dstv: An ontology-based extension of the DSTV-NC standard for the use of linked data in the automation of steel construction

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Motivation

Video 01: Example for state of the art automated steel assembly: ZEMAN's "SBA2 Conti+„ [1]

Oberservation 1:

Automated assembly requires very tight tolerances both in material and prefabricated components.

- economic viability suffers

Oberservation 2:

Many production machines have inbuilt metrology but their information system is closed / encapsuled.

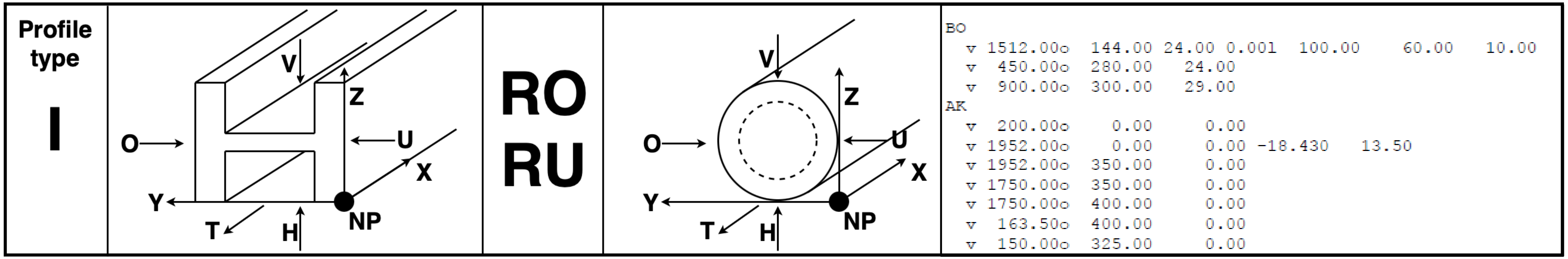
- Metrology data can not be used outside of the machine

Approach:

Extension of an already used format / standard by metrology data to allow machines to adapt their processes accordingly.

DSTV-NC

DSTV-NC: A standard interface of steel construction part geometries for NC manufacturing operations



Advantages:

- ✓ Commonly used in steel industry
- ✓ Widely used version (ASCII) easy to implement
- ✓ Process driven design
- ✓ „Well-defined“ / „clear“

Shortcomings:

– Cannot store tolerances
– Cannot store measurements

– Not linked to resulting building product
– Not linked to machine information

– No dynamic information
– Standard itself not machine-readable

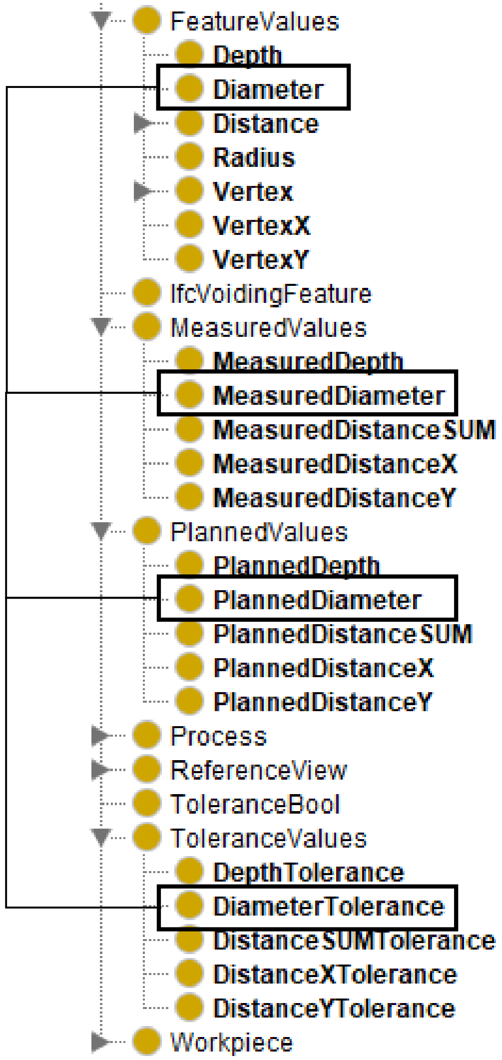
Ontology Design

Methodology according to „Ontology Development 101“ by Noy and McGuinness [2]

