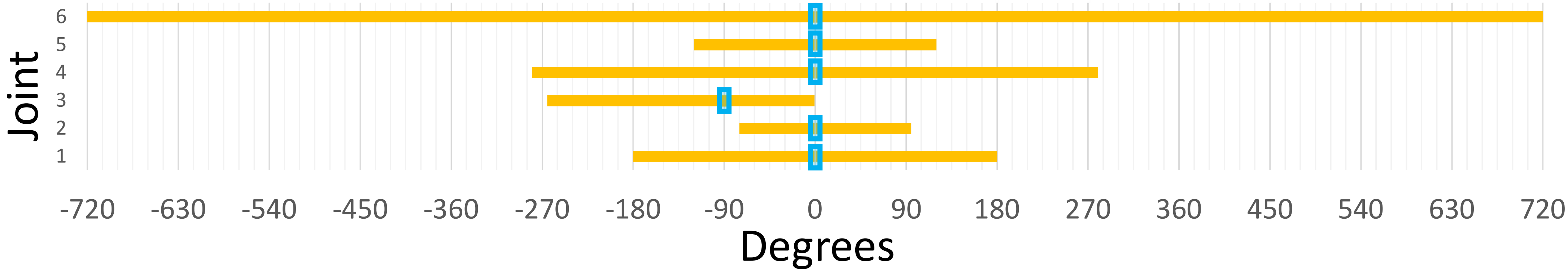


Robotic simulation: Joints

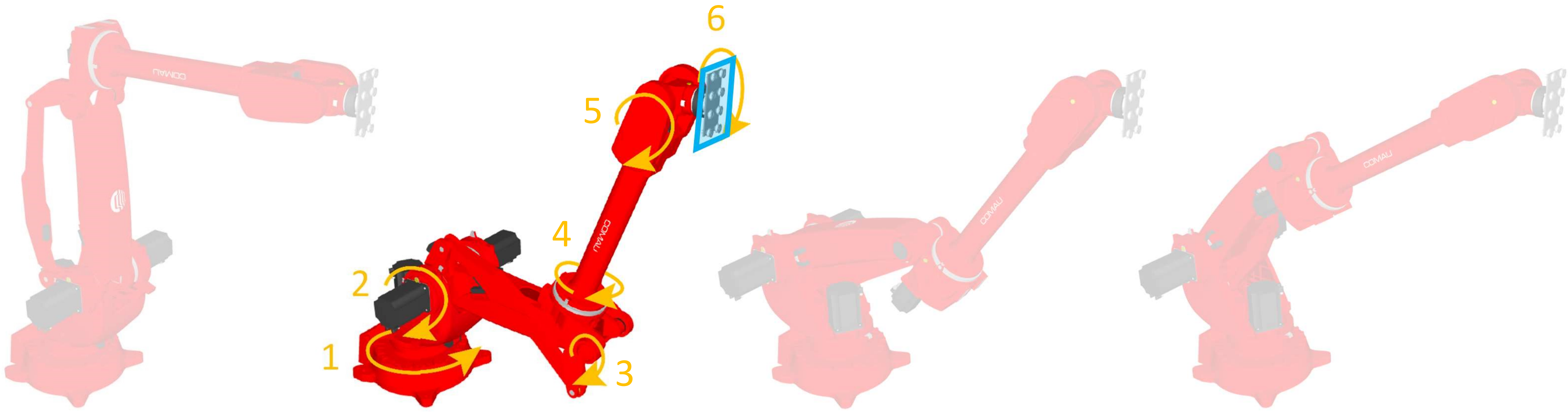


