PBF-AMP-Onto: An Ontology For Powder Bed Fusion Additive Manufacturing Processes

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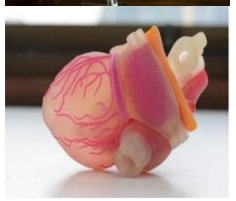
LINKÖPING UNIVERSITY

Outline

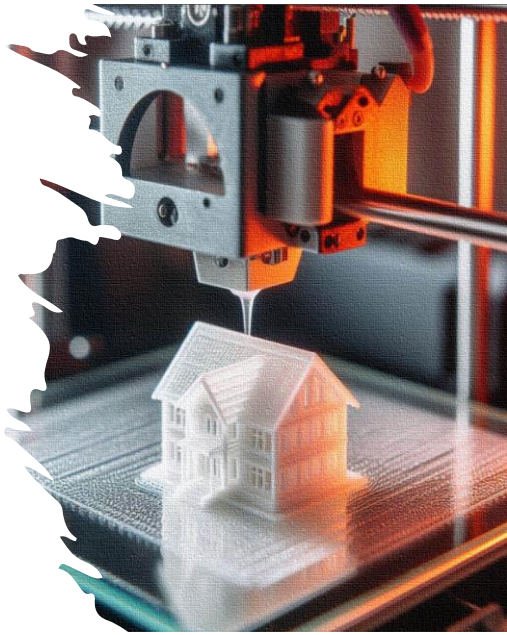
- Introduction and Motivation
- Ontology Development
  - PBF-AMP-Onto
- Evaluation
- Conclusion

Introduction: Additive Manufacturing (AM)

- AM or 3D printing
  - Layer by layer printing
- Creating products that traditional techniques cannot produce with the desired quality and requirements
- Applications of AM
  - E.g., aerospace, medicine, automotive, and construction
- Different media and methods for AM
  - Media, e.g.
    - Polymer
    - Carbon fiber
    - Metal



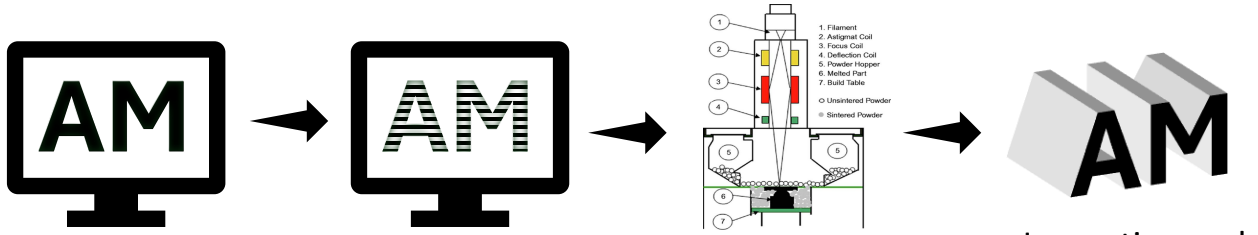
Singh, Riya, et al. "Powder bed fusion process in additive manufacturing: An overview." Materials Today: Proceedings 26 (2020).



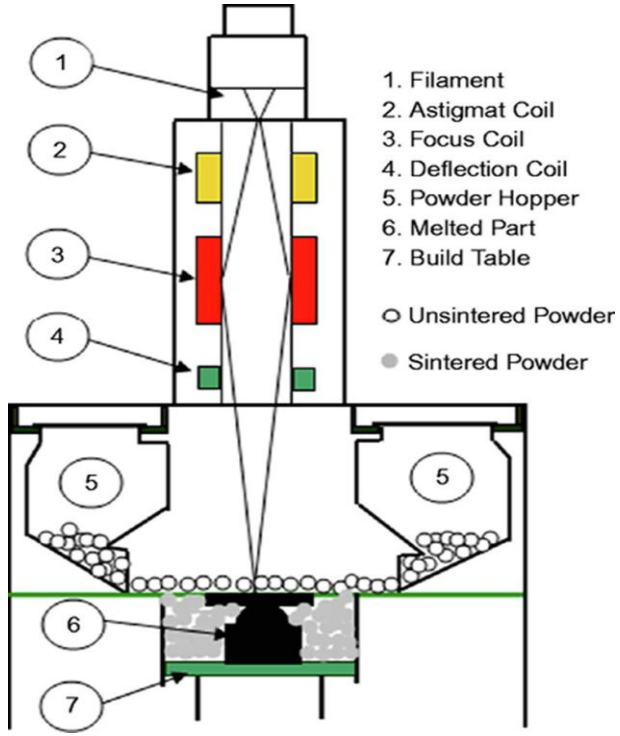
Generated with AI

Introduction: Powder Bed Fusion

- Powder Bed Fusion (PBF) 3D printing method
  - A method for AM using powdered material as printing medium
  - Energy source
    - Electron Beam
    - Laser beam
- AM processes common steps
  - 3D model design
  - Slicing software and slicing parameters
  - 3D printing
  - Inspection and testing the printed object