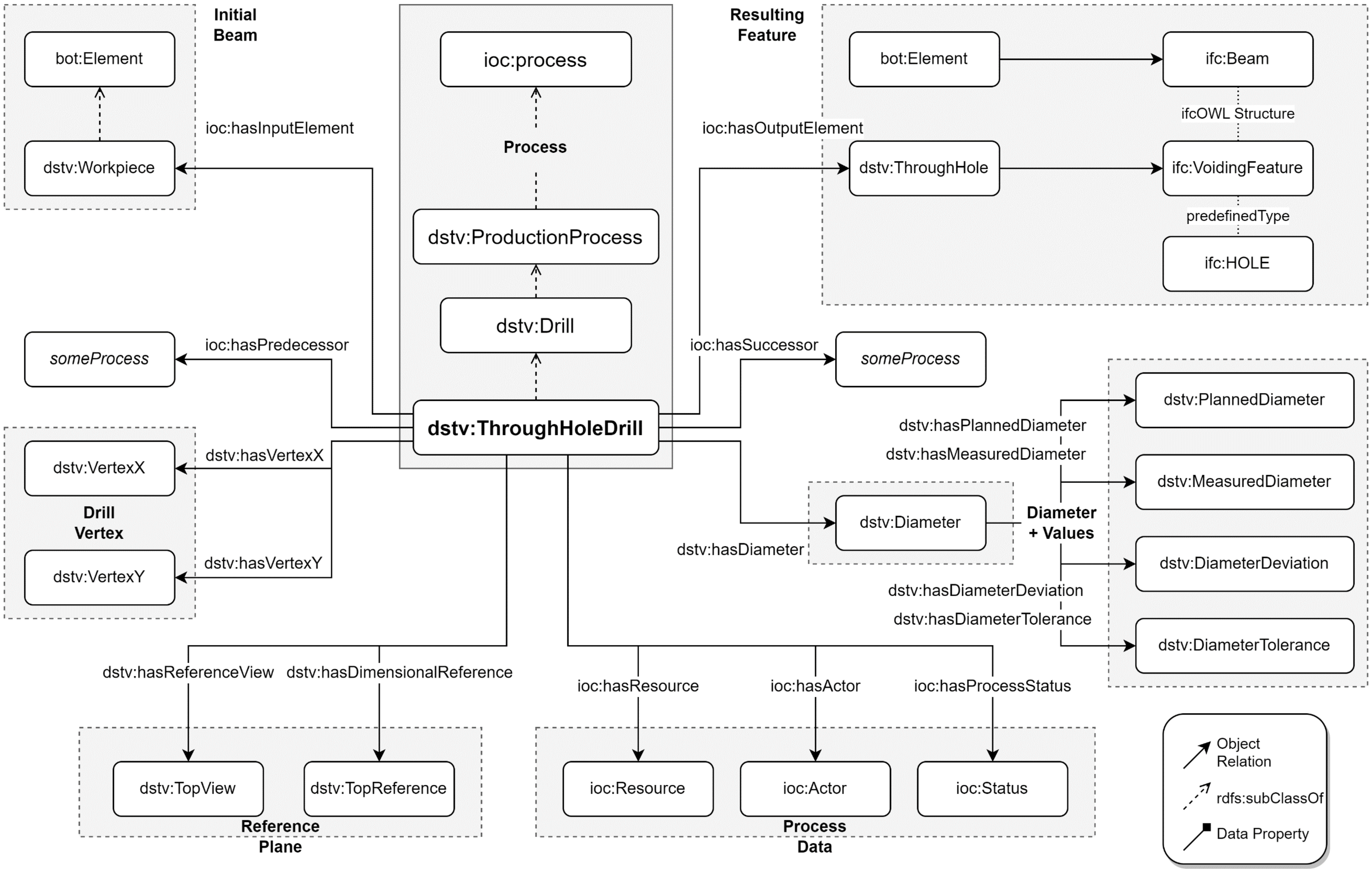
- Formulation of 10 „simple“ competency questions (CQ)
- No specific Ontology for the domain of „**automated steel manufacturing**“ available
- Creating concepts directly aligned to DSTV-NC standard