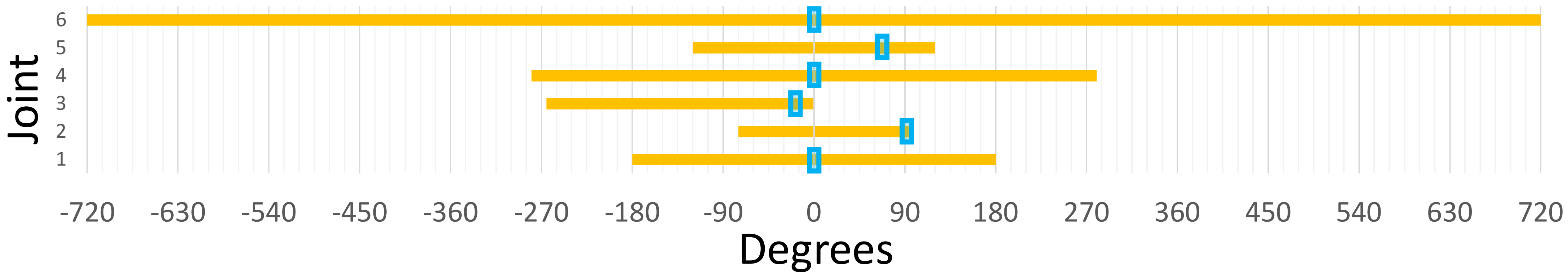
Robotic simulation: Joints



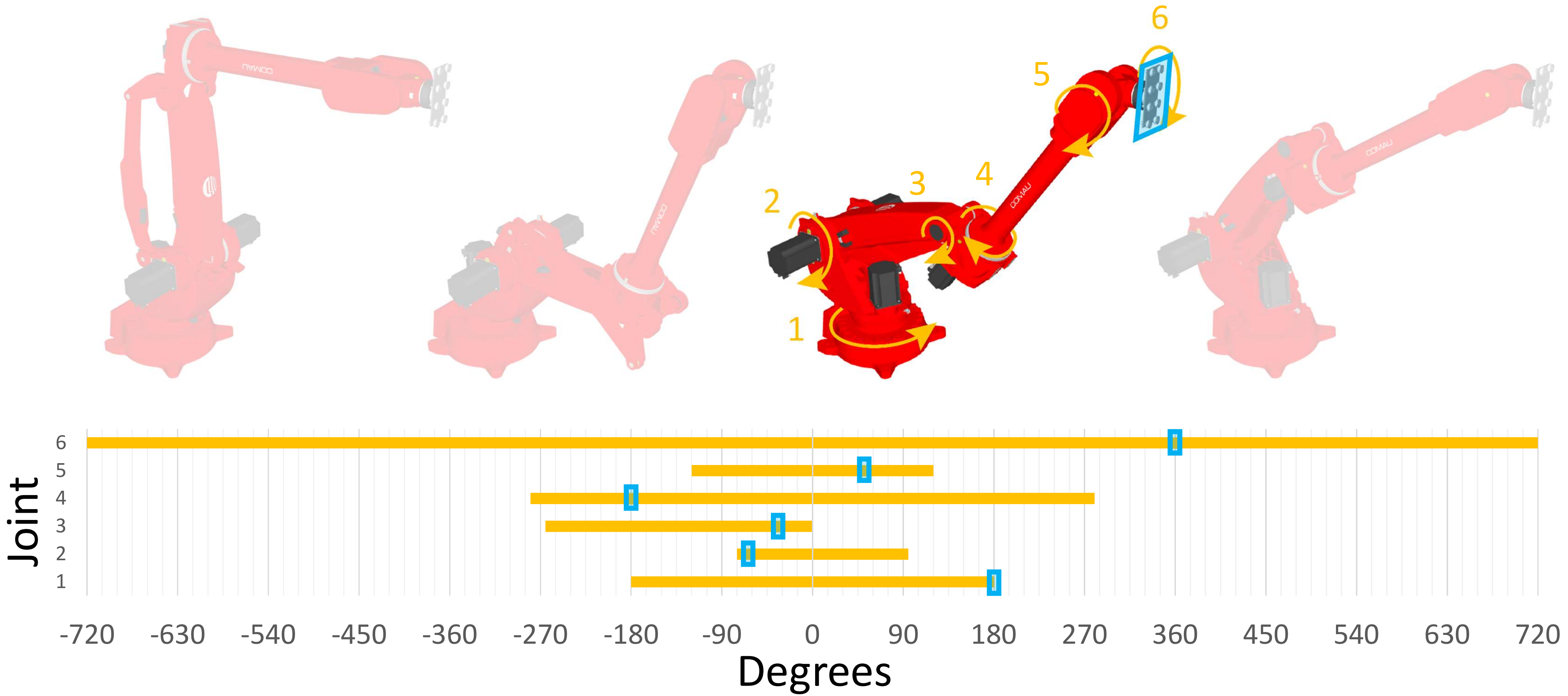


Robotic simulation: Joints

