Point cloud processing for geometric and semantic interpretation

Florent Poux

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Arts. L335-2 to L335-4

Visual perception

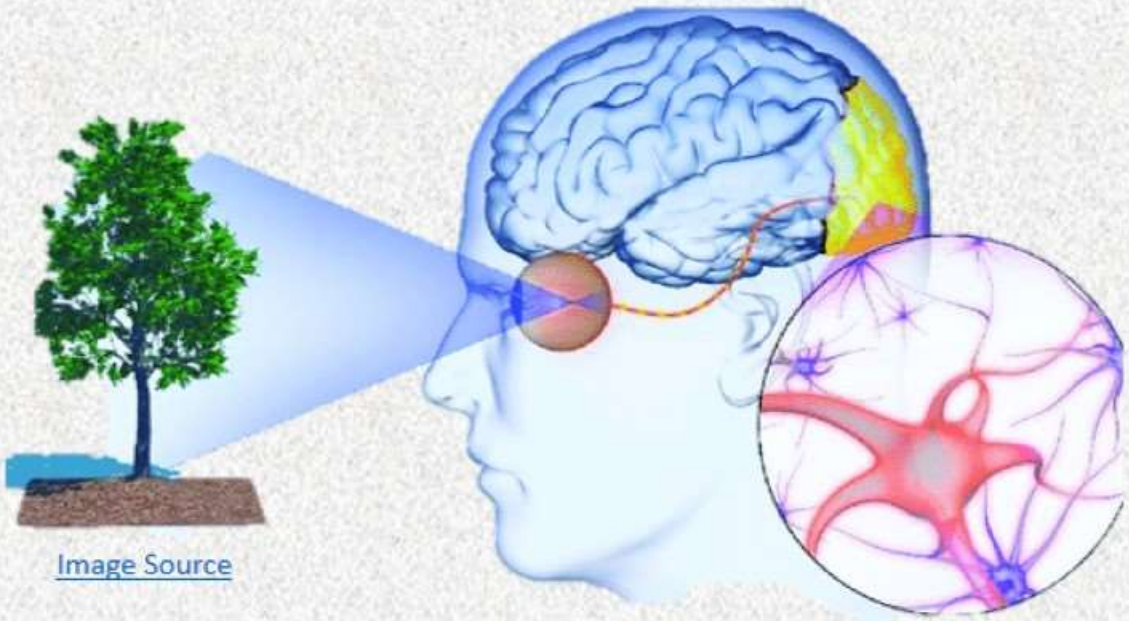


Image Source

Sensory Data

Knowledge stored in the brain

Inference about what is out there

" when we open **our eyes** on a familiar scene, we form an immediate impression of recognizable objects, organized coherently in a spatial framework " (Treisman, 1980)

Digital Environment

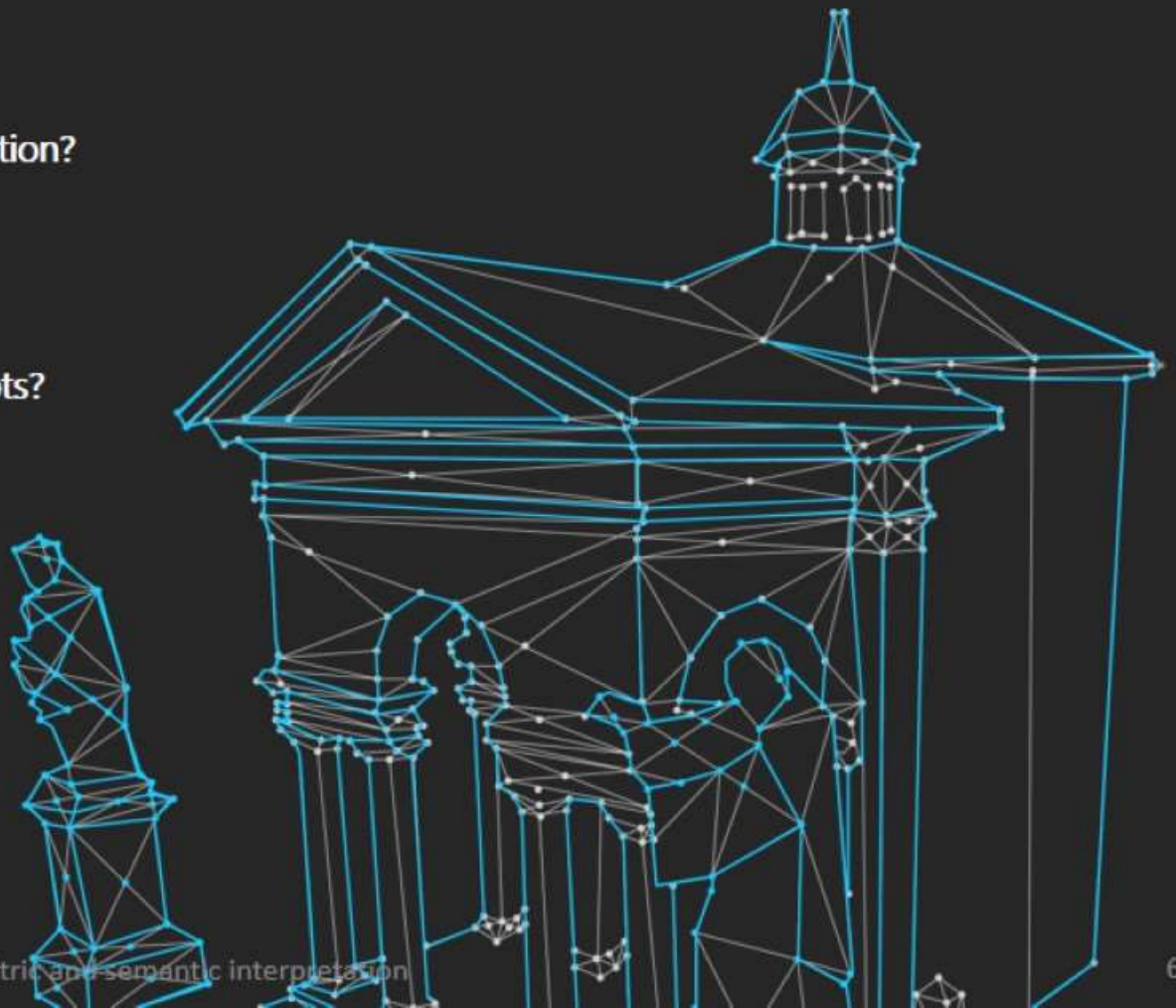
Human Perception?

" when we open our eyes on a familiar scene, we form an immediate impression of recognizable objects, organized coherently in a spatial framework " (Treisman, 1980)

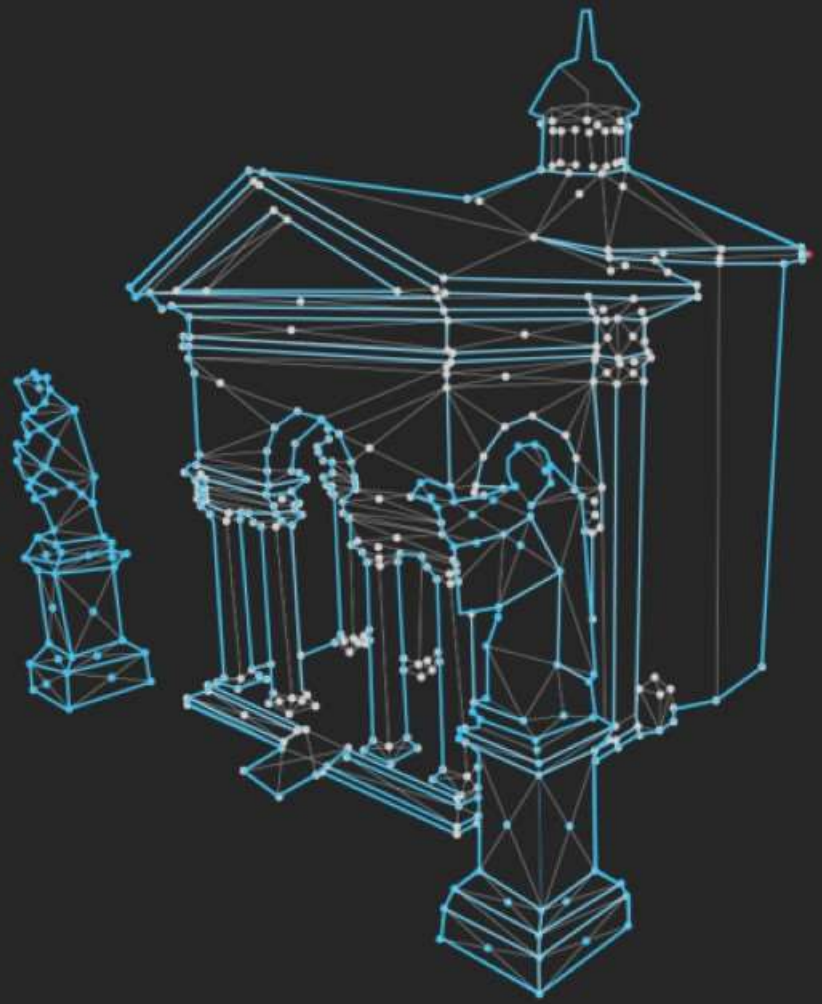
A sensor captures a scene, and the computer will make sense out of the gathered data through available knowledge and output a semantic representation.

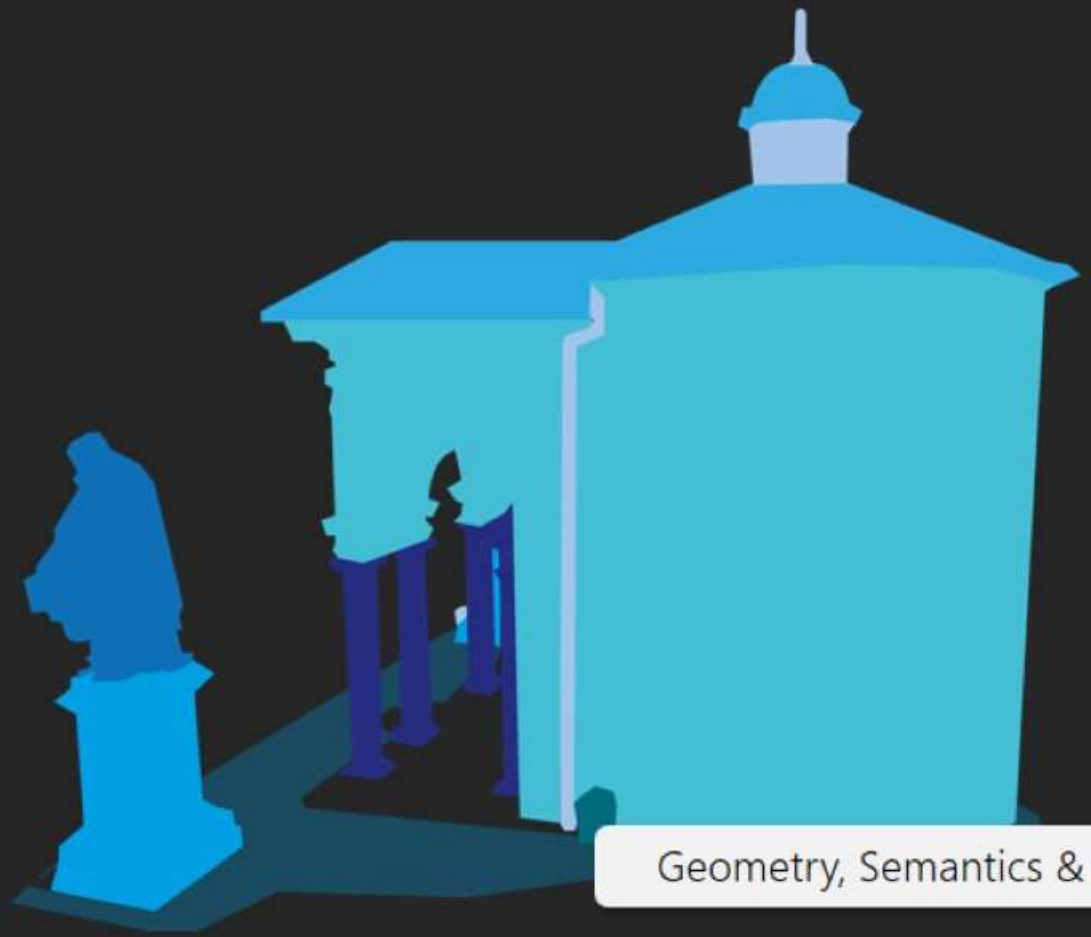
Keynote summary

1. **Can we mimick our perception system powers? (geometry, semantics & interpretation)**
    1. The high-level workflow
    2. Point cloud processing automation
    3. The Smart Point Cloud
    4. Interpretation for decision-making
2. **Can we play on multi-layered perception and representation?**
    1. Reality Capture methods for geometric consistency
    2. 3D Geometric representation
    3. Semantic representation
    4. Level of Detail and Semantics
    5. The viewpoint case
3. **Can we address widely different applications and concepts?**
    1. Method adaptation to the needs
    2. ANI vs AGI vs ASI
    3. Detection, Classification and Segmentation
    4. Seemantic augmentation methods
    5. 3D Geometric representation
    6. Semantic augmentation
4. **A word on generalization?**
5. **Identified Perspectives**
6. **Conclusion**



1. A parallel to our perceptual system for Decision-Making?





Geometry, Semantics & Interpretation

Workflow

Real world

Digitization

Low-level digital model

Transformation (additional info from domain or app.)