Example of EB-PBF printing machine



Singh, D. Dev, T. Mahender, and Avala Raji Reddy. "Powder bed fusion process: A brief review." Materials Today: Proceedings 46 (2021)

Introduction: Challenge

- **One of the Challenges**
  - Data management
    - Generated or used data
      - Materials properties
      - Printer characteristics and settings
      - Monitoring data during printing
      - Slicing strategies and setting parameters
      - …
- Need for FAIR data
  - **F**indable, **A**ccessible, **I**nteroperable, and **R**eusable

Photo by Thor Balkhed

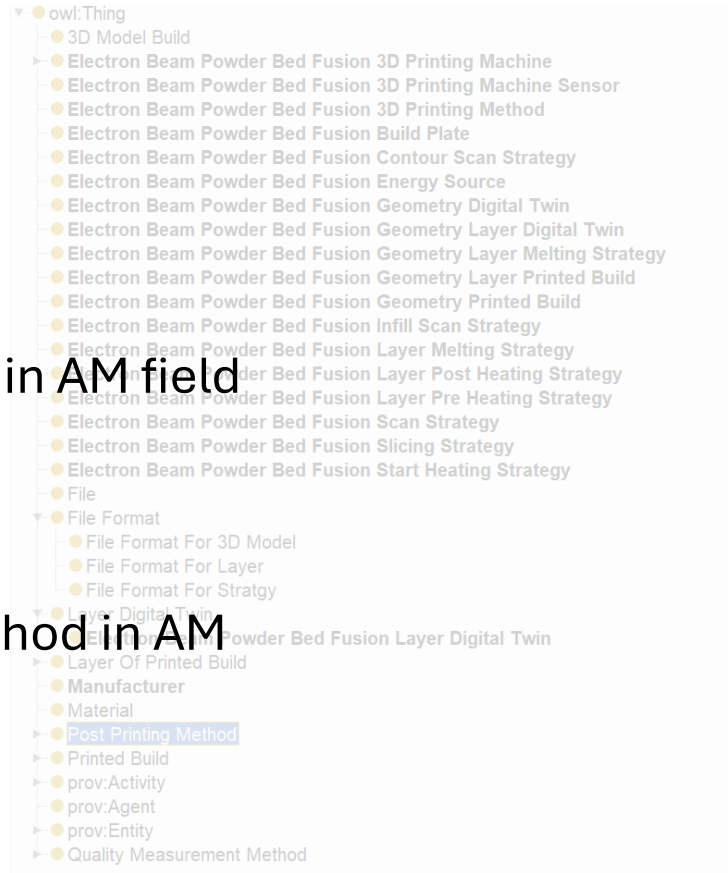
Motivation: Why PBF-AMP-Onto?

- The foundation for a comprehensive framework designed to support decision-making systems
- Formally representing domain knowledge in AM
  - Formalizing the processes
  - Identifying relationships between different steps
- Improve data interoperability

Ontology Development

PBF-AMP-Onto_EB

- Using **NeOn** ontology engineering methodology
- Developing PBF-AMP-Onto as a **modular ontology**
  - Collaboration between knowledge engineers and domain experts in AM field
- Focusing on **Powder Bed Fusion (PBF)** method
  - Specifically on **Electron Beam Powder Bed Fusion (EB-PBF)** method in AM
- Used **Protégé** as ontology development tool



Ontology Development

- Competency questions
  - **CQ1: What is the material used for each printed build in an EB-PBF printing process?**
  - **CQ2: Who is the manufacturer of the metal powder used in an EB-PBF printing process?**
  - **CQ3:** What are different sub-processes in an EB-PBF process?
  - **CQ4:** What are the inputs and outputs of each sub-process in an EB-PBF process?
  - **CQ5:** What are the properties of the layer melting strategy used in an EB-PBF slicing sub-process?
  - **CQ6:** Which 3D printing machine has been used for an EB-PBF printing process?
  - **CQ7:** What types of sensors are utilized in an EB-PBF 3D printing machine?
  - **CQ8:** What is the total number of layers used in an EB-PBF printing process?
  - **CQ9:** What is the layer thickness used in an EB-PBF printing process?
  - **CQ10:** What is the start and end date and time for a PBF-AM process?
  - **CQ11:** What is the typical beam power for the energy source used in an EB-BPF printing process?