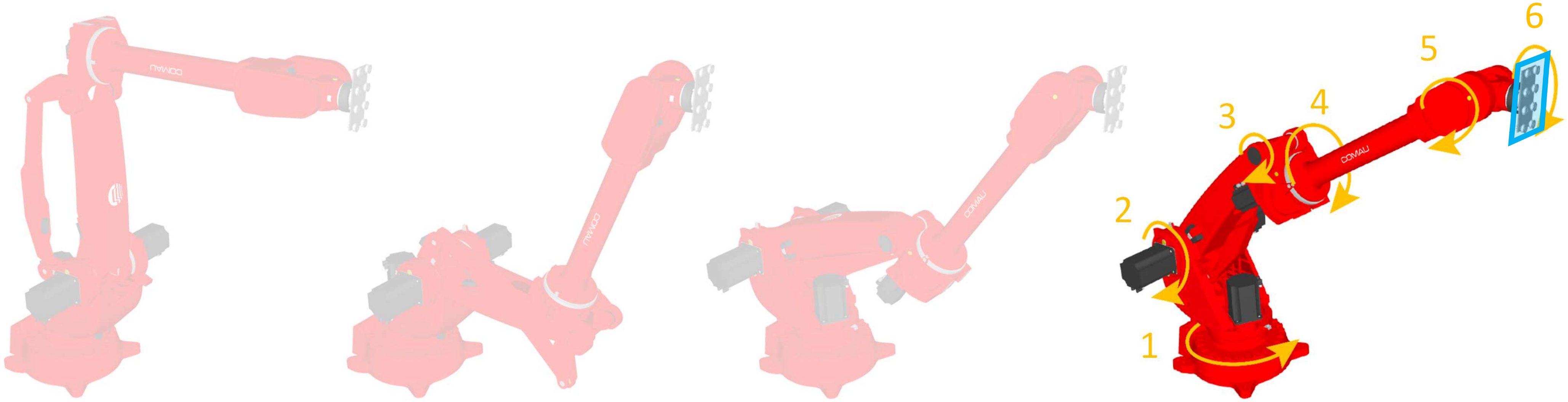


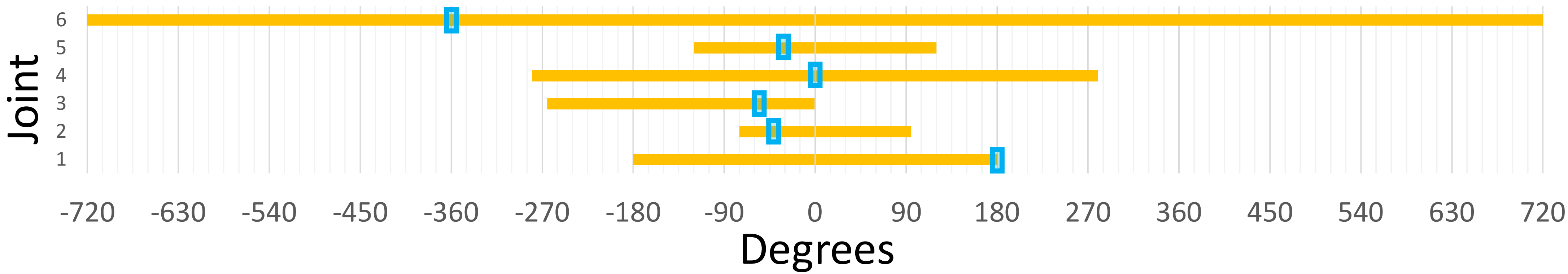


Robotic simulation: Joints