High-level digital model

Usage Interpretation

Automation

- Acquisition
- Pre-processing
- Registration
- Segmentation
- Classification
- Structuration
- Application

Image sourceVR Modeler: From image sequences to 3D models

- Acquisition
- Pre-processing
- Registration
- Segmentation
- Classification
- Structuration
- Application

Image sourceVR Modeler: From image sequences to 3D models

- Acquisition
- Pre-processing
- **Registration**
- Segmentation
- Classification
- Structuration
- Application

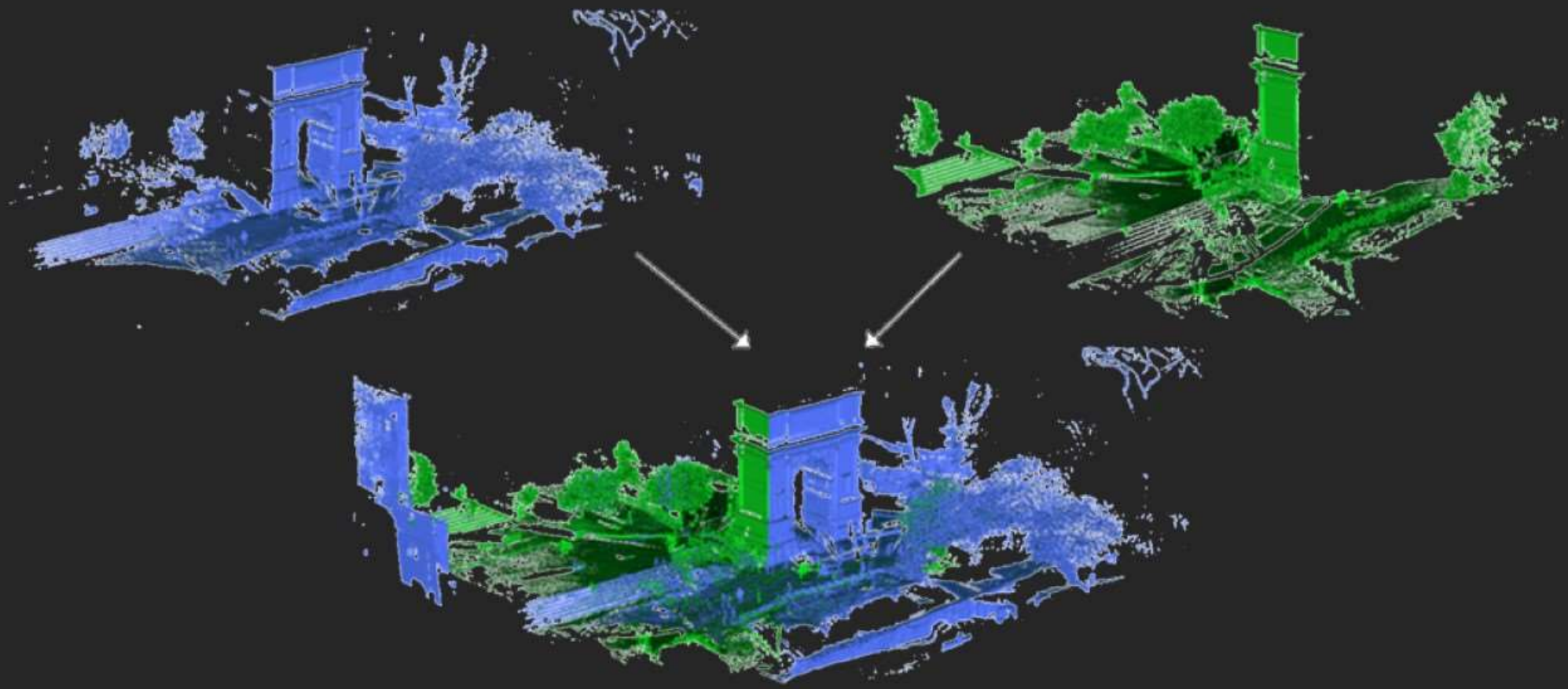
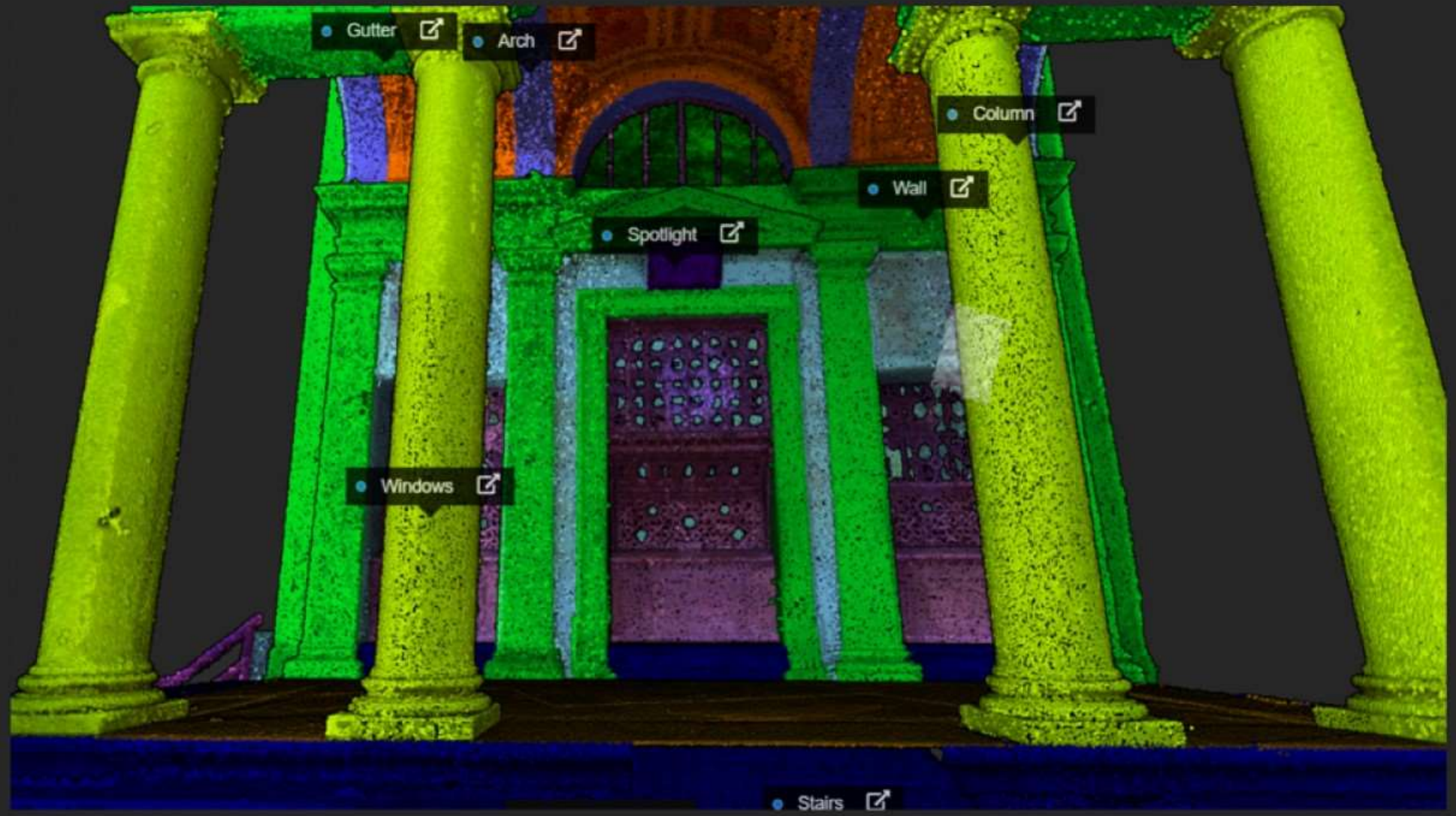


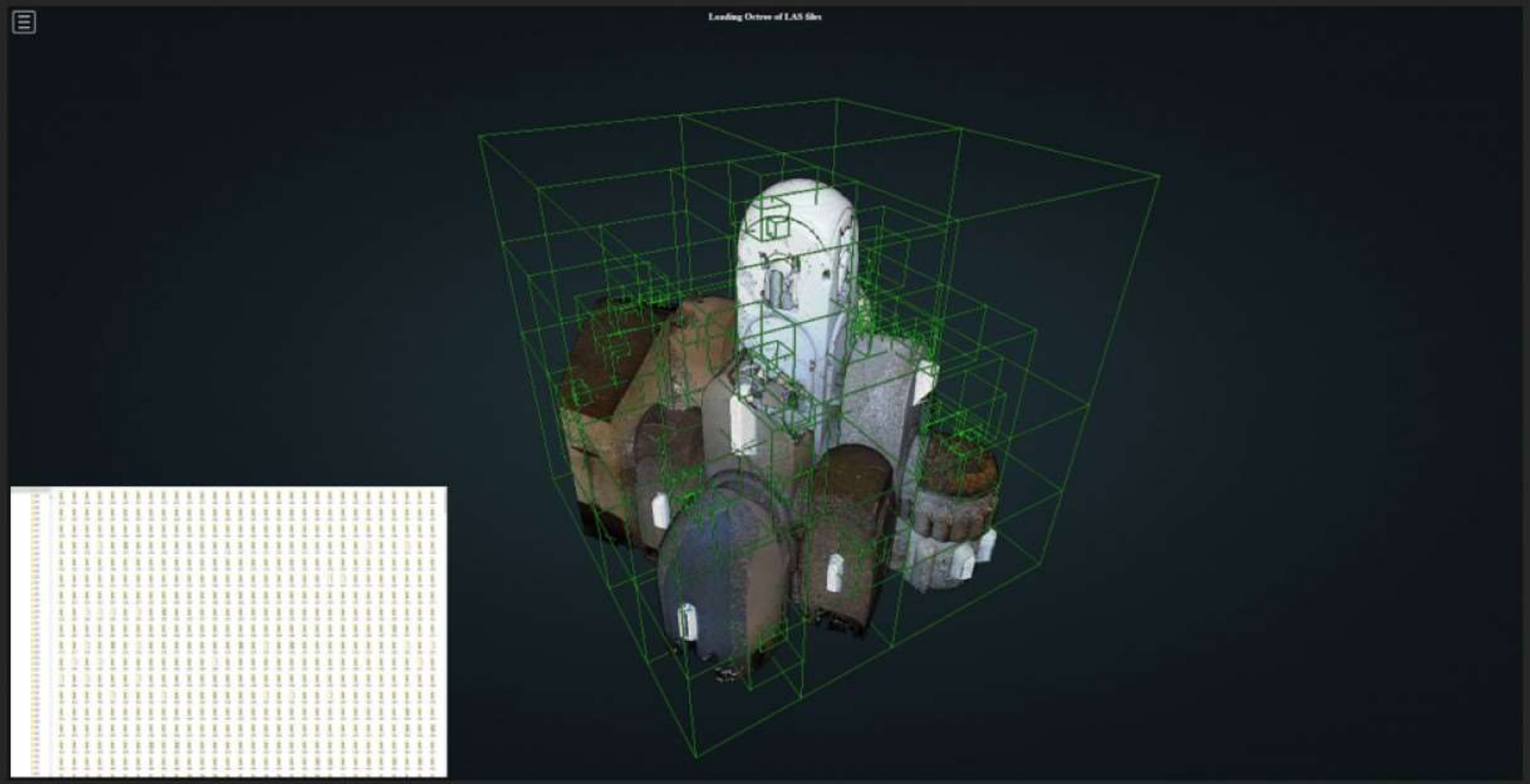
Image source: ETH Zürich

- Acquisition
- Pre-processing
- Registration
- **Segmentation**
- Classification
- Structuration
- Application

- Acquisition
- Pre-processing
- Registration
- Segmentation
- **Classification**
- Structuration
- Application



- Acquisition
- Pre-processing
- Registration
- Segmentation
- Classification
- **Structuration**
- Application