Specific Features

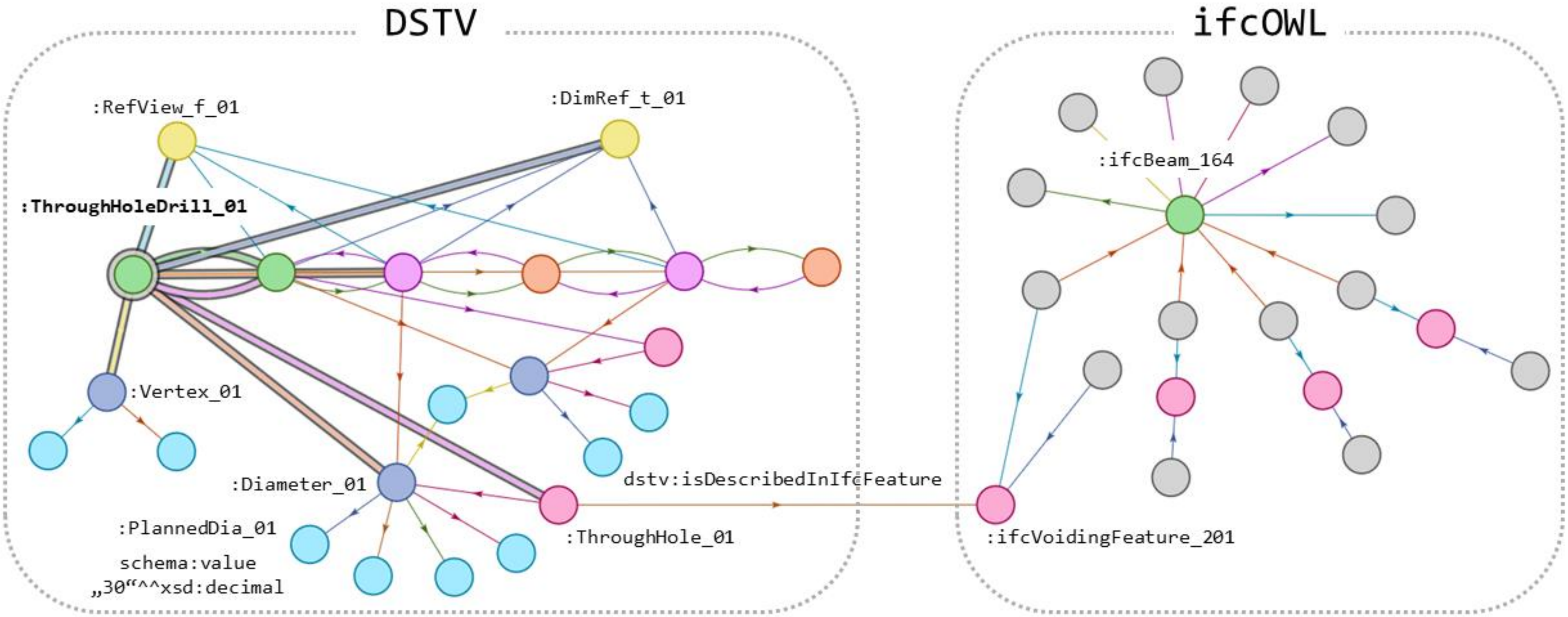
- Process-driven design (feature values linked to processes)
- Works with and without *LBD/ifcOWL* concepts
- Structure for „planned“, „measured“, „deviation“, … duplicated
- Versioning / dynamic features according/inspired by *OPM* ontology [3]



Example: Drill



Example: Drill

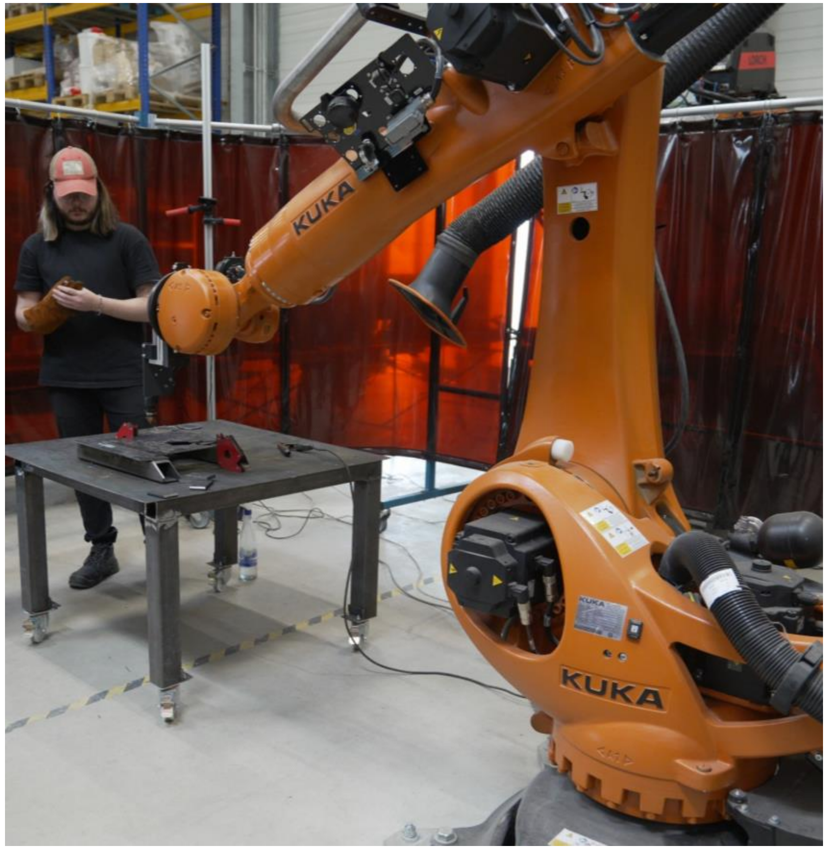


Process-Scenario: Plasma-Cutting an IPE 220

Process: **Plasma Arc Cutting**
Workpiece: IPE 220
Machine: KUKA KR240 R2700 „optimus“
Tool: Hypertherm Powermax

Constraints / Parameters:

Torch	status	on/off
Torch	distance	(mm)
Robot	speed	(mm/s)