Ontology Development

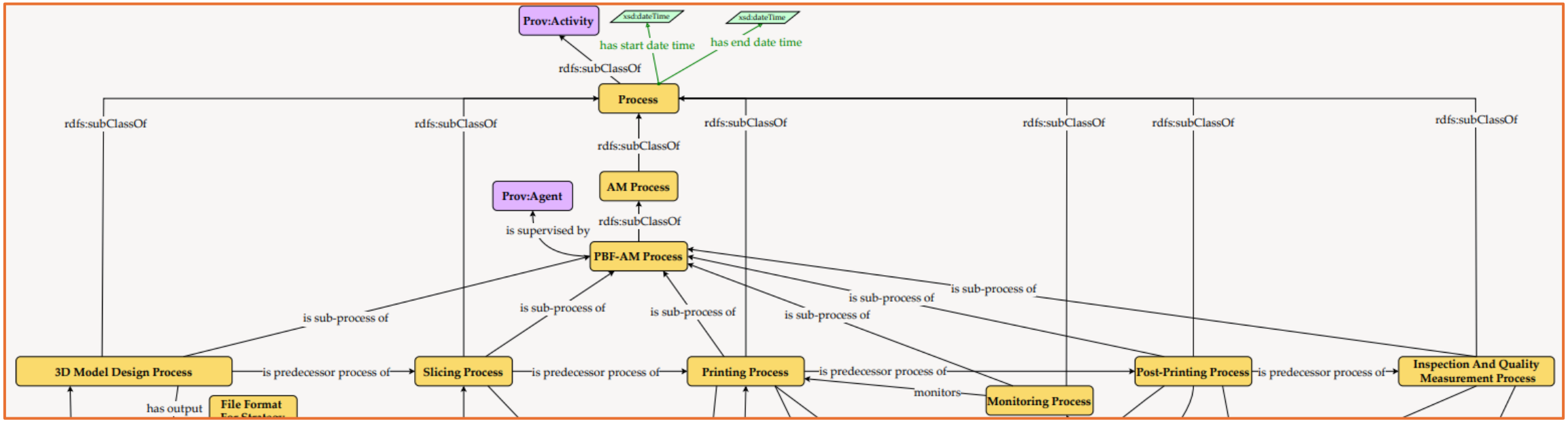
- PBF-AMP-Onto, a modular ontology

PBF-AMP-Onto_Core — Modelling the core concepts and relationships in PBF processes

PBF-AMP-Onto_EB — Modelling the concepts and relationships in Electron Beam PBF processes