- Acquisition
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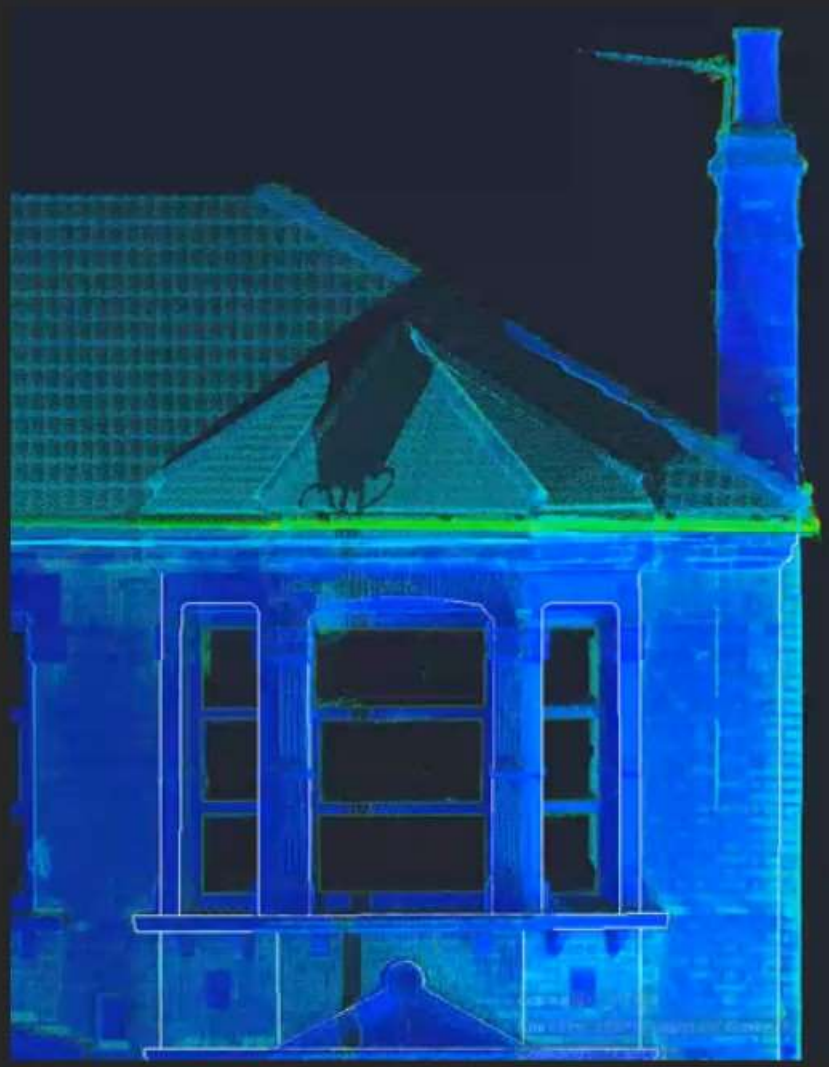
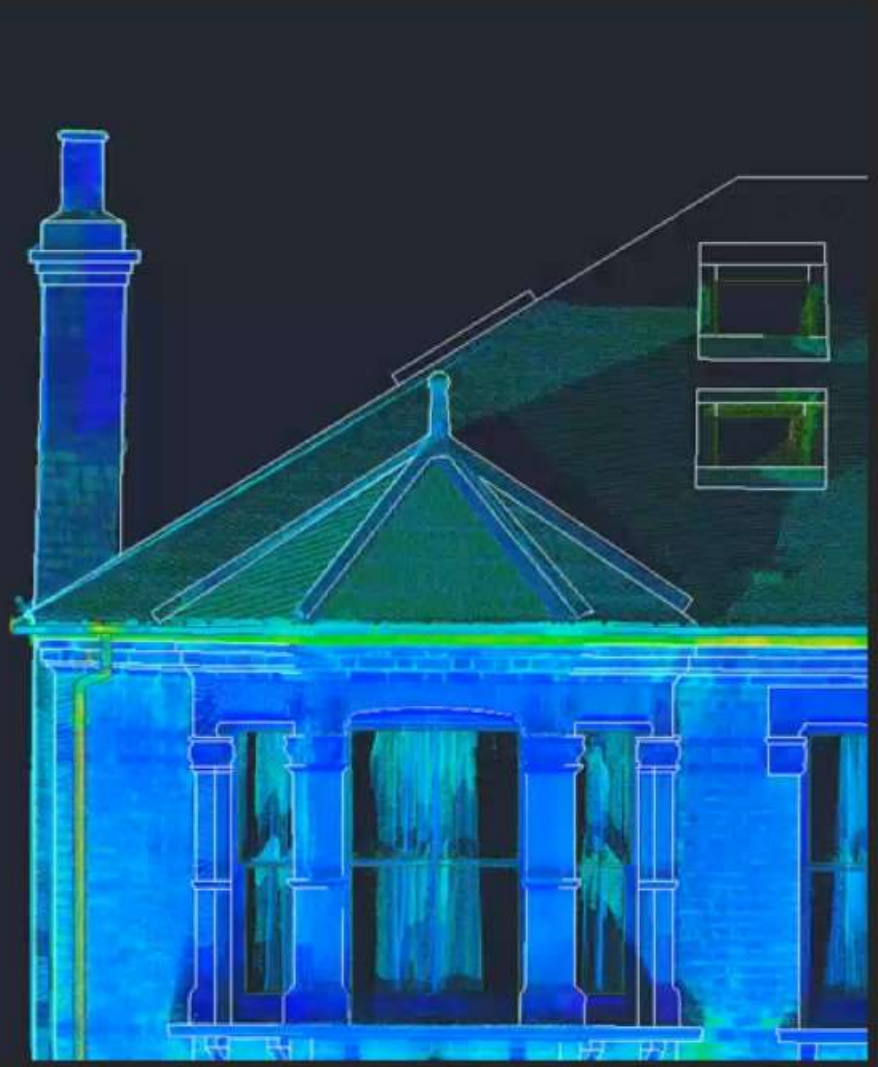
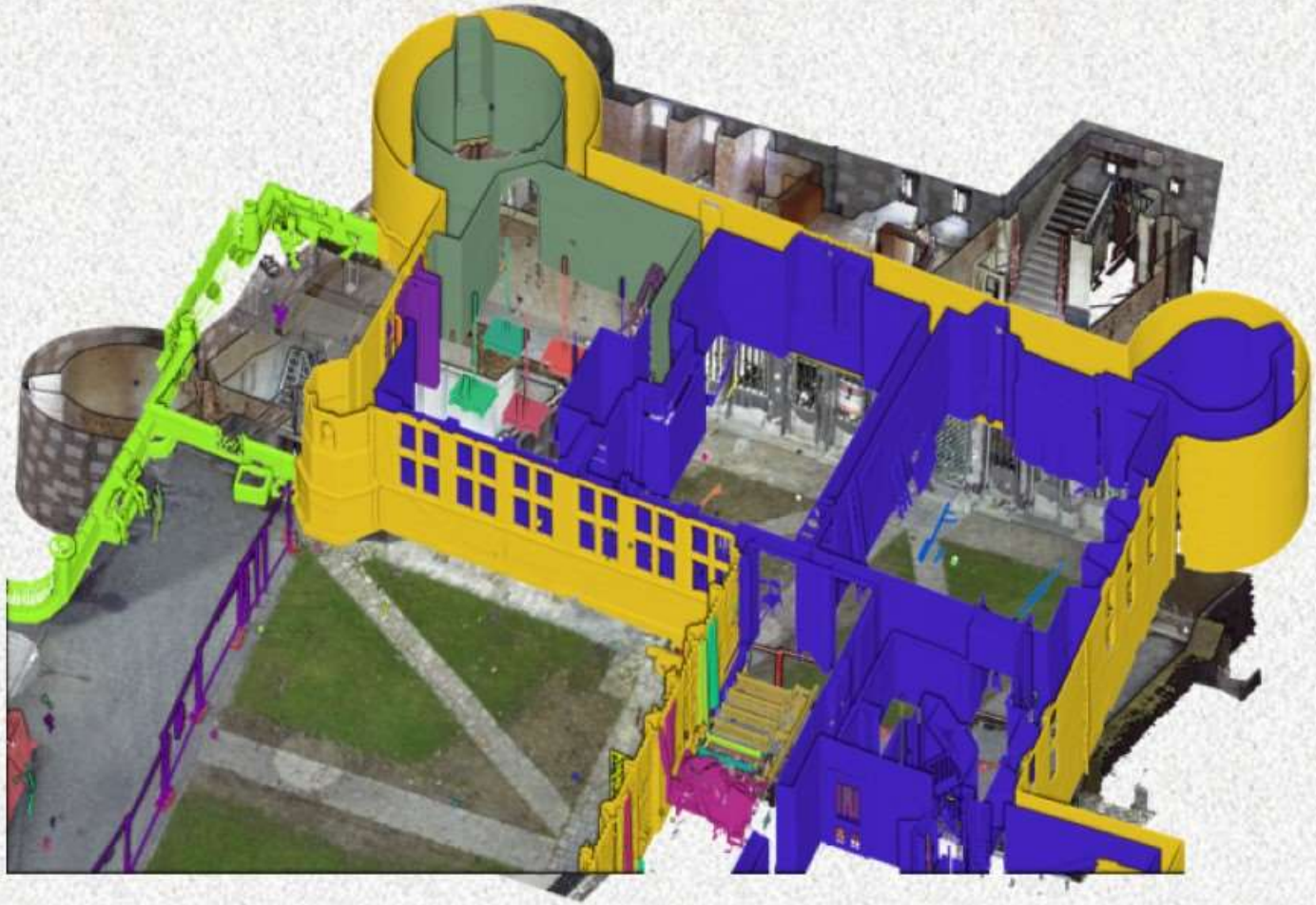




The Smart Point Cloud



CLASSICAL

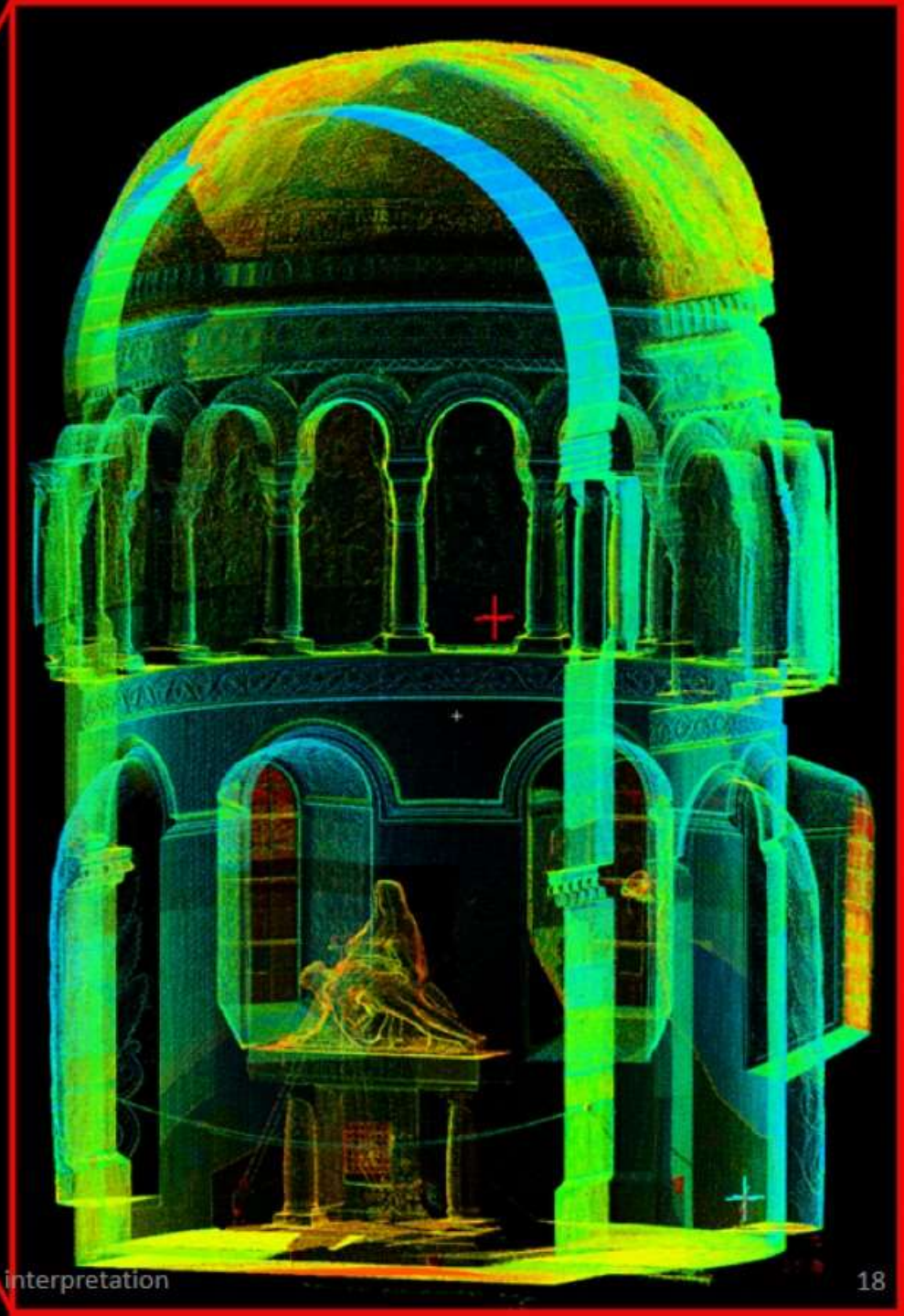
THE SPC

KNOWLEDGE

DELINEATION
INTERPRETATION
EXTRACTION
SIMULATION

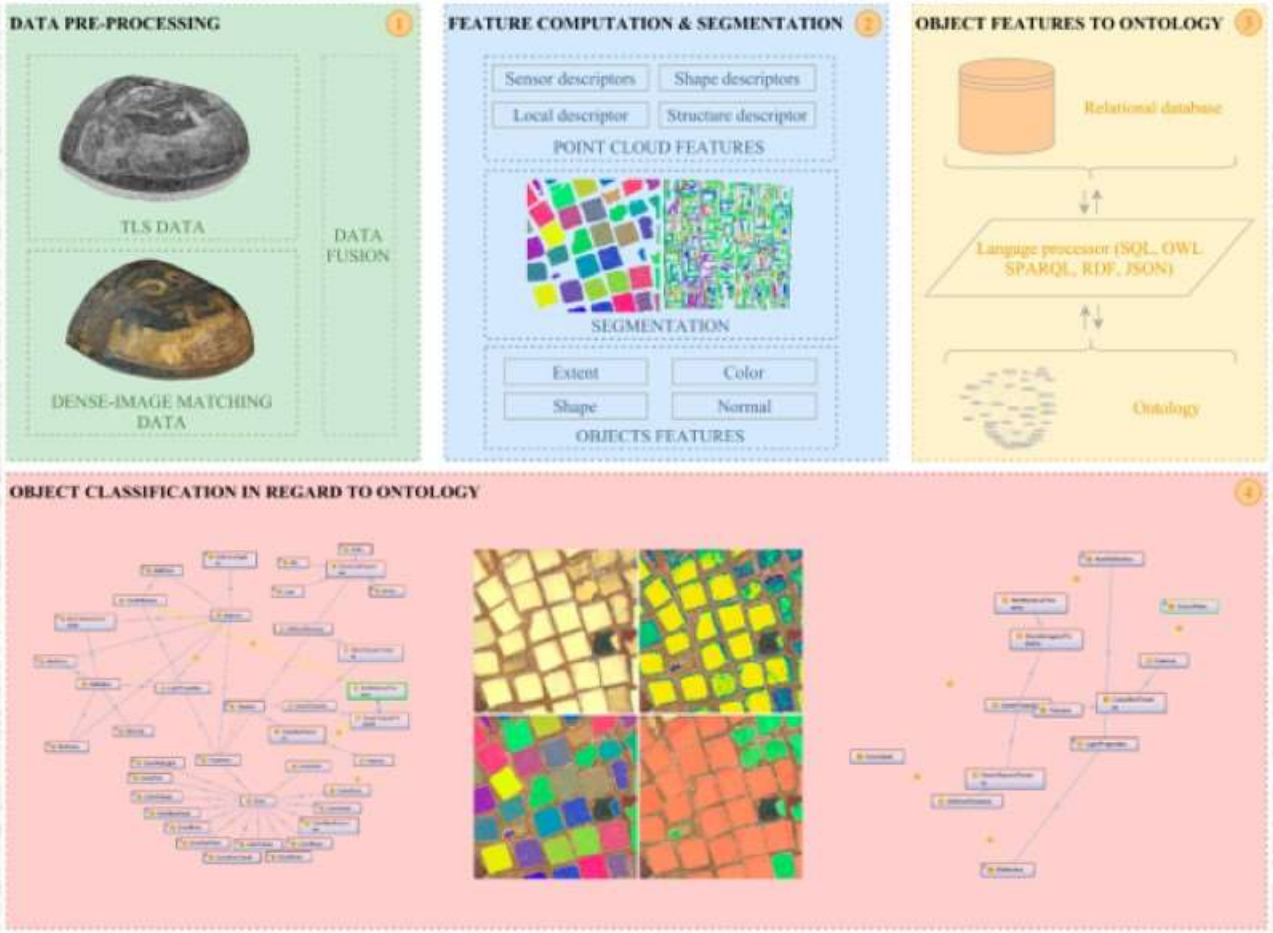
SMART POINT CLOUD: DEFINITION AND REMAINING CHALLENGES, Poux et al., 2016