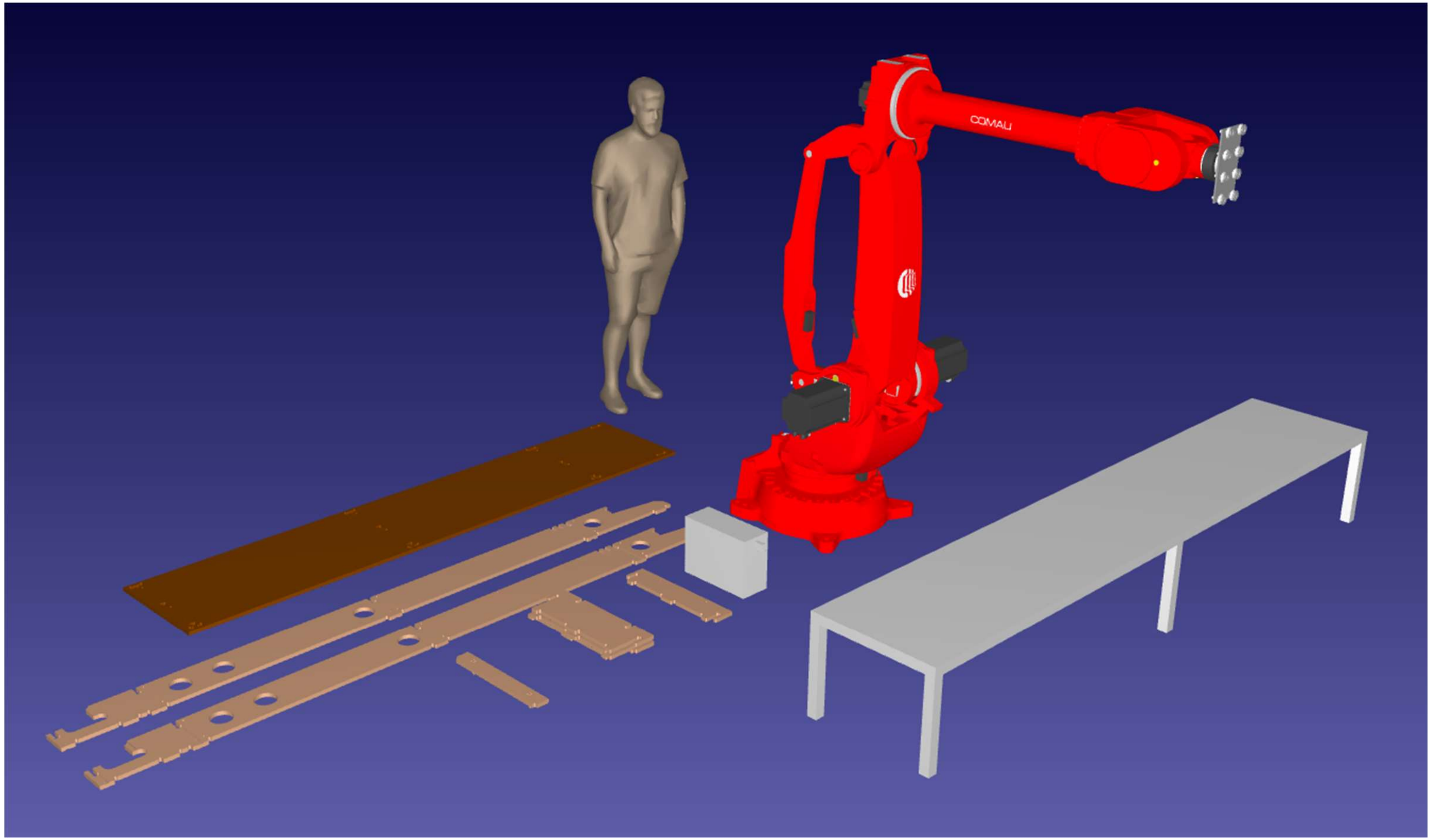


Robotic simulation: Joints





Robotic simulation



Compare time [s]