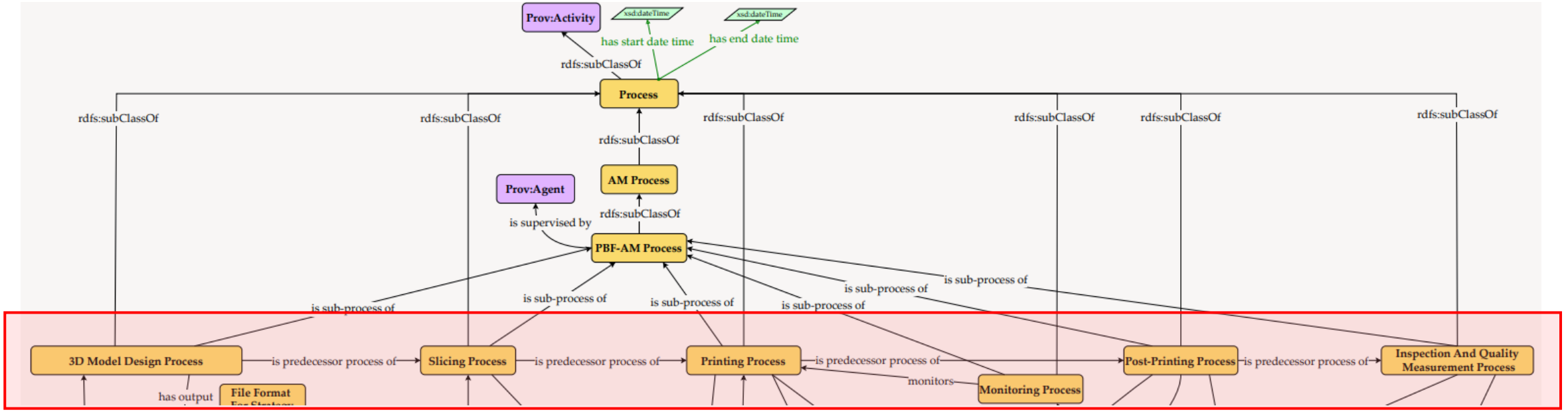
PBF-AMP-Onto_Core

- Sub-processes of PBF-AM Process



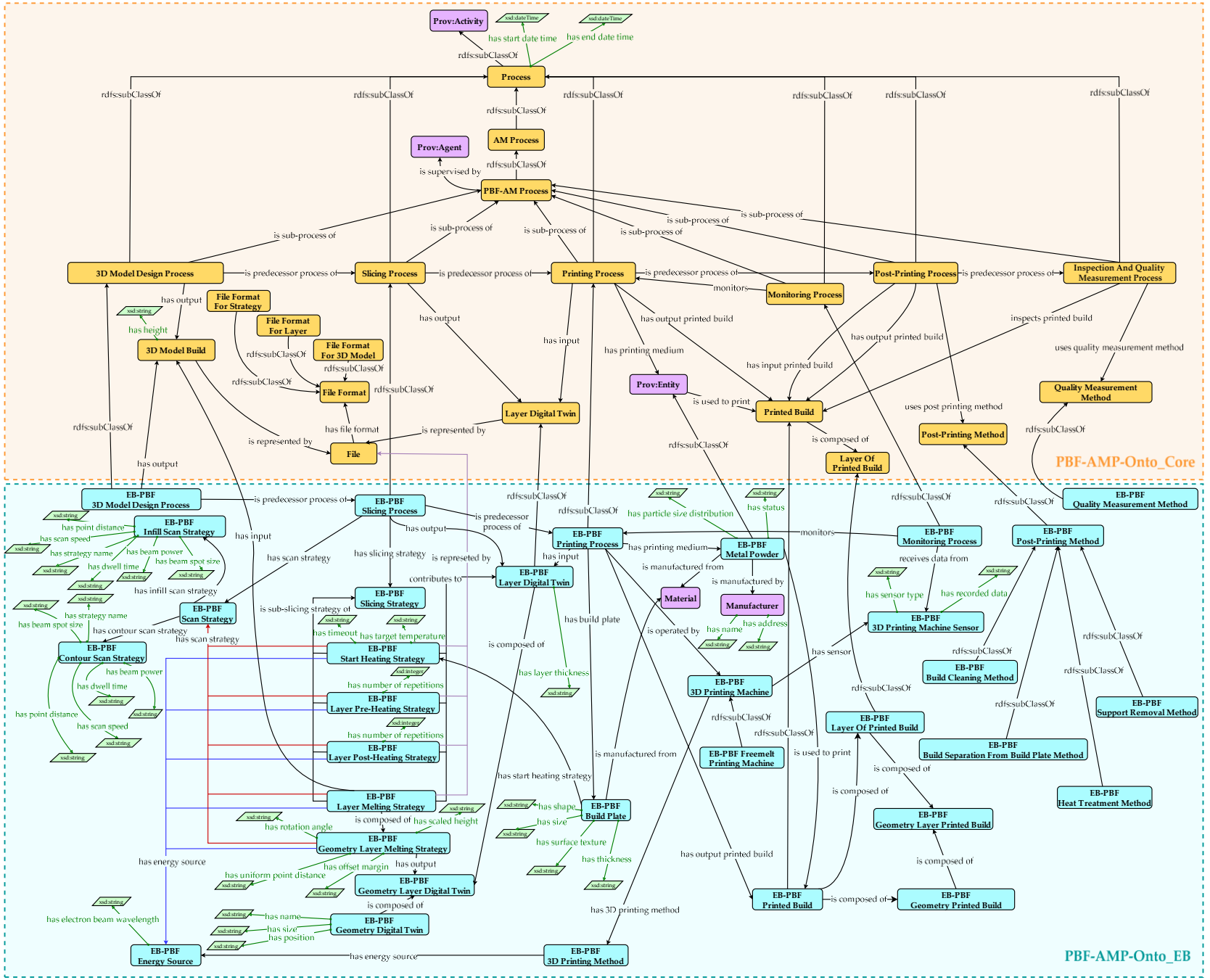
PBF-AMP-Onto_Core

- Sub-processes of PBF-AM Process



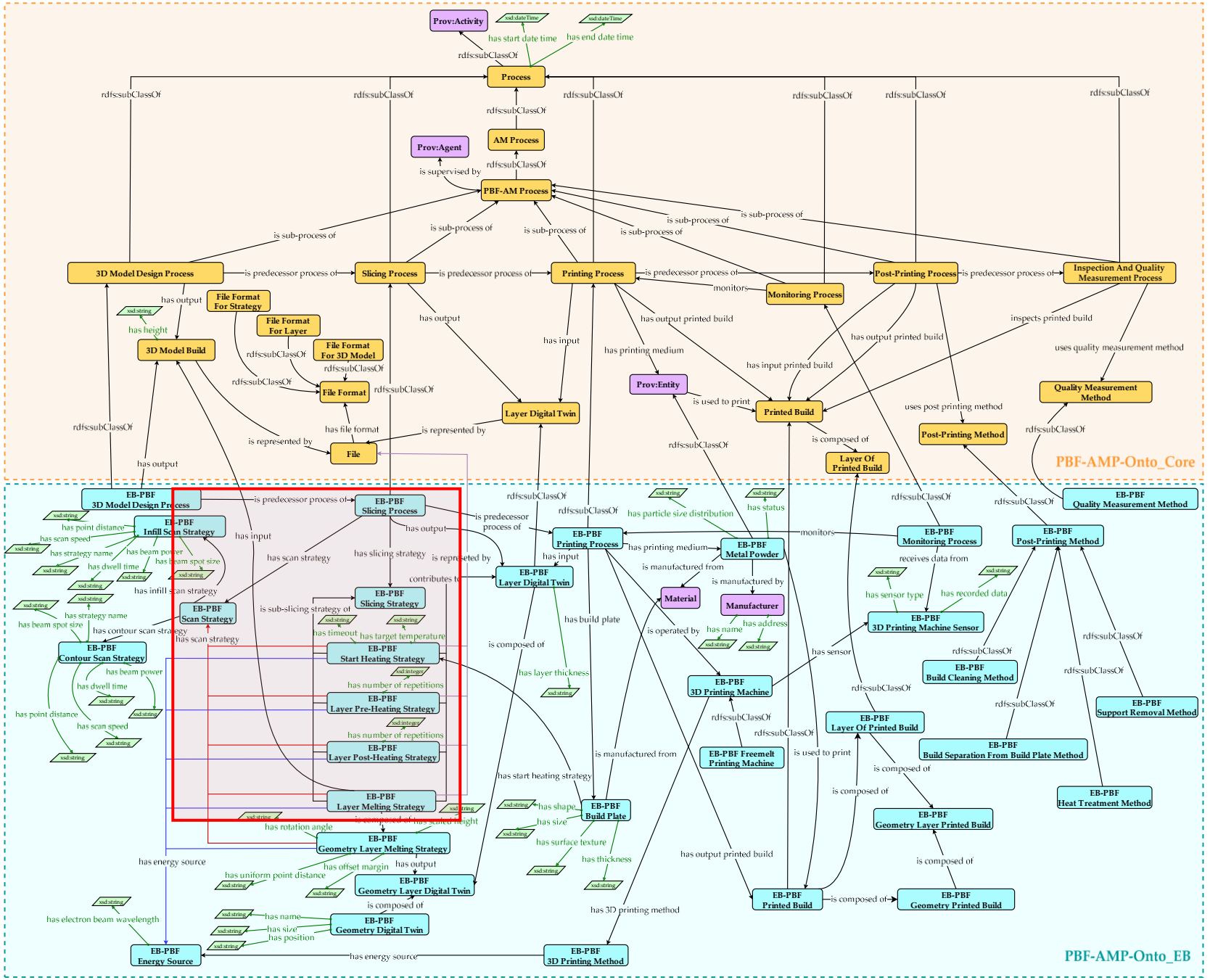
PBF-AMP-Onto_Core

PBF-AMP-Onto_EB



PBF-AMP-Onto_Core

PBF-AMP-Onto_EB



Evaluation

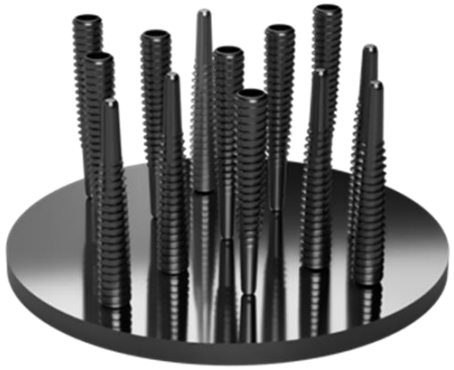
Construct a knowledge graph (KG) for an EB-PBF experiment

Execute SPARQL queries to address competency questions and retrieve the corresponding answers