The 3D Laser Scan

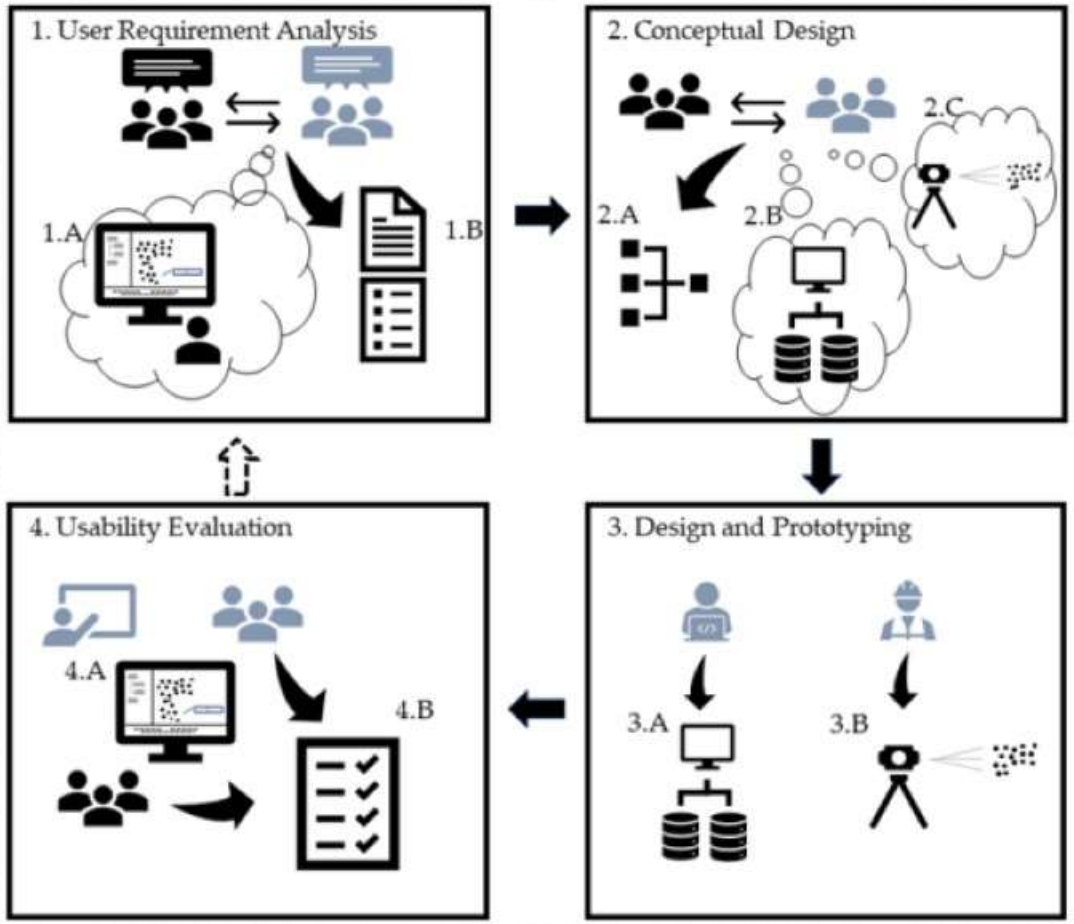


The Image acquisition

A specialized workflow



3D Point Clouds in Archaeology: Advances in Acquisition, Processing and Knowledge Integration Applied to Quasi-Planar Objects, Poux et al., 2017

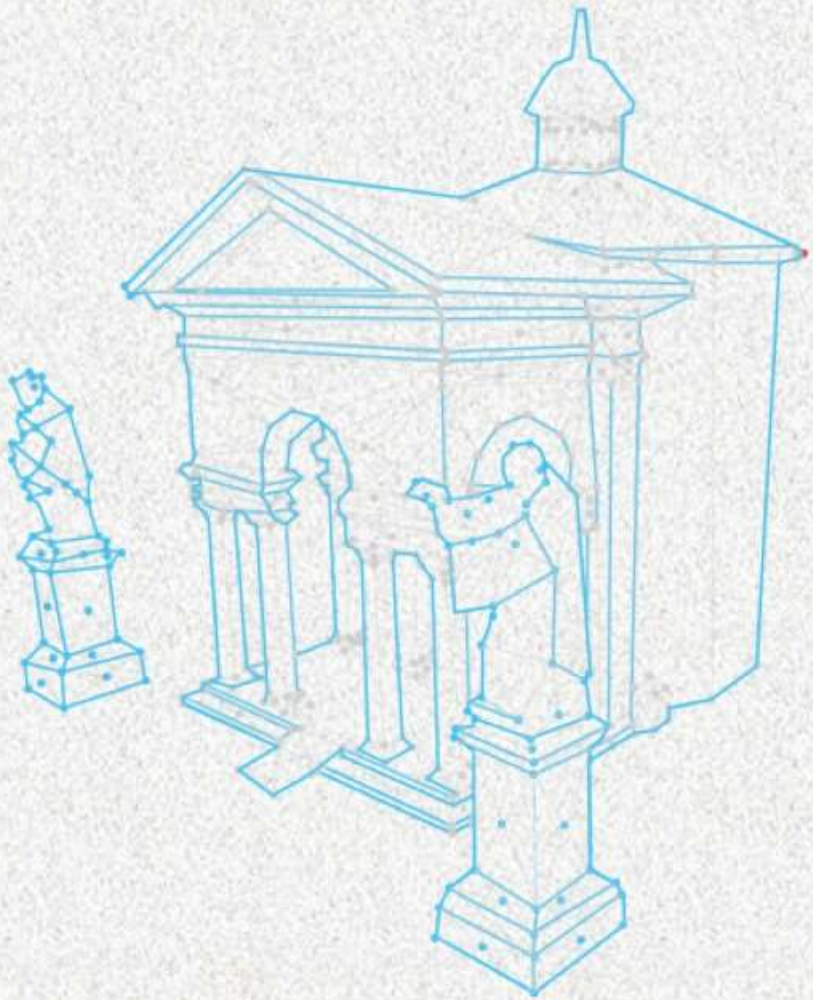


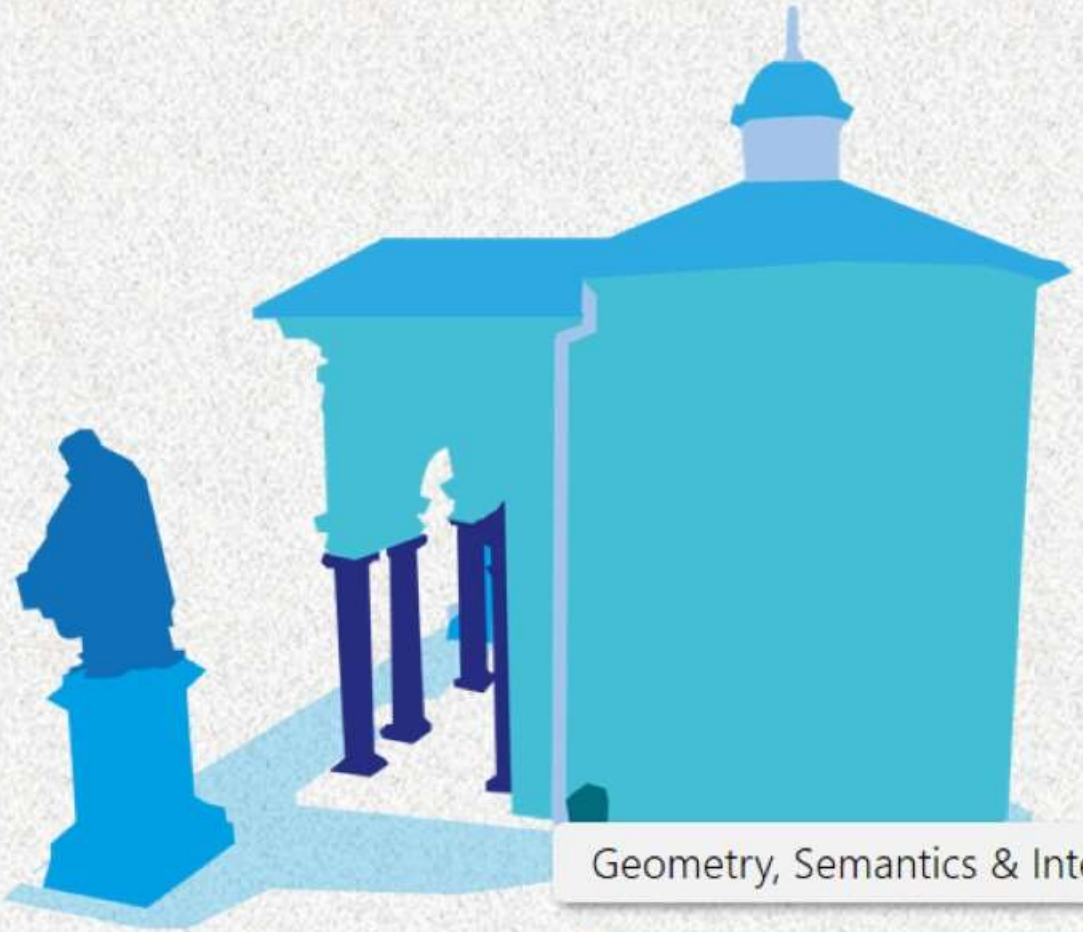
A Built Heritage Information System Based on Point Cloud Data: HIS-PC, Poux et al., 2020