Assembly method:				Robotic simulation
Q2 geometry version:		Version B - DFA2 (Design For Automatic Assembly)		
Extra gap tolerances:				yes
1. Assembly [s]				187

Compare time [s]

Compare time [s]

Assembly method:	Manual			Robotic simulation
Q2 geometry version:	Version A - Original	Version B - DFA2 (Design For Automatic Assembly)		
Extra gap tolerances:	N/A	no	yes	yes
1. Assembly [s]	456	389	366	187

Compare time [s]

Assembly method:	Manual			Robotic simulation
Q2 geometry version:	Version A - Original	Version B - DFA2 (Design For Automatic Assembly)		
Extra gap tolerances:	N/A	no	yes	yes
1. Assembly [s]	456	389	**366**	**187**

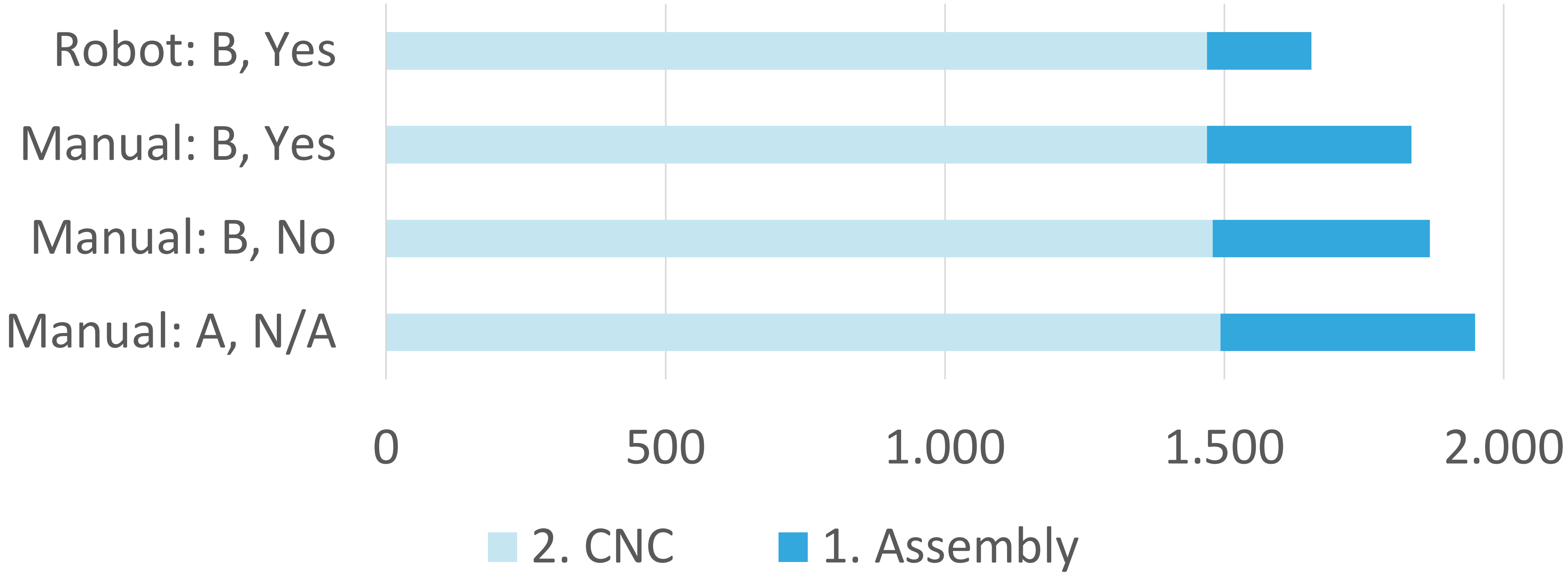
Robot 1,96 times faster

Compare time [s]

Compare time [s]

Assembly method:	Manual			Robotic simulation
Q2 geometry version:	Version A - Original	Version B - DFA2 (Design For Automatic Assembly)		
Extra gap tolerances:	N/A	no	yes	yes
1. Assembly [s]	456	389	366	187
2. CNC [s]	1.493	1.479	1.469	1.469
1+2 = Total time	1.949	1.868	1.835	1.656

Compare time [s]



Conclusions & recommendations

Main research question

How could the elements of a wall component of TheNewMakers be redesigned for automatic assembly while taking less time to assemble than the current manual process?