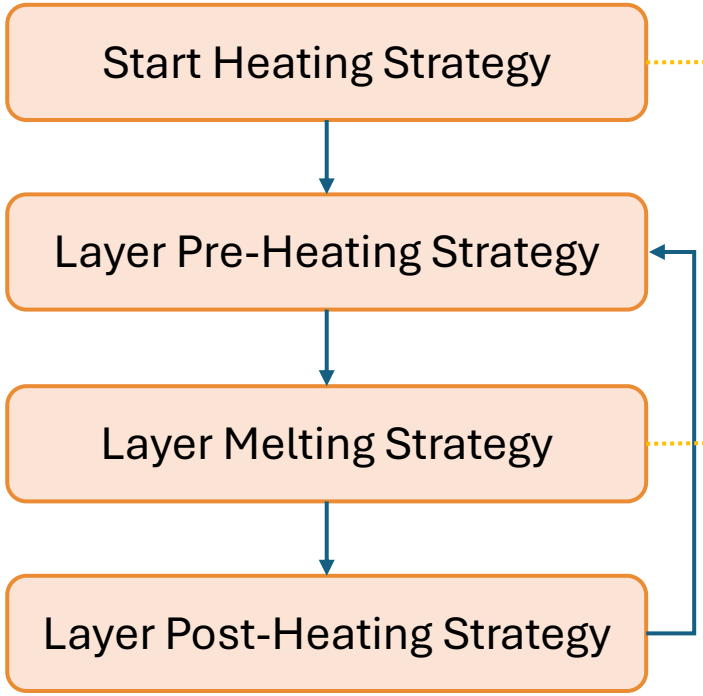
Use Case

- An EB-PBF printing experiment
  - Printing 13 screws
  - Printing medium material: stainless steel
  - Build plate material: stainless steel
  - Slicing the 3D model to layers using various slicing strategies