INITIAL GOLD FAIENCE SILVER

The Decision-making tool

1. A parallel to our perceptual system for Decision-Making?

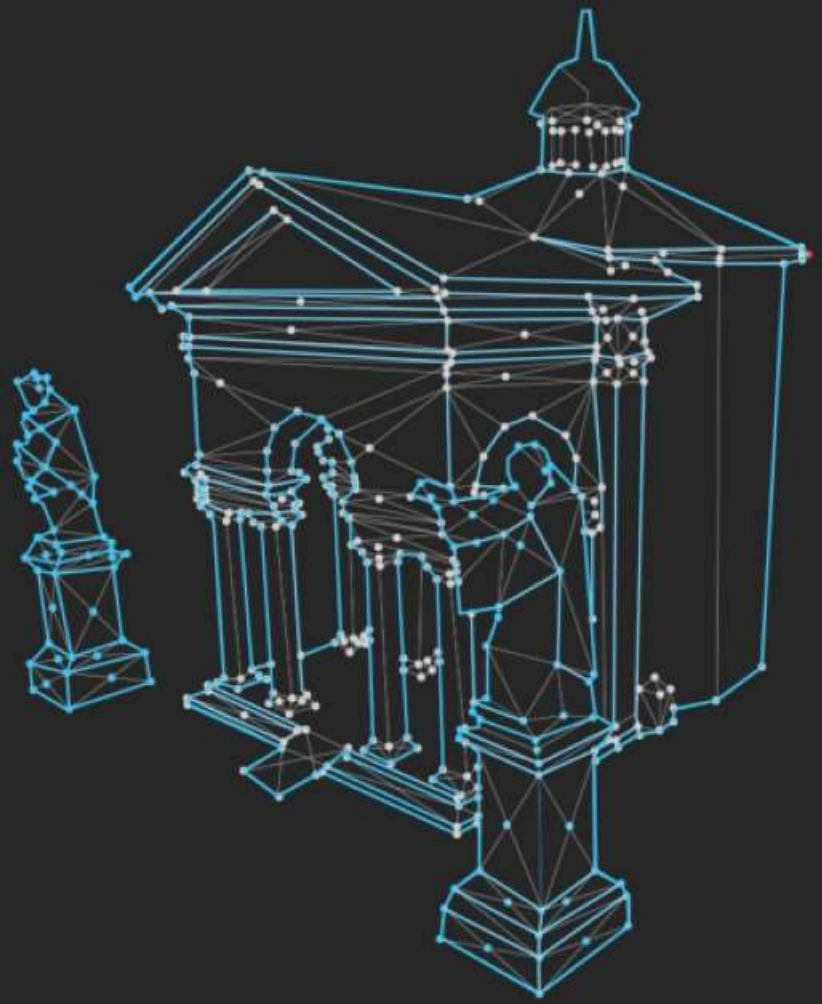


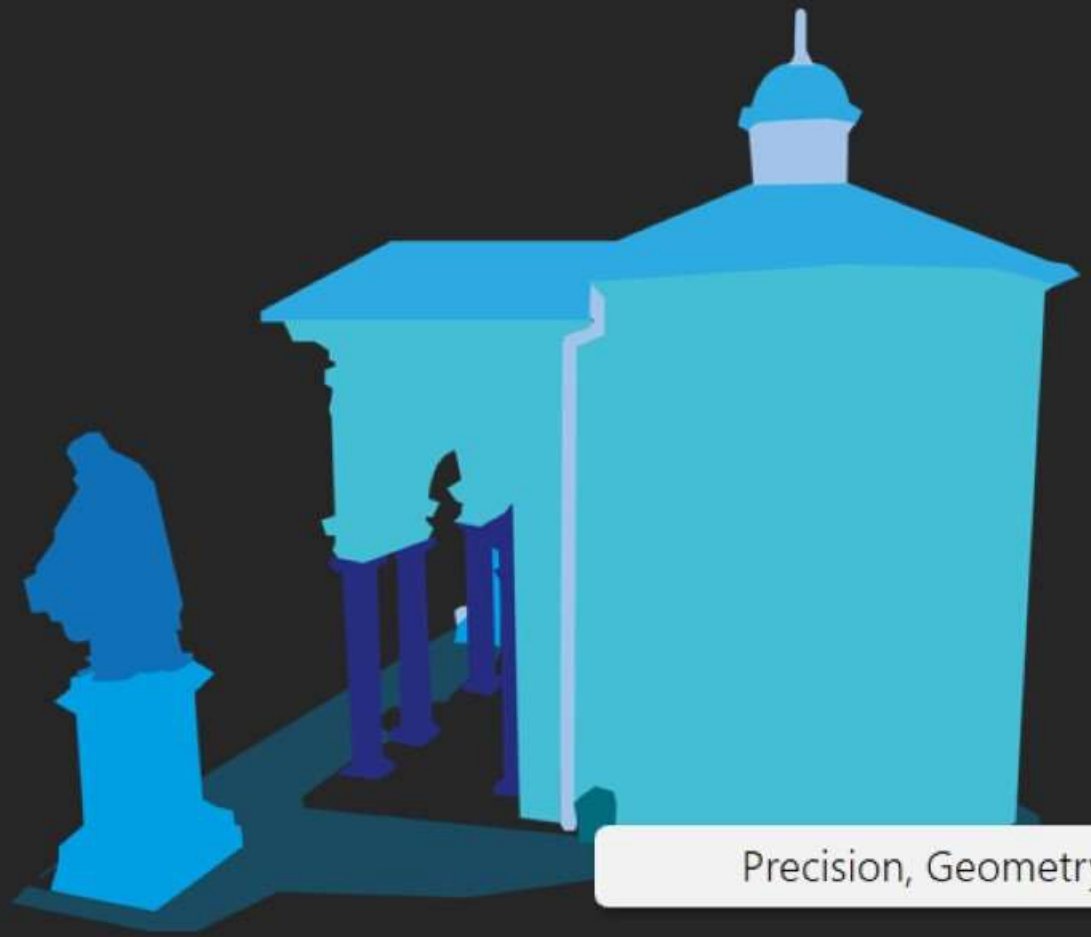


Geometry, Semantics & Interpretation ✓

Enhanced Sensing +

2. Multiple levels of representation and perception?

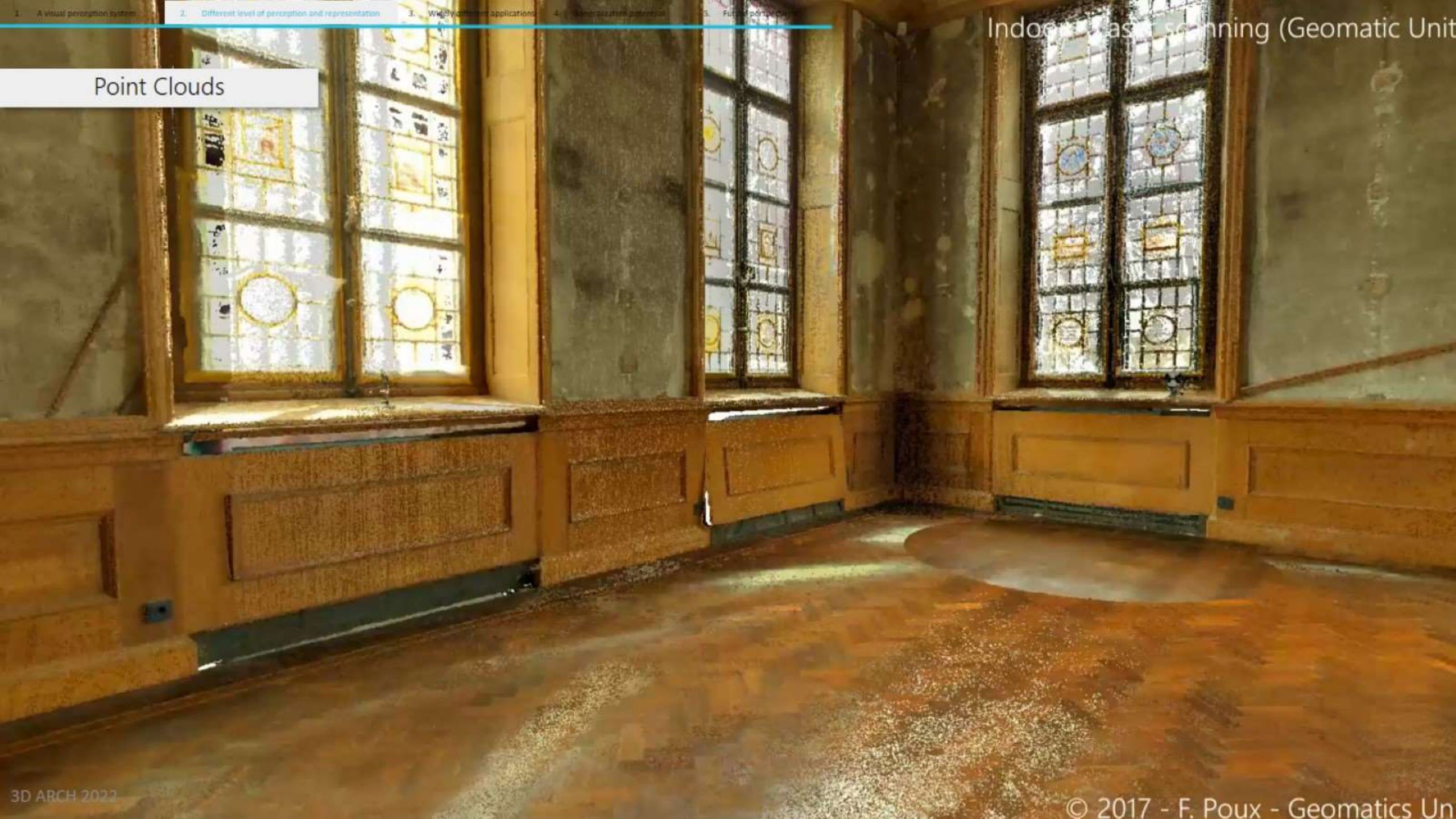




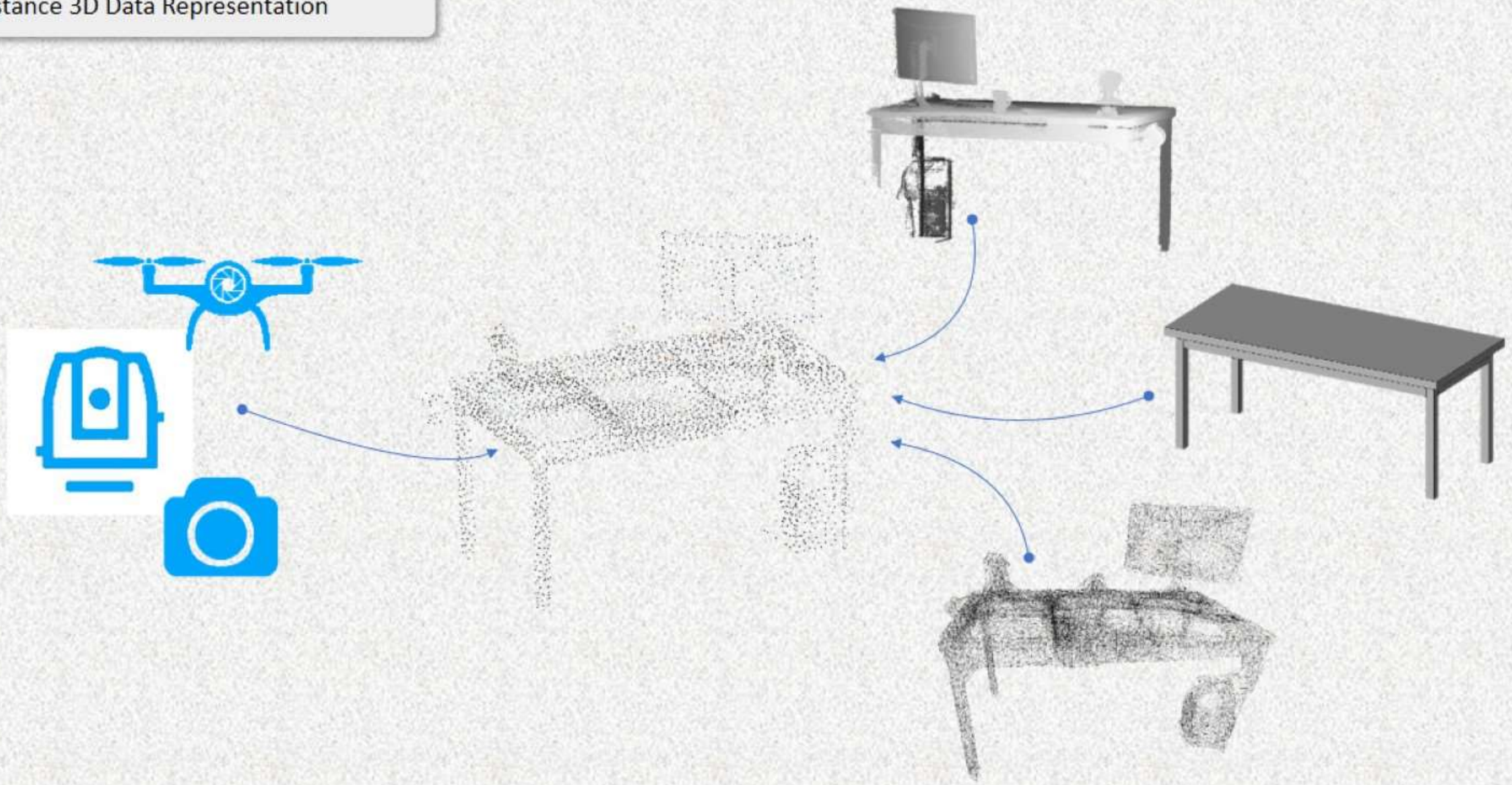
Precision, Geometry & Semantics

1. A visual perception system 2. Different level of perception and representation 3. Widely different applications 4. Generalization potential 5. Future perspectives