Conclusions

Q1) Geometry version A - Original

Q2) Geometry version B - DFA2 with extra gap tolerances

Q3) Robot: Smart5 by Comau

Q4) Robotic process is faster

Recommendations

Robotic process

- Workflow of TNM
- Unloading area
- Compare with manual process
- Design end effector
- Limitations
- Geometry modifications
- Structure wall component

Design a new construction method based on:

- Robotic assembly
- TNM building system
- DFA2 design guidelines

Robots will help us!

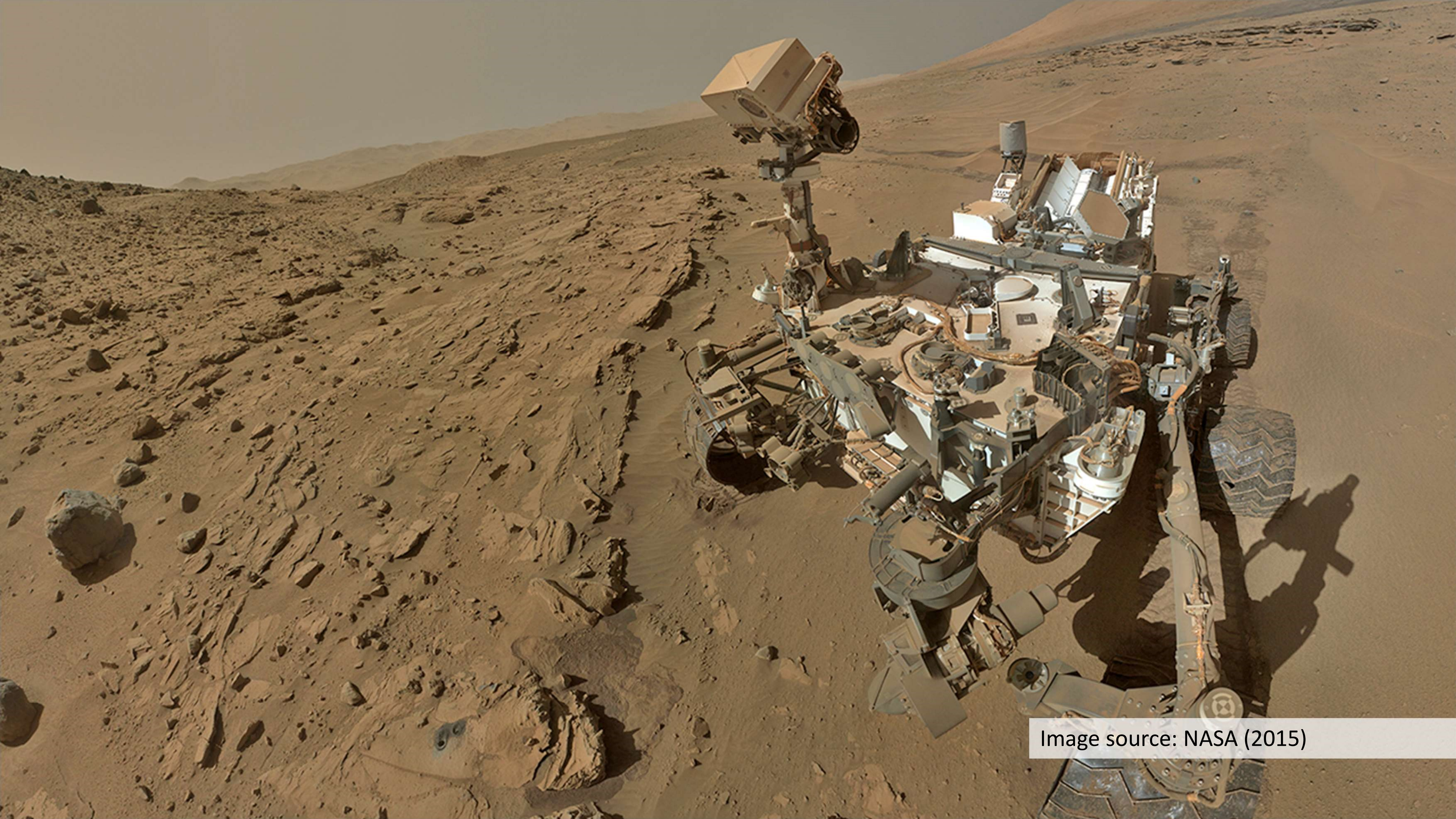


Image source: NASA (2015)


Image source: OceanX (2019)