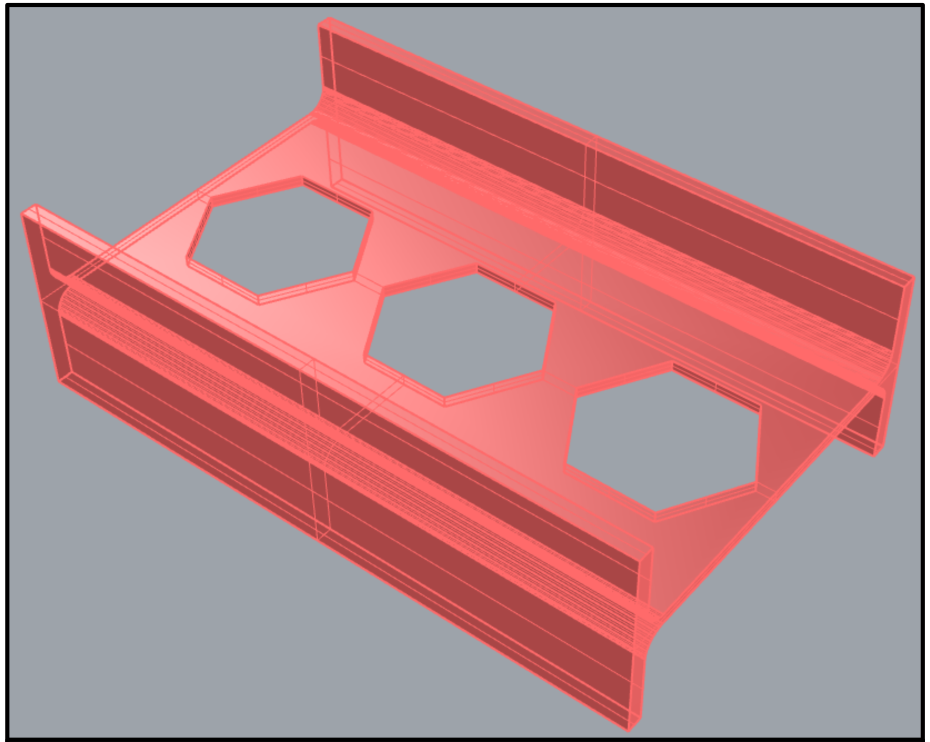
Process Sequence:

Travel from save to first cut → **First cut** → **Travel** from first to second cut → **Second cut** → **Travel** from second to third cut → **Third cut** → **Travel** to EndPOS

Sequence – Step 1: Workpiece Modeling

- **Create workpiece**
  - Model as IFC4 (SPF)
  - IFCtoLBD including ifcOWL
  - SPARQL UPDATE

- **Generate *DSTV* planning data**
  - Query Geometry: SPARQL SELECT
  - Define Reference Plane
  - Generating RDF-Lists of Vertices
  - SPARQL UPDATE

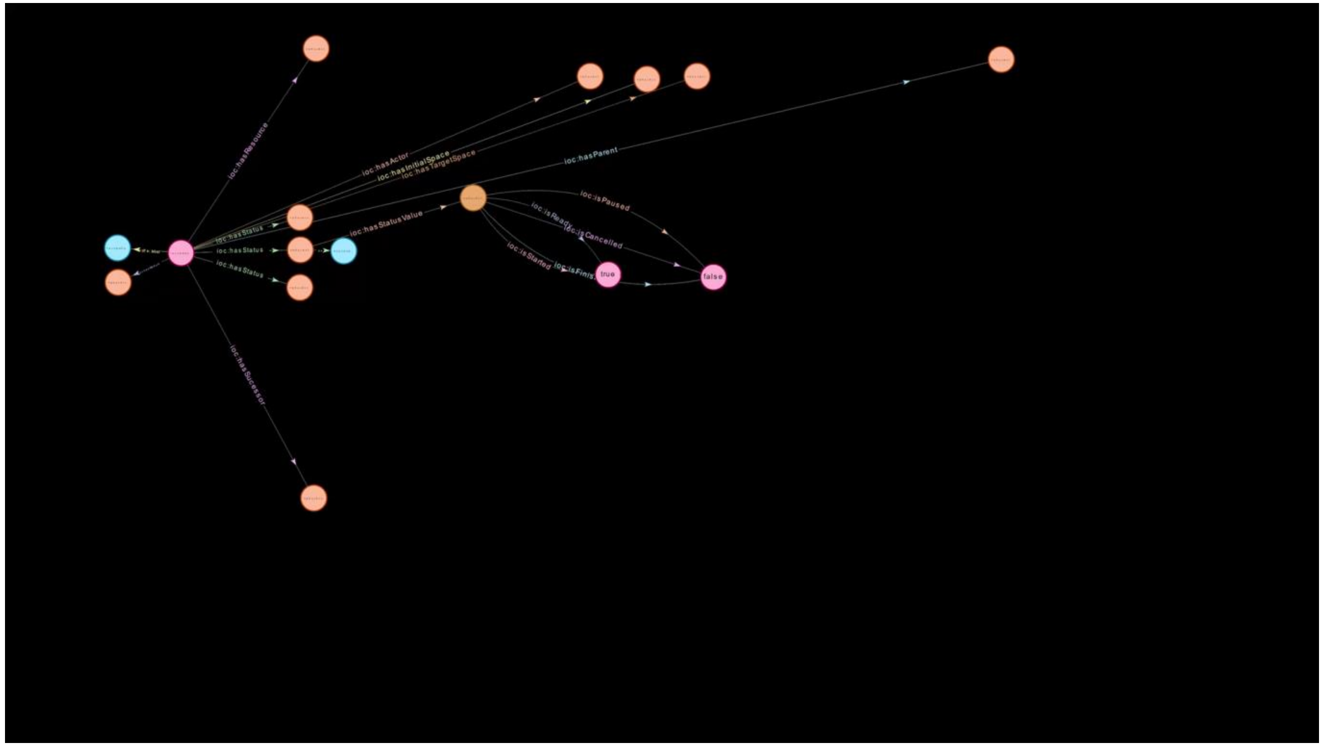


```
#PlannedVertexX_01_1> schema:value "110.0"^^xsd:double.
#PlannedVertexY_01_1> schema:value "-10.5"^^xsd:double.
#PlannedVertexZ_01_1> schema:value "0.0"^^xsd:double.
```