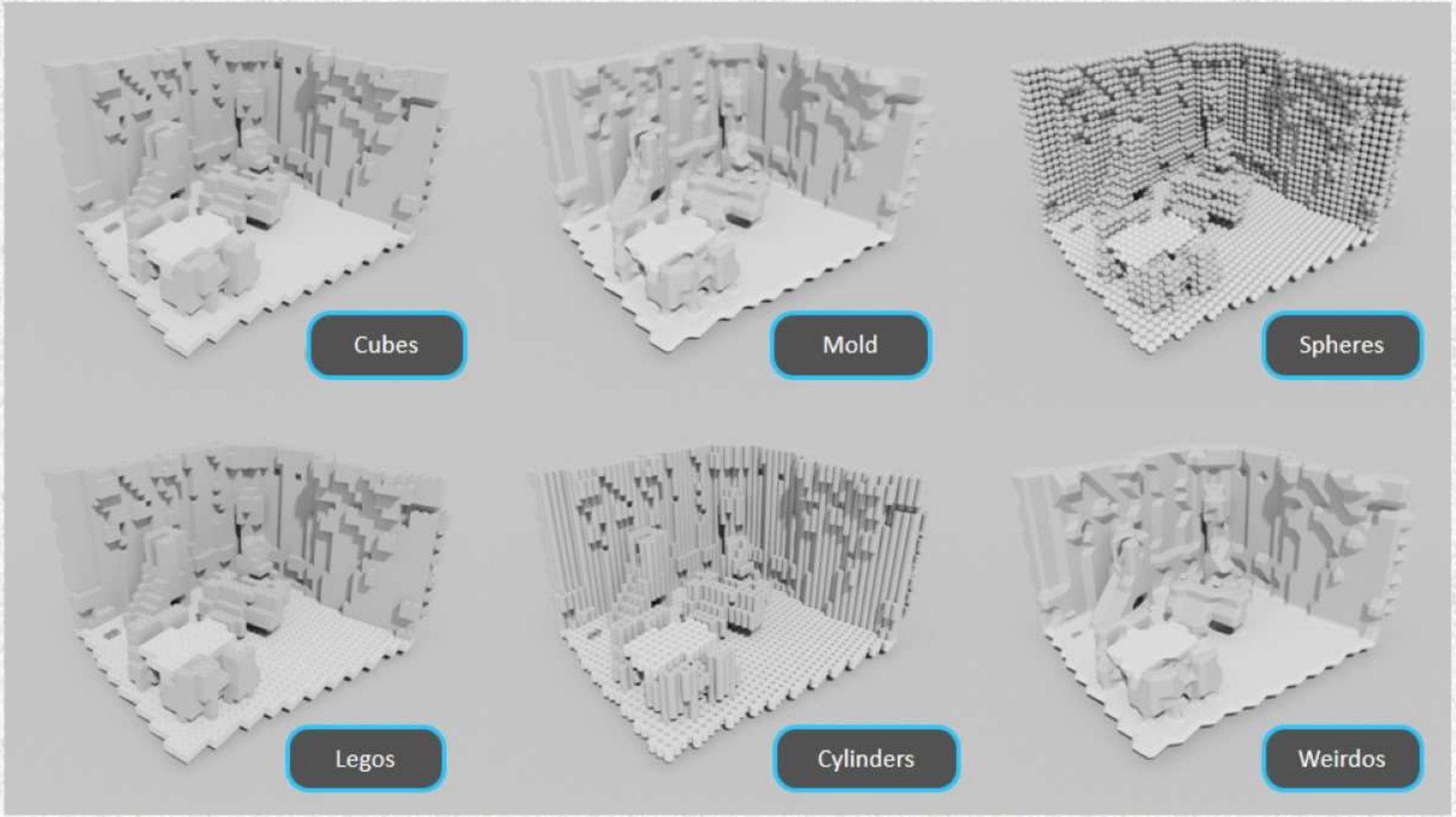
Point Clouds



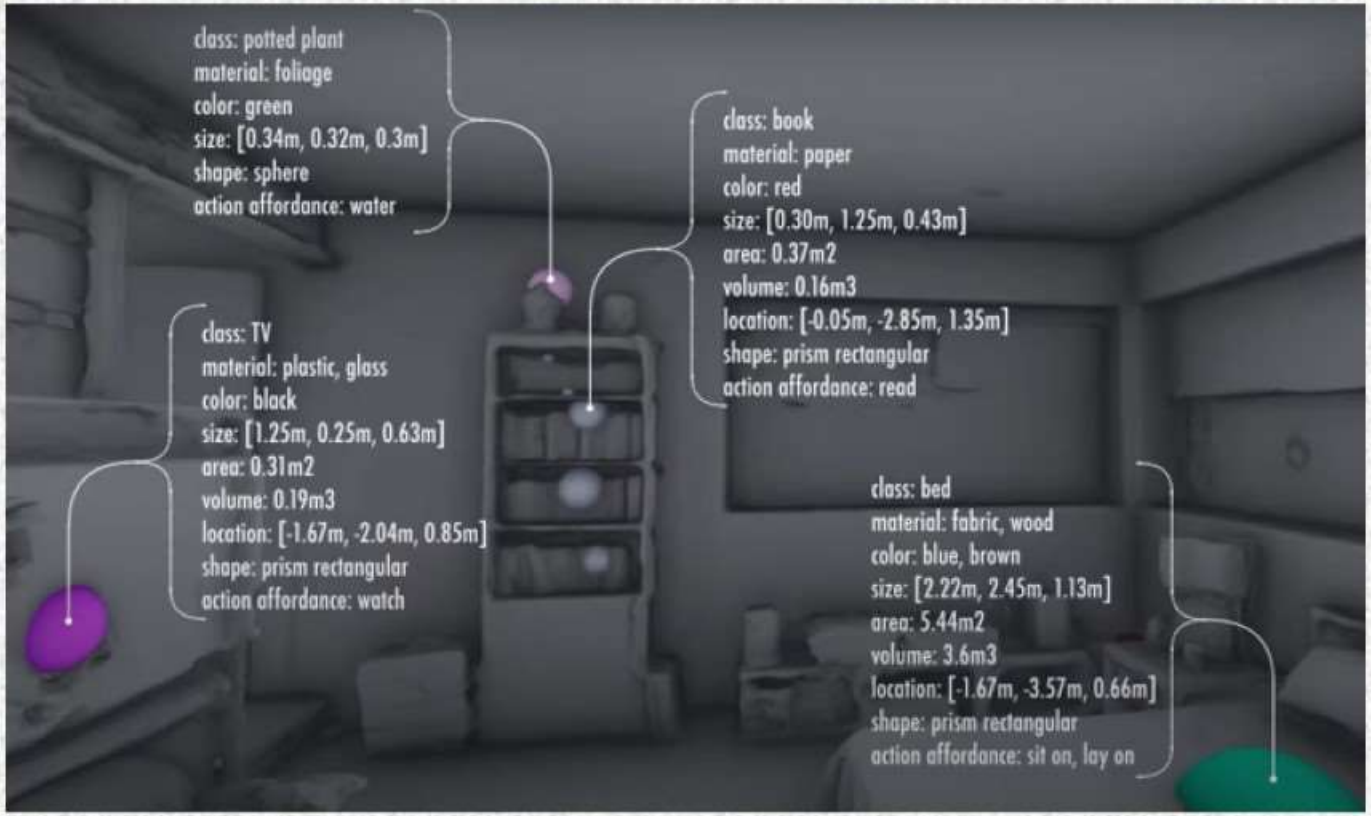
Instance 3D Data Representation



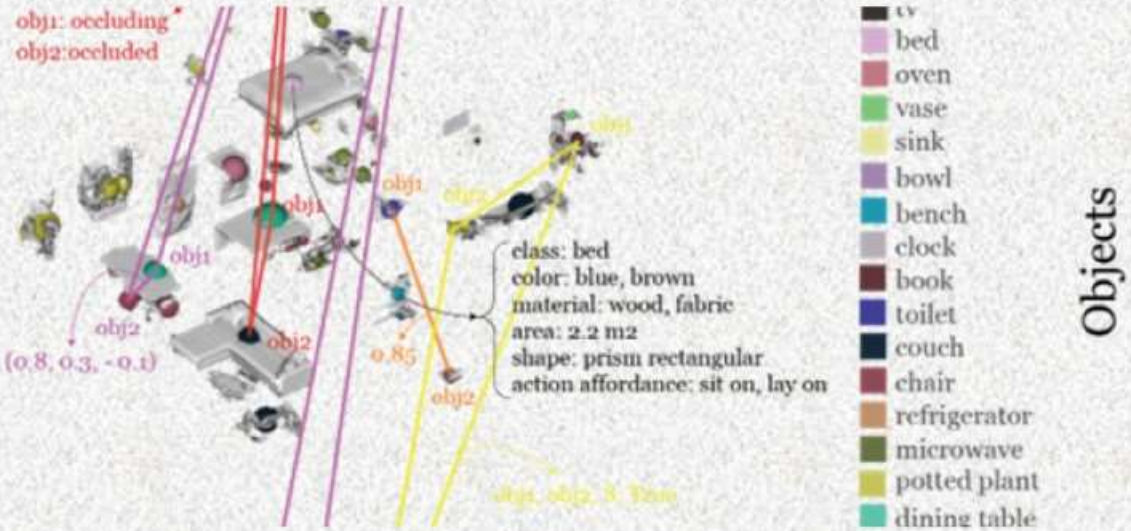
Scene Data Representation

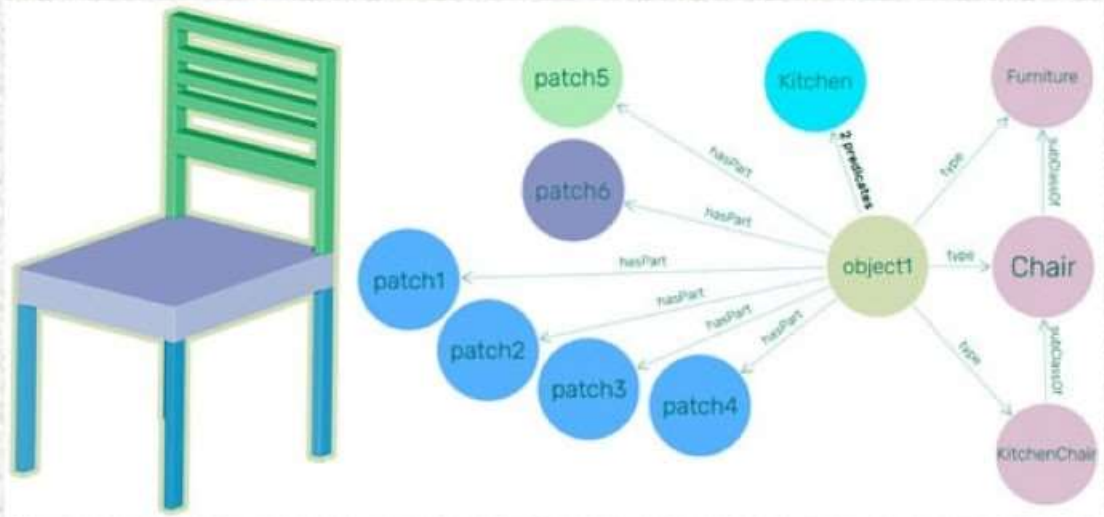


Obj. Semantic Representation



[3D Scene Graph: A Structure for Unified Semantics, 3D Space, and Camera](), Armeni et al., 2019

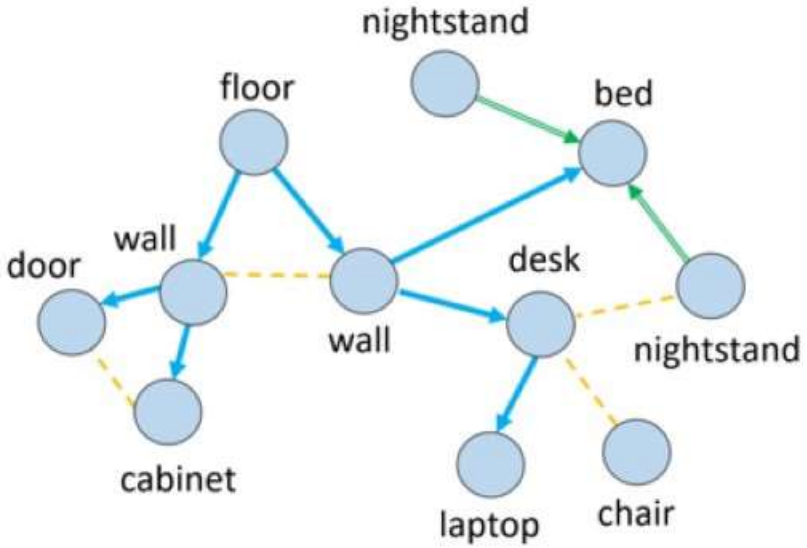


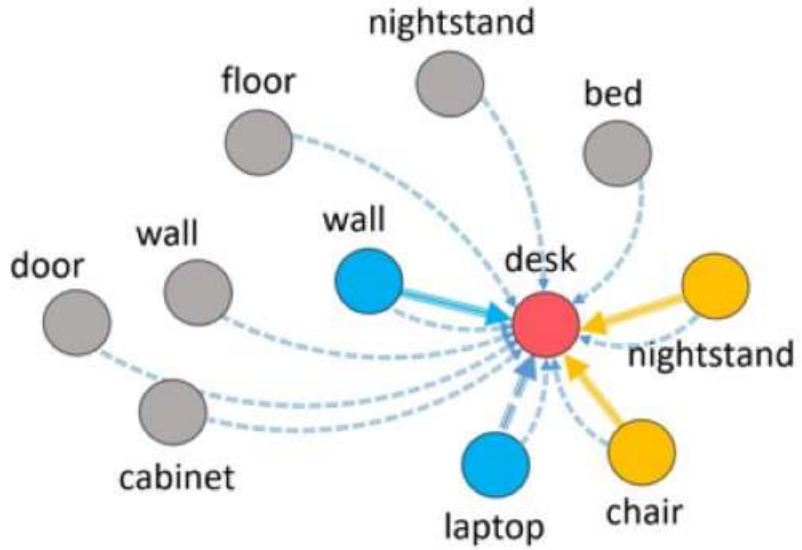


[3D Point Cloud Semantic Modelling: Integrated Framework for Indoor Spaces and Furniture](), Poux et al., 2018