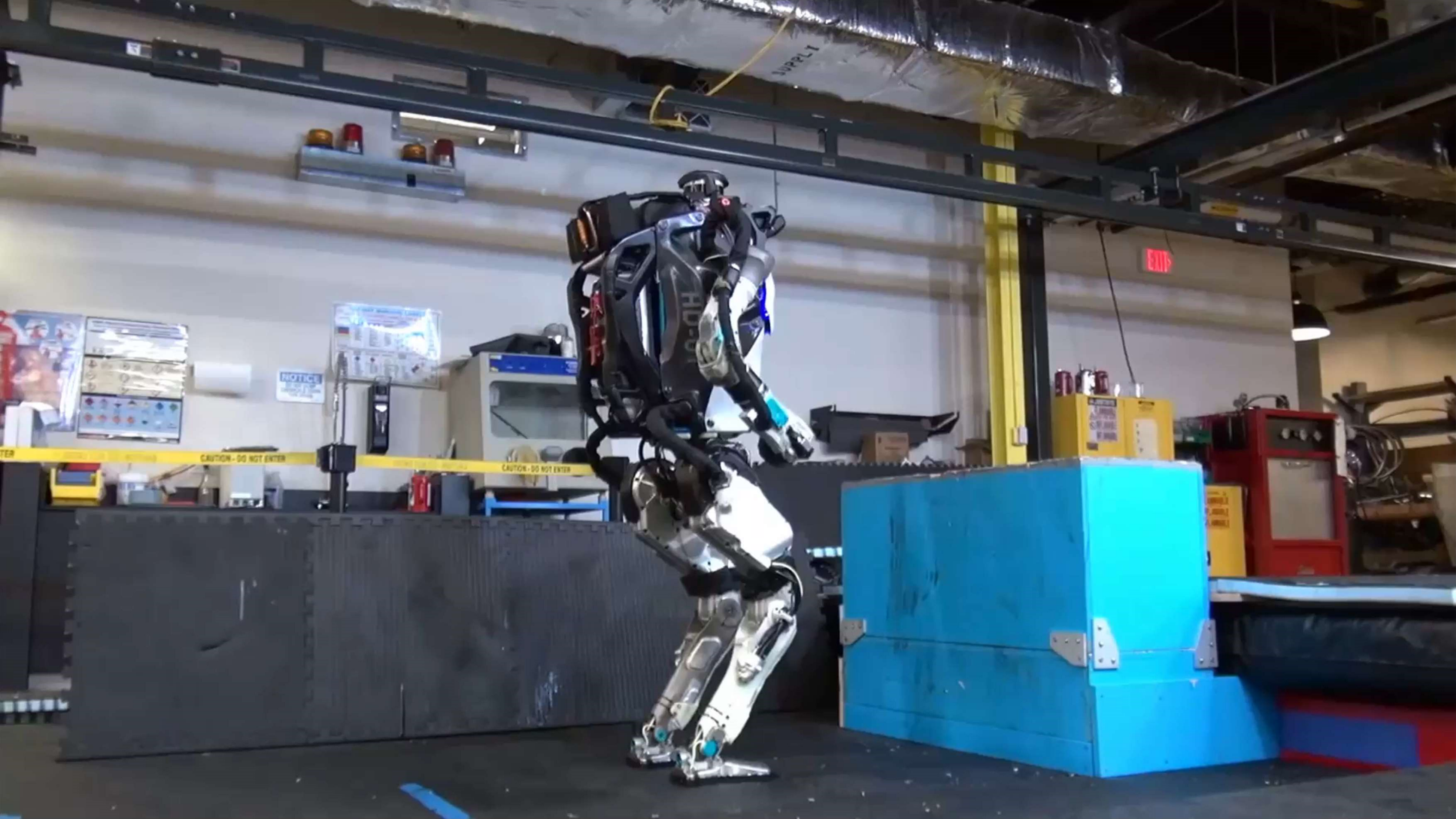

CAUTION - DO NOT ENTER
CAUTION - DO NOT ENTER
NOTICE

Image source: Autodesk BrickBot (2018)

Google Duplex

Advancing AI for Everyone

Image source: Google (2018)

Video source: Google (2018)

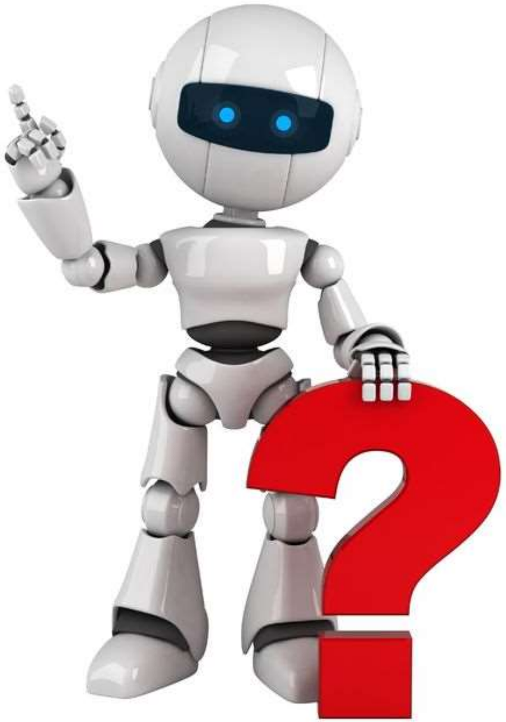