Photo by Anton Wiberg



Use Case

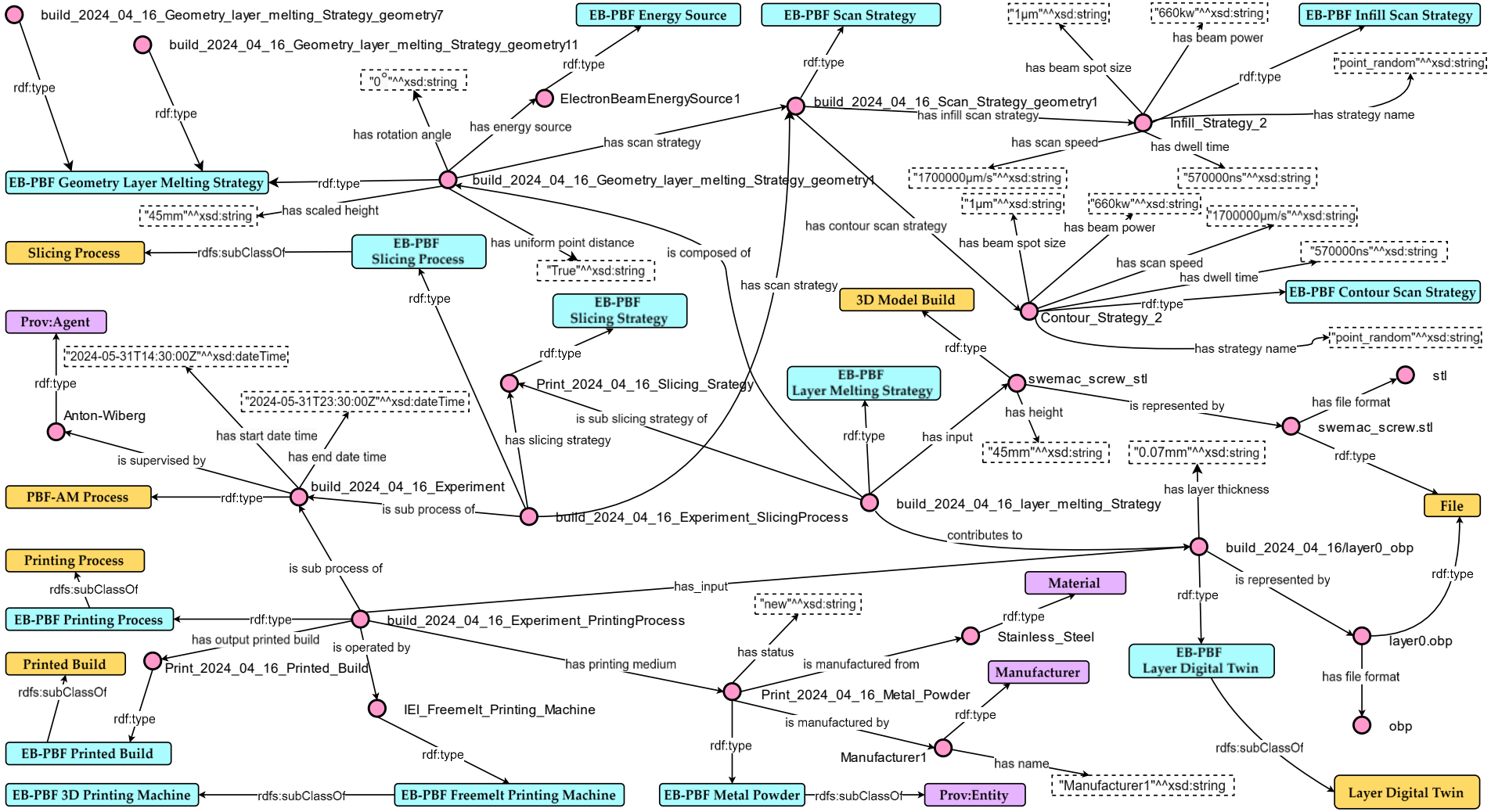


Applying on build plate once

```
build = SimpleBuild(
    meshes = [part7, part1, part11, part5, part8, part13, part3, part9, part6,
    part2, part12, part4, part10],
    spot_size = [1],
    beam_power = [720, 660, 660,  660, 660, 660, 660, 660, 660, 660, 660, 660, 660, 660],
    scan_speed = [1700000],
    dwell_time = [58333, 570000, 570000, 700000, 700000, 186122, 186122, 228571,
    228571, 46530, 46530, 57142, 57142],
    infill_strategy = ["point_random"],
    infill_settings = [{}],
    infill_point_distance = [0.1, 0.35, 0.35, 0.35, 0.35, 0.2, 0.2, 0.2, 0.2, 0.1, 0.
    1, 0.1, 0.1],
    layer_height = 0.07,
    rotation_angle = [0],
    bse_melt = True,
    bse_step = 1,
    )
```

Use Case

- Part of the KG constructed for the use case (an EB-PBF experiment)



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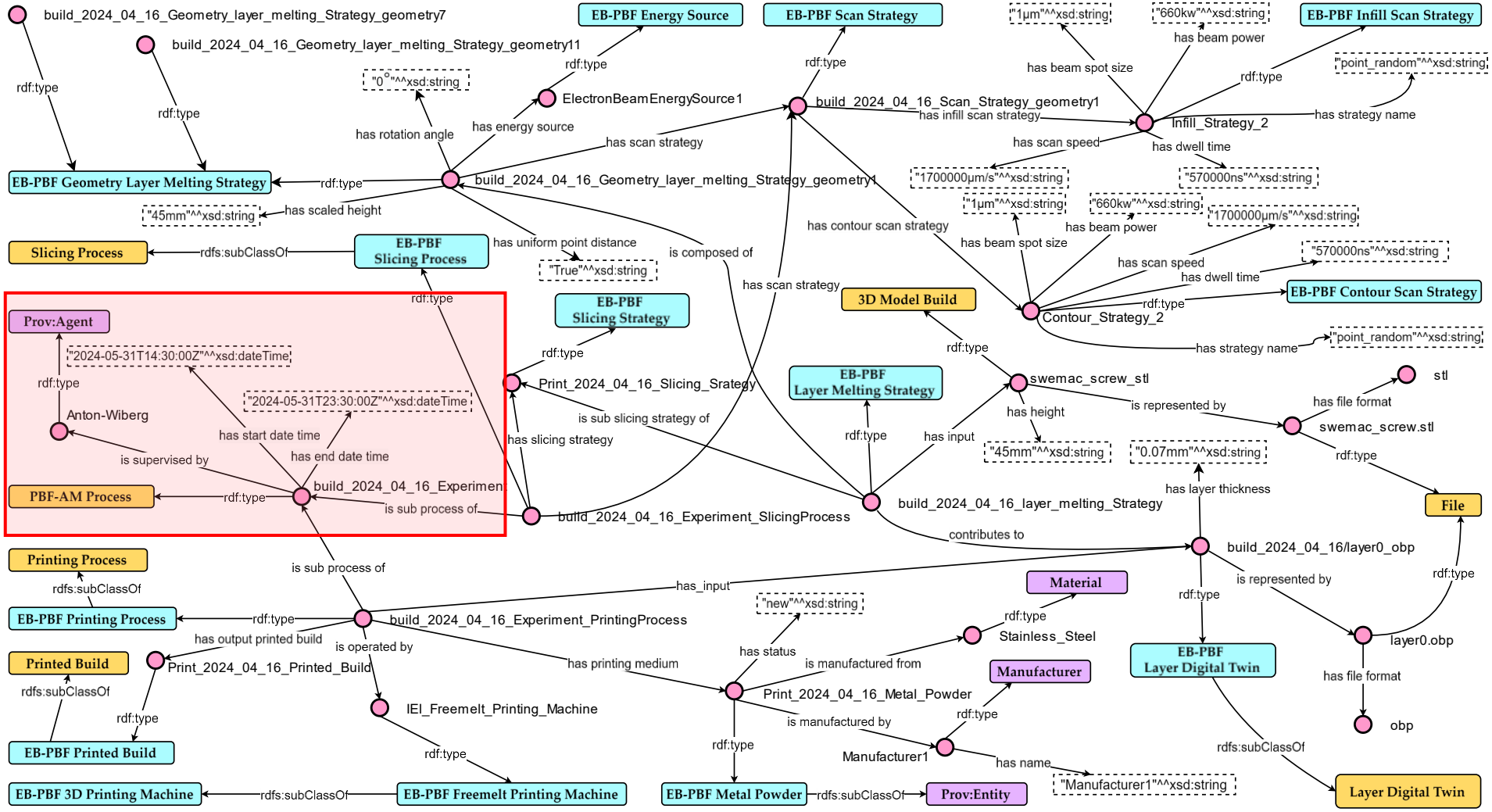