Scene Semantic Representation

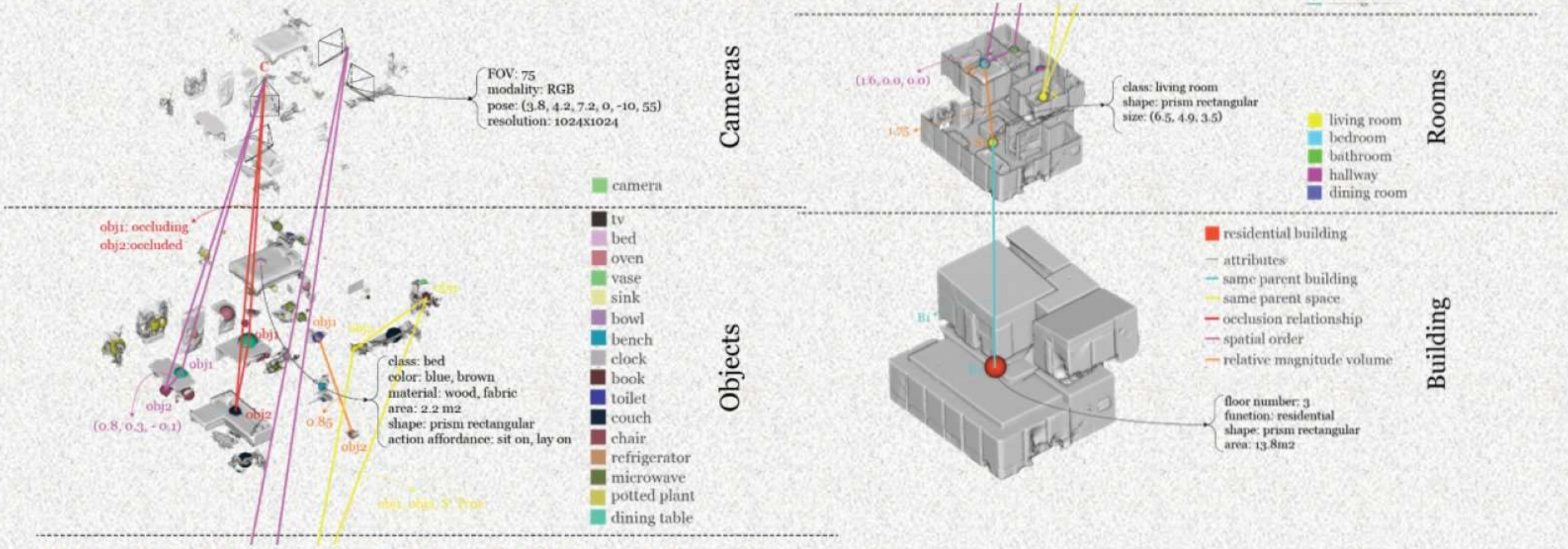
3D indoor scene example (bedroom)





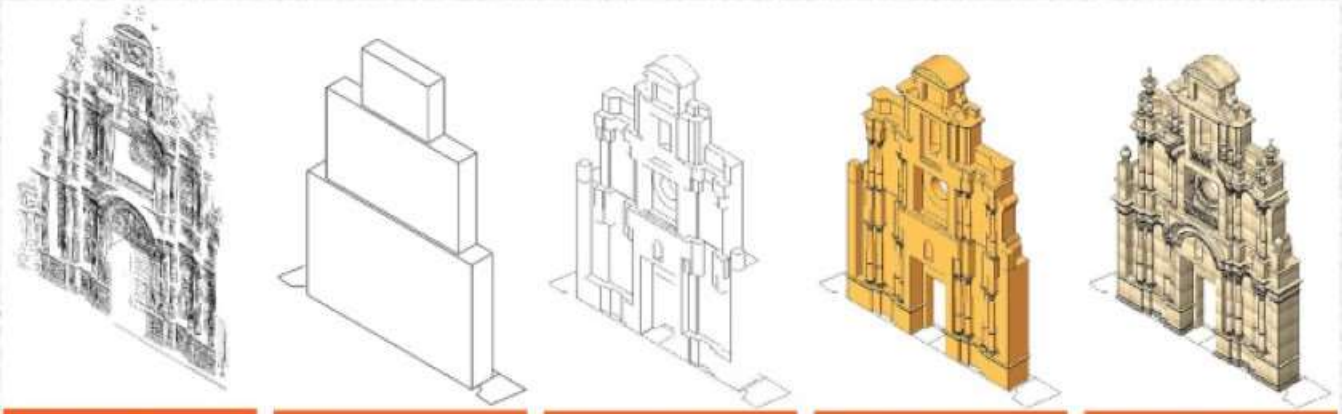
SceneGraphNet: Neural Message Passing for 3D Indoor Scene Augmentation, Zhou et al., 2019

Scene Semantic Representation



3D Scene Graph: A Structure for Unified Semantics, 3D Space, and Camera, Armeni et al., 2019

3D Level of Detail



LOK100
IDENTIFICATION

Graphic codification, simbolic or accurate, but not categorized.

Basic characterization.

Georeferenced location and orientation.

LOK200
PROTECTION AND DISSEMINATION

Basic structures and constructive evolution modelling.

Legal protection documentation and estrategic planning.

Graphical support for dissemination.

LOK300
ADVANCED RESEARCH

Complex structures modelling.

Advanced material characterization and disciplinary diagnosis.

LOK400
CONSERVATION & INTERVENTION

Conservation and intervention projects.

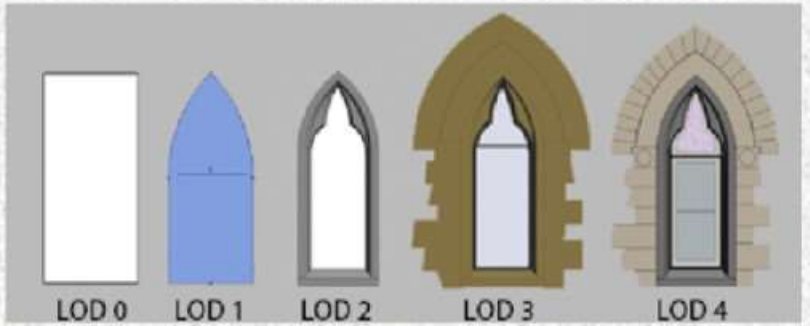
Criteria and procedures definition.

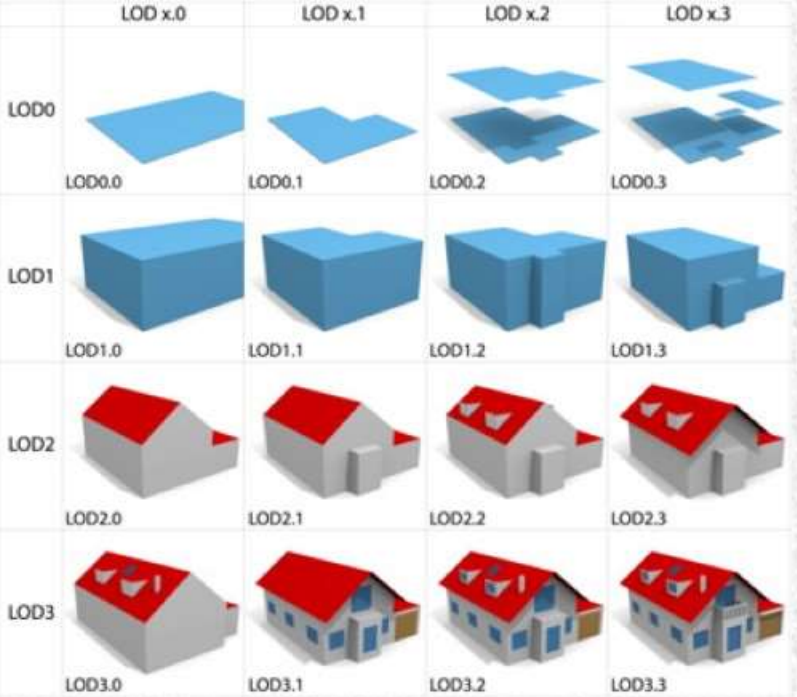
LOK500
COMPREHENSIVE MANAGEMENT

Periodic programs of research, preventive conservation, use and dissemination.

Periodic investment plan.

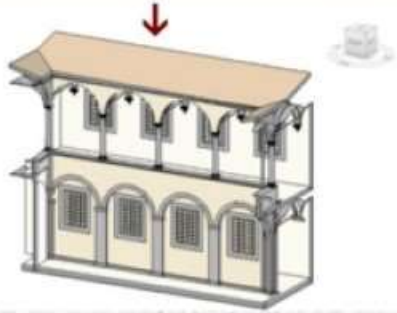
Dimensions and Levels of Knowledge in Heritage Building Information Modelling, HBIM: The model of the Charterhouse of Jerez (Cádiz, Spain), M. Castellano-Román, F. Puerto

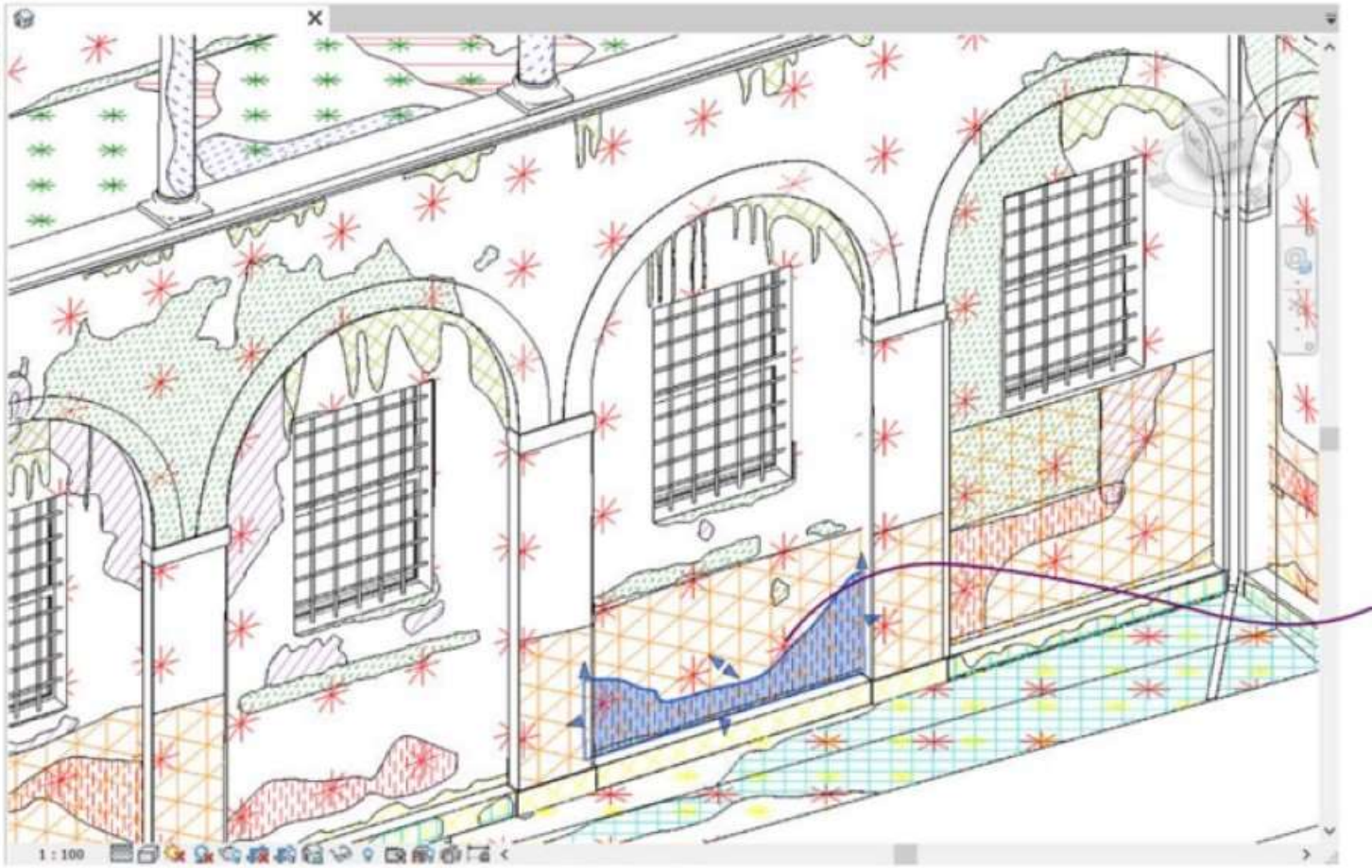




H-BIM

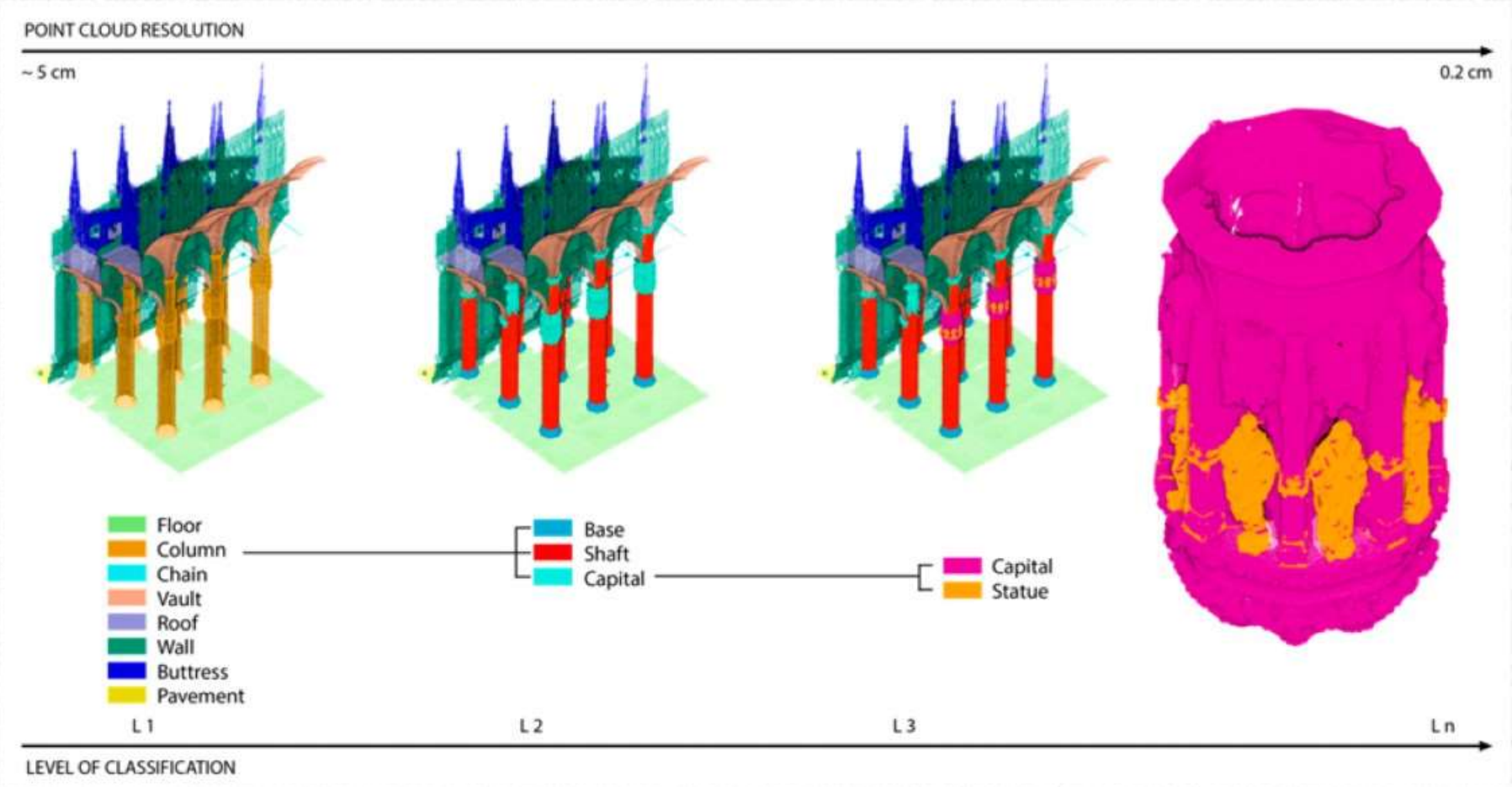
Scan-to-Building Information Modeling (BIM)