Image source: Global Robots (n.d.)

How will robots change our lives?

Hoe zullen robots onze levens veranderen?

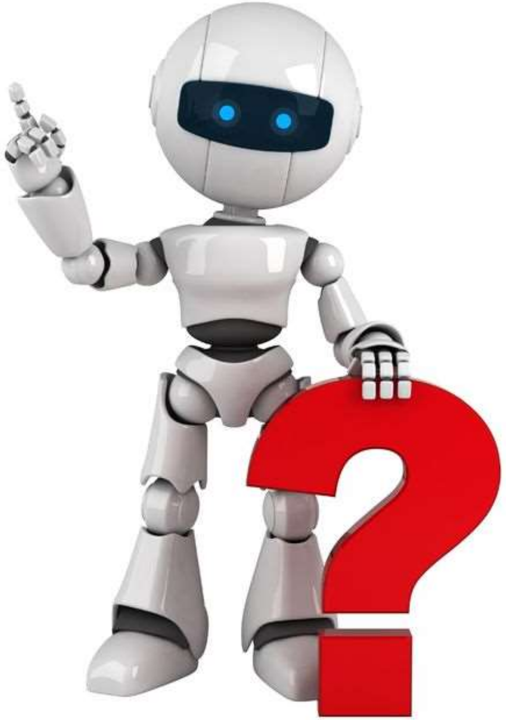


Image source: Global Robots (n.d.)

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Image source: Global Robots (n.d.)