Sequence – Step 2: Process Modeling

- **Creating a process-sequence using the *ioc: process ontology* (in Publication)**
    - ➢ Query workpiece data: SPARQL SELECT
    - ➢ Generate sequence
    - ➢ Interconnect workpiece data (DSTV – LBD/ifcOWL)
    - ➢ Add resource (machine) including MQTT topic
    - ➢ Add tool including MQTT topic
    - ➢ Add workspace, constraints, actor, etc…
    - ➢ SPARQL UPDATE

- **Generate robot control data**
    - ➢ Query process data: SPARQL SELECT
    - ➢ Automated path-planning
    - ➢ Convert KRL code to linked data via *crc* ontology
    - ➢ SPARQL UPDATE

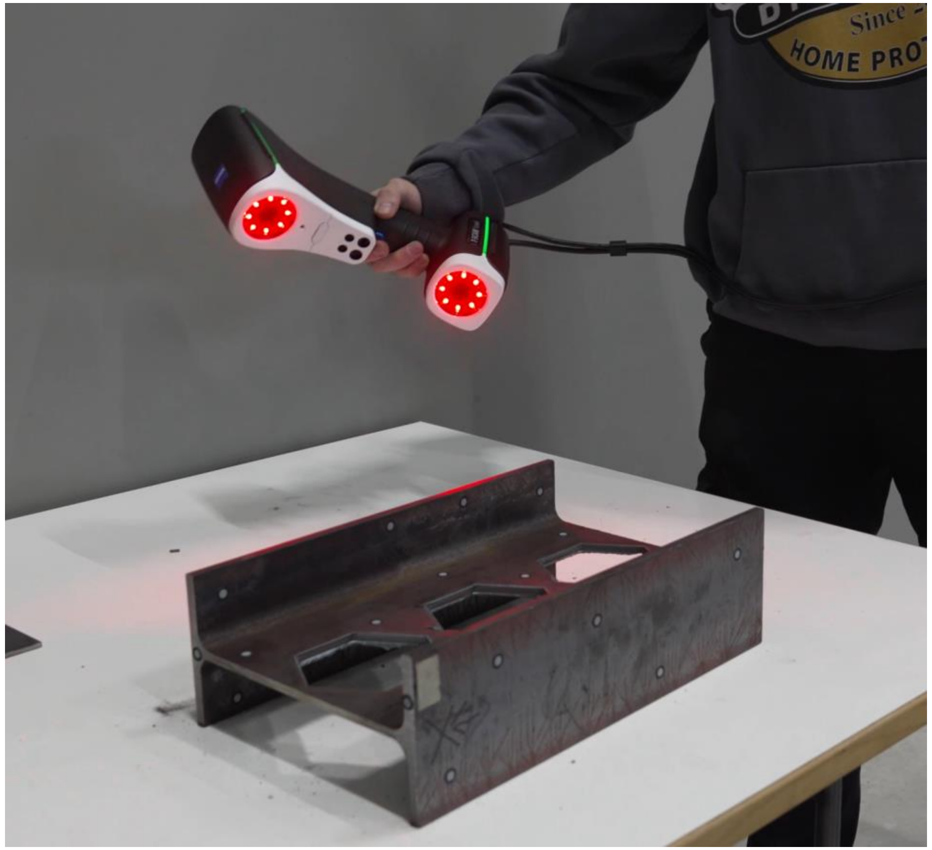


Sequence – Step 3: Plasma-Cutting

- **Running control script**
  - Query process: SPARQL UPDATE
  - Check constraints: SPARQL SELECT
  - Toggle Status: SPARQL UPDATE
  - Send commands via MQTT (Robot or Torch)
  - Wait …
  - Receive Feedback via MQTT
  - Update Status: SPARQL UPDATE
  - Repeat

Sequence – Step 4: Quality Control

- **Let the workpiece cool down**
  - Wait …
- **Compare to planning data**
  - Scan workpiece
  - Create mesh from pointcloud
  - Query planned geometry: SPARQL SELECT
  - *Best-Fit* Alogrithm to align
  - Measure Vertices
  - SPARQL UPDATE