From the Semantic Point Cloud to Heritage-Building Information Modeling: A Semiautomatic Approach Exploiting Machine Learning, Croce et al., 2021

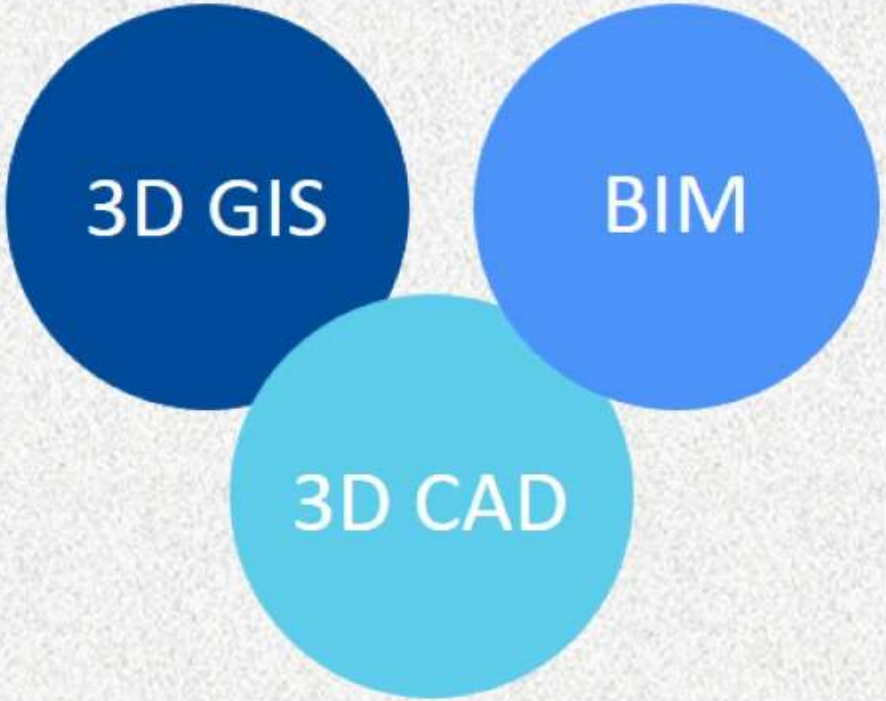
3D Hierarchical Semantics



A Hierarchical Machine Learning Approach for Multi-Level and Multi-Resolution 3D Point Cloud Classification, Teruggi et al., 2020

Semantics Interoperability

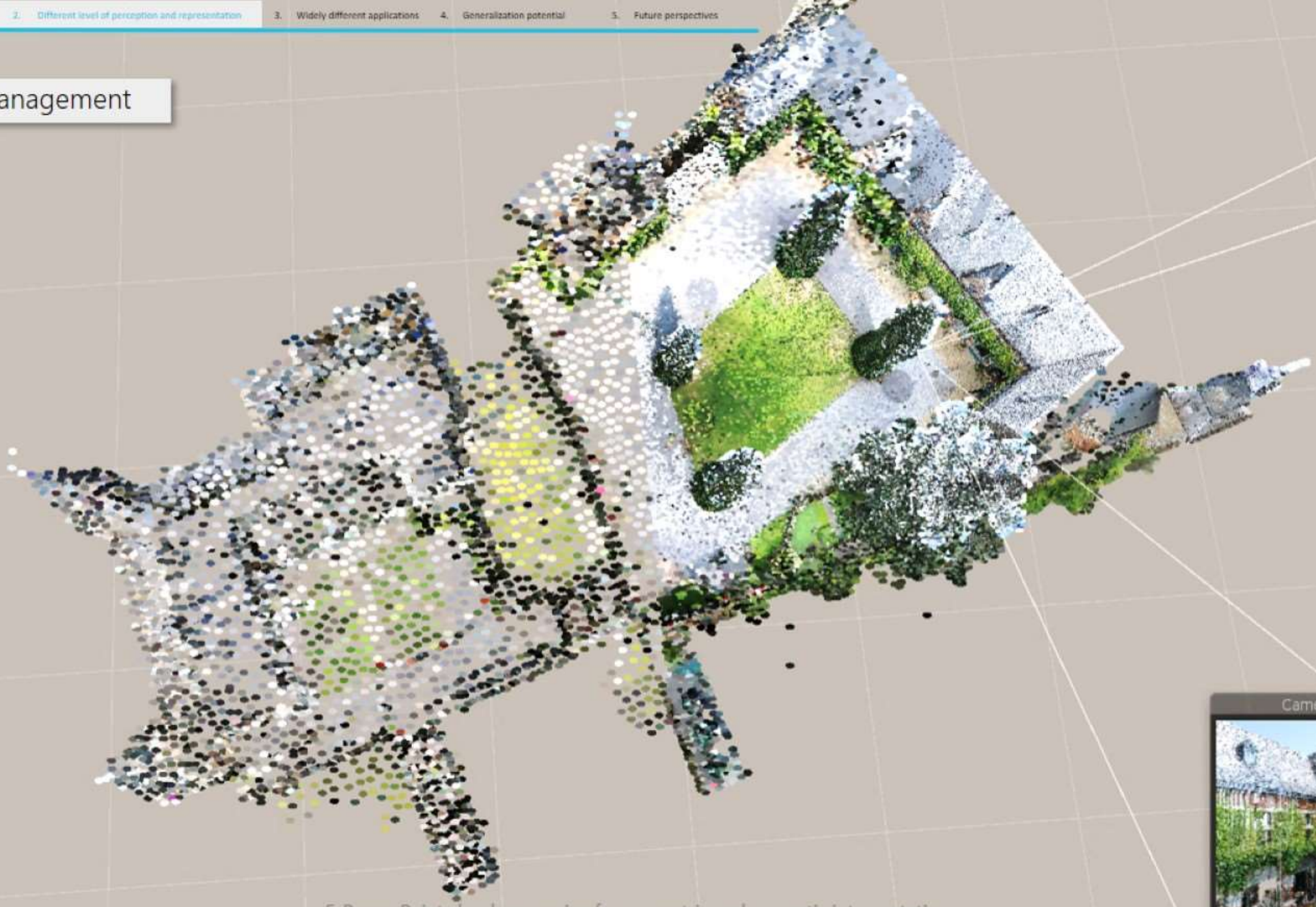
Explicit 3D Spatial IS



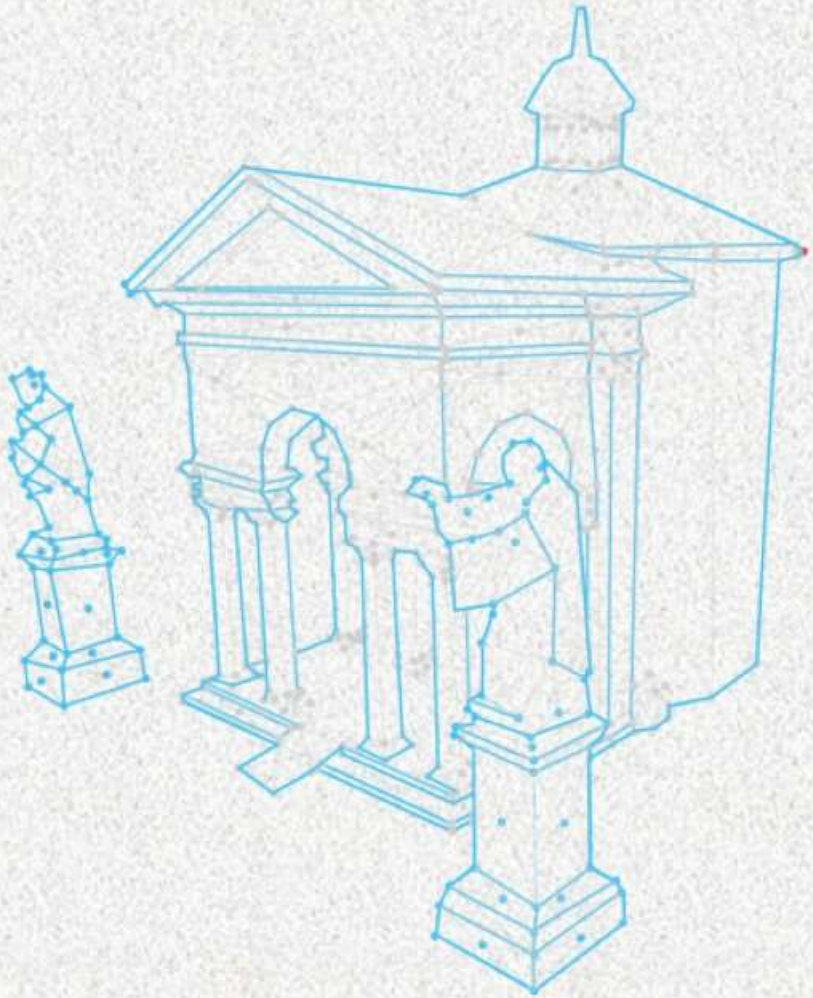
" Semantic interoperability is the technical analogue to human communication and cooperation "

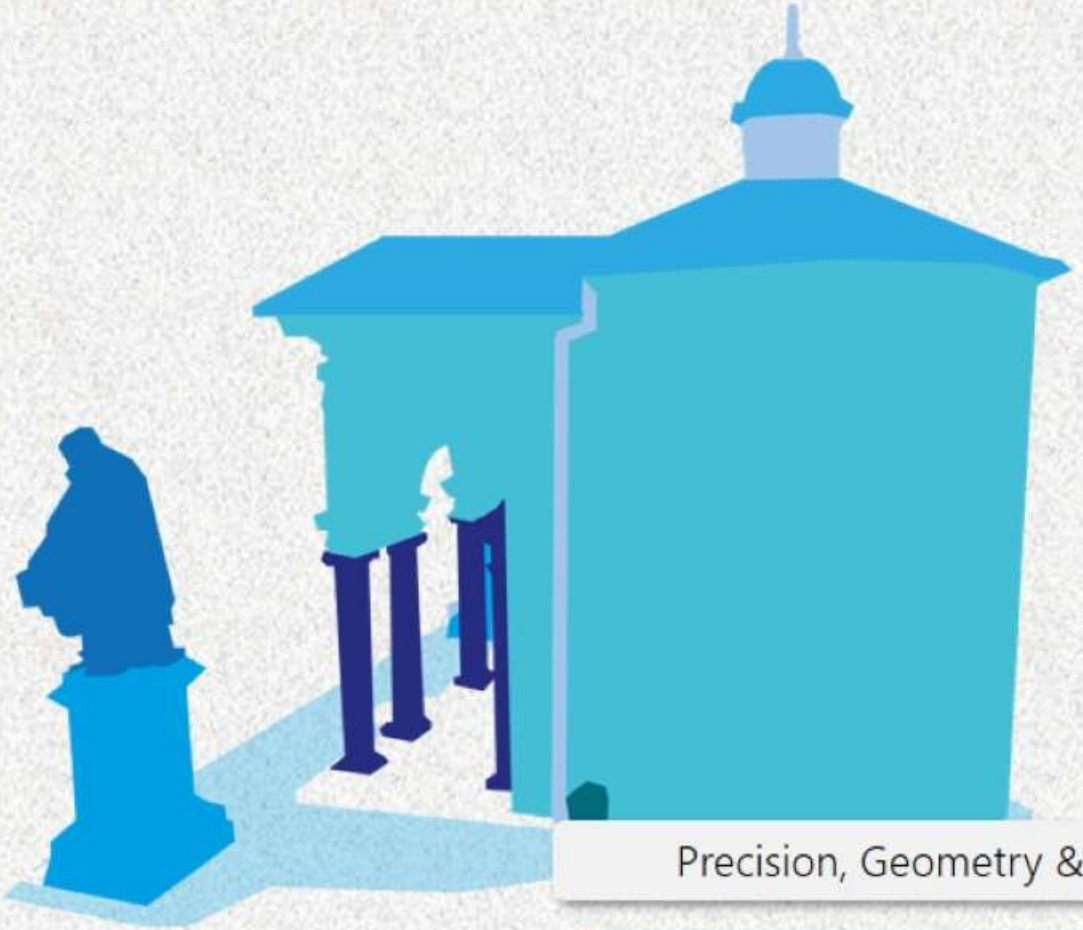
(Kuhn, 2005)

Viewpoint management



2. Multiple levels of representation and perception?