Evaluation

- Demonstrate how the competency questions can be answered using SPARQL queries
  - Use blazegraph for executing SPARQL queries

An example SPARQL query CQ1 (What is the material used for each printed build in an EB-PBF printing process?).

```
PREFIX pbfampocore: <http://www.semanticweb.org/minab62/ontologies/2024/4/PBF-AMP-Onto_Core#>
PREFIX pbfampoeb: <http://www.semanticweb.org/minab62/ontologies/2024/5/PBF-AMP-Onto_EB#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
SELECT ?printing_process ?printed_build ?material
WHERE {
  ?printed_build rdf:type pbfampoeb:Electron_Beam_Powder_Bed_Fusion_Printed_Build.
  ?printing_process rdf:type pbfampoeb:Electron_Beam_Powder_Bed_Fusion_Printing_Process.
  ?printing_process pbfampoeb:has_output_printed_build ?printed_build.
  ?metal_powder rdf:type pbfampoeb:Electron_Beam_Powder_Bed_Fusion_Metal_Powder.
  ?printing_process pbfampocore:has_printing_medium ?metal_powder.
  ?metal_powder pbfampoeb:is_manufactured_from ?material. }
```

CQ1

printing_process	printed_build	material
pbfampoeb:build_2024_04_16_Experiment_PrintingProcess	pbfampoeb:Print_2024_04_16_Printed_Build	pbfampoeb:Stainless_Steel

An example SPARQL query for CQ7 (What types of sensors are utilized in an EB-PBF 3D printing machine?).

```
PREFIX pbfampocore: <http://www.semanticweb.org/minab62/ontologies/2024/4/PBF-AMP-Onto_Core#>
PREFIX pbfampoeb: <http://www.semanticweb.org/minab62/ontologies/2024/5/PBF-AMP-Onto_EB#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT ?printing_machine ?sensor ?sensor_type
WHERE {
  ?printing_machine_subclass rdfs:subClassOf
  pbfampoeb:Electron_Beam_Powder_Bed_Fusion_3D_Printing_Machine.
  ?printing_machine rdf:type ?printing_machine_subclass.
  ?printing_machine pbfampoeb:has_sensor ?sensor.
  ?sensor pbfampoeb:has_sensor_type ?sensor_type. }
```

CQ7

printing_machine	sensor	sensor_type
pbfampoeb:IEI_Freemelt_Printing_Machine	pbfampoeb:Temp_Sensor_1	Temperature
pbfampoeb:IEI_Freemelt_Printing_Machine	pbfampoeb:Temp_Sensor_2	Temperature
pbfampoeb:IEI_Freemelt_Printing_Machine	pbfampoeb:Temp_Sensor_3	Temperature
pbfampoeb:IEI_Freemelt_Printing_Machine	pbfampoeb:Temp_Sensor_4	Temperature

Conclusion

- We developed a modular ontology for PBF with a specialized module for EB-PBF
- We executed queries on the use case example to show the usefulness of the ontology

Future work

- Proposing a standardized way to integrate information from different sources
- Extending our ontology with new modules
- Reusing some concepts from existing ontologies

Visit our GitHub repository for this project

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