Sequence – Step 5: Evaluation

- **Query process metadata**

DSTV data			ifcOWL	machine data				status feedback		
Name	**class**	**Feature**	**Output**	**cmdCount**	**cmd**	**dev**	**speed**	**TimeStart**	**TimeFinish**	**Duration**
Travel from Save to first Cut	-	-	-	2	MoveLin	optimus	-1.0	2023-03-28T15:43:25.499584+02:00	2023-03-28T15:43:55.393978+02:00	PT 29.894S
first Cut	http://w3id.org/dstv#InternalContouring	http://baufest.org/dstv-test02#ContourList_0101	http://ip.rwth-aachen/baufest/ifc#IfcVoidingFeature_186	27	MoveLin	optimus	**5.0**	2023-03-28T15:43:55.770522+02:00	2023-03-28T15:45:03.253795+02:00	PT 1M7.483S
Travel from first to second Cut	-	-	-	3	MoveLin	optimus	-1.0	2023-03-28T15:45:03.847113+02:00	2023-03-28T15:45:32.219640+02:00	PT 28.372S
second Cut	http://w3id.org/dstv#InternalContouring	http://baufest.org/dstv-test02#ContourList_0201	http://ip.rwth-aachen/baufest/ifc#IfcVoidingFeature_170	27	MoveLin	optimus	**10.0**	2023-03-28T15:45:32.572661+02:00	2023-03-28T15:46:18.222345+02:00	PT 45.650S
Travel from second to third Cut	-	-	-	3	MoveLin	optimus	-1.0	2023-03-28T15:46:18.720389+02:00	2023-03-28T15:46:36.752713+02:00	PT 18.032S
third Cut	http://w3id.org/dstv#InternalContouring	http://baufest.org/dstv-test02#ContourList_0301	http://ip.rwth-aachen/baufest/ifc#IfcVoidingFeature_154	27	MoveLin	optimus	**20.0**	2023-03-28T15:46:37.193713+02:00	2023-03-28T15:47:00.235659+02:00	PT 23.042S
Travel to EndPOS	-	-	-	2	MoveAxis	optimus	-1.0	2023-03-28T15:47:00.643774+02:00	2023-03-28T15:47:10.531371+02:00	PT 9.888S

Sequence – Step 5: Evaluation

- **Calculate deviation & check tolerances**
  - Can be done directly via SPARQL SELECT & UPDATE

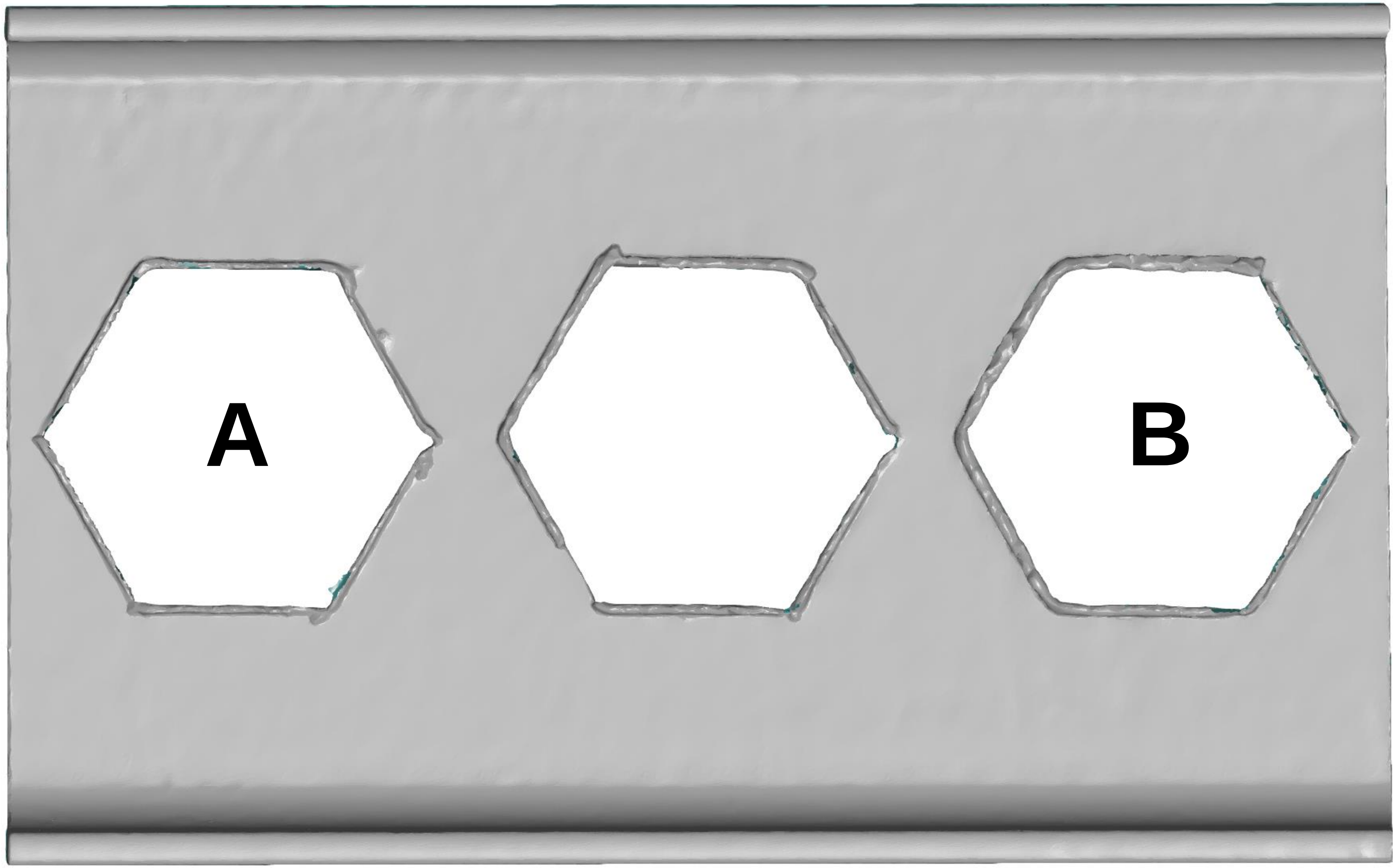
	planned			measured			deviation			
Feature	PlannedVertexX	PlannedVertexY	PlannedVertexZ	MeasuredVertexX	MeasuredVertexY	MeasuredVertexZ	VertexXDeviation	VertexYDeviation	VertexZDeviation	**tcpZ**
http://baufest.org/dstv-test02#Vertex_01_1	110.0	-10.5	**0.0**	109.858	-9.255	**0.304**	-0.141	1.244	**0.304**	**708.65**

- **Find patterns in the data**
  - Query deviations and machine data: SPARQL SELECT
  - Analyze / plot

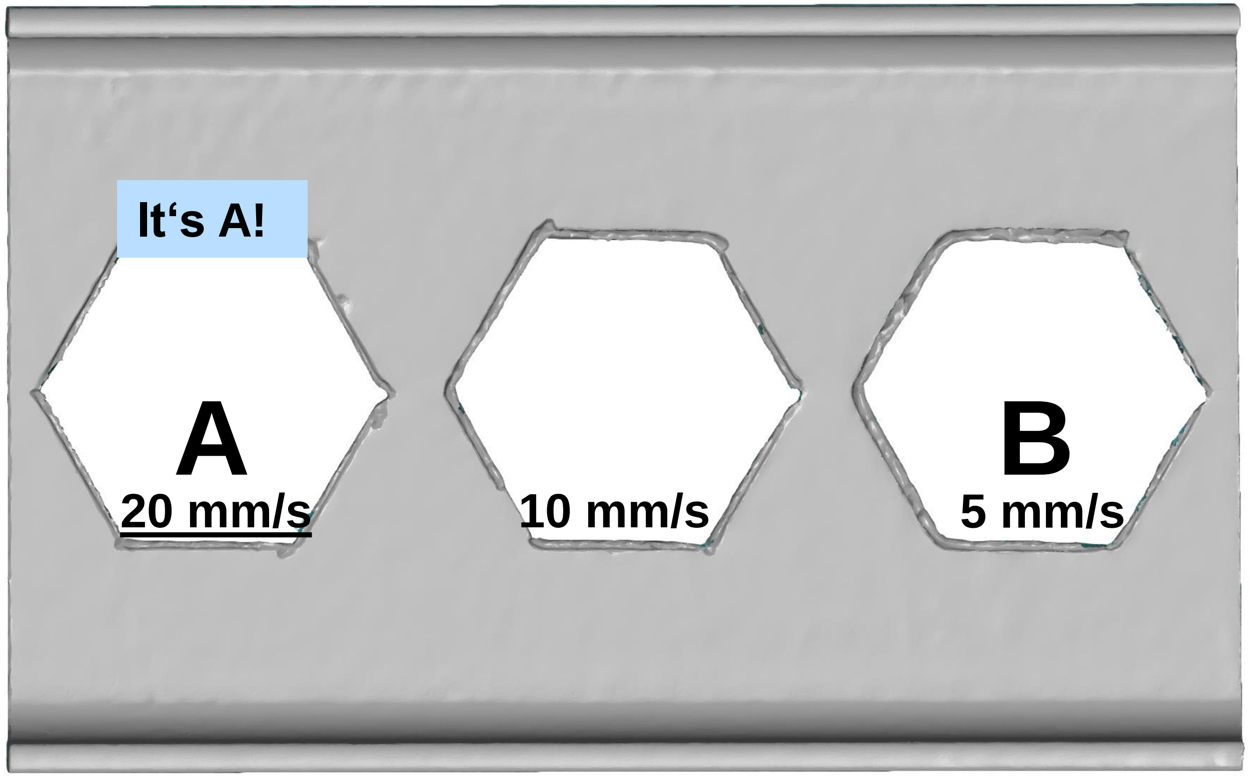
Name	cmd	dev	speed	tcpPose	Avg(AbsDevX)	Avg(AbsDevY)	Avg(AbsDevZ)	AbsTolXYZ	tcpZ
first Cut	MoveLin	optimus	5.0	http://baufest.org/dstv-test02#tcpPose_8c328310-a47c-5ac7-be84-d3db1d2007c3	0.368	0.547	4.079	-0.6 …+0.6	708.65
second Cut	MoveLin	optimus	10.0	http://baufest.org/dstv-test02#tcpPose_3050c77a-63b8-5869-a864-5635105b5023	0.231	0.504	3.399	-0.6 …+0.6	708.65
third Cut	MoveLin	optimus	20.0	http://baufest.org/dstv-test02#tcpPose_706a2a54-ba7f-5750-b8ed-6d99f1802774	0.190	0.413	3.086	-0.6 …+0.6	708.65

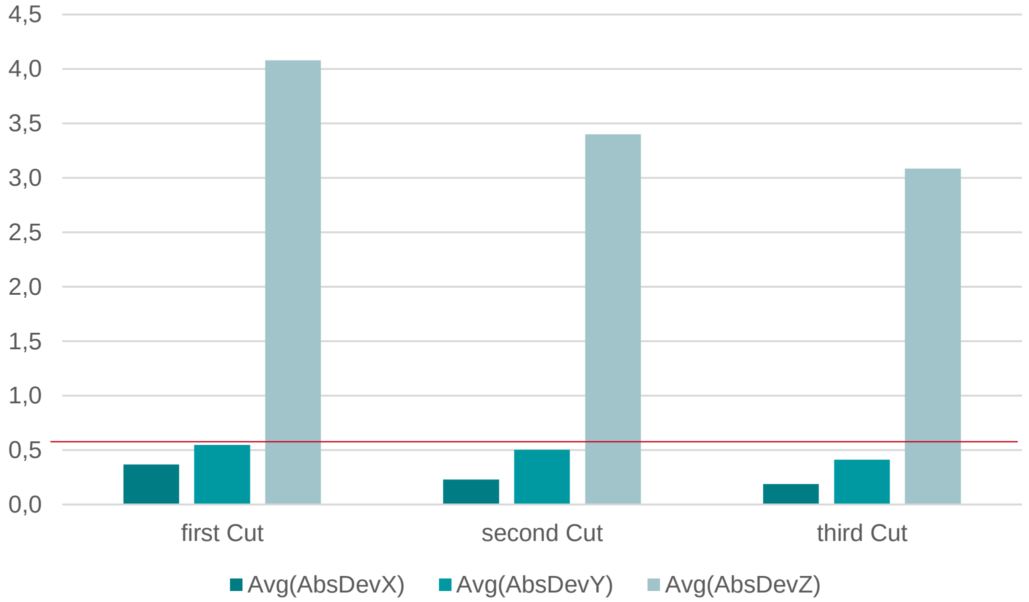
QUIZ

Which of the notches is the „third Cut“ produced with the highest speed ?



QUIZ





Name	cmd	dev	speed	tcpPose	Avg(AbsDevX)	Avg(AbsDevY)	Avg(AbsDevZ)	AbsTolXYZ	tcpZ
first Cut	MoveLin	optimus	**5.0**	http://baufest.org/dstv-test02#tcpPose_8c328310-a47c-5ac7-be84-d3db1d2007c3	0.368	0.547	4.079	-0.6 …+0.6	708.65
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third Cut	MoveLin	optimus	**20.0**	http://baufest.org/dstv-test02#tcpPose_706a2a54-ba7f-5750-b8ed-6d99f1802774	0.190	0.413	3.086	-0.6 …+0.6	708.65

Conclusion & Outlook

Conclusion

- ✓ An autonomous robotic steel machining process using the proposed DSTV ontology can be realized
- ✓ Modeling the DSTV planning data via conversion of IFC to LBD/ifcOWL is easy to implement
- ✓ The extended concepts like measurement and tolerance data can be queried with rather simple SPARQL queries
- ✓ The proposed approach enables linking of production data with machine data and building element data
- ✓ Querying the data enables further optimization and can help to clarify process dependencies (~ *slow plasma cutting* ~ *bad results*)

- ➢ **Proposed approach is feasible**

Outlook

- ➢ Further extension of DSTV ontology needed (more processes)
- ➢ Dynamic status information: OPM vs RDF-Star?
- ➢ SHACL for process constraints?
- ➢ Further work on ontology-based capability matching
- ➢ Implementing the Asset Administration Shell – **AAS** for machine / network description
- ➢ Practical: Retrofit old CNC machine in the workshop ☺

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References

[1] YouTube. (2019). *ZEMAN's "SBA2 Conti+" - The largest and most efficient Steel Beam Assembler*. *YouTube*. Retrieved June 6, 2023, from https://www.youtube.com/watch?v=MDjMuk4rWPA.

[2] Noy, N. & Mcguinness, Deborah. (2001). Ontology Development 101: A Guide to Creating Your First Ontology. Knowledge Systems Laboratory. 32.

[3] Rasmussen, Mads Holten & Lefrançois, Maxime & Bonduel, Mathias & Hviid, Christian & Karlshøj, Jan. (2018). OPM: An ontology for describing properties that evolve over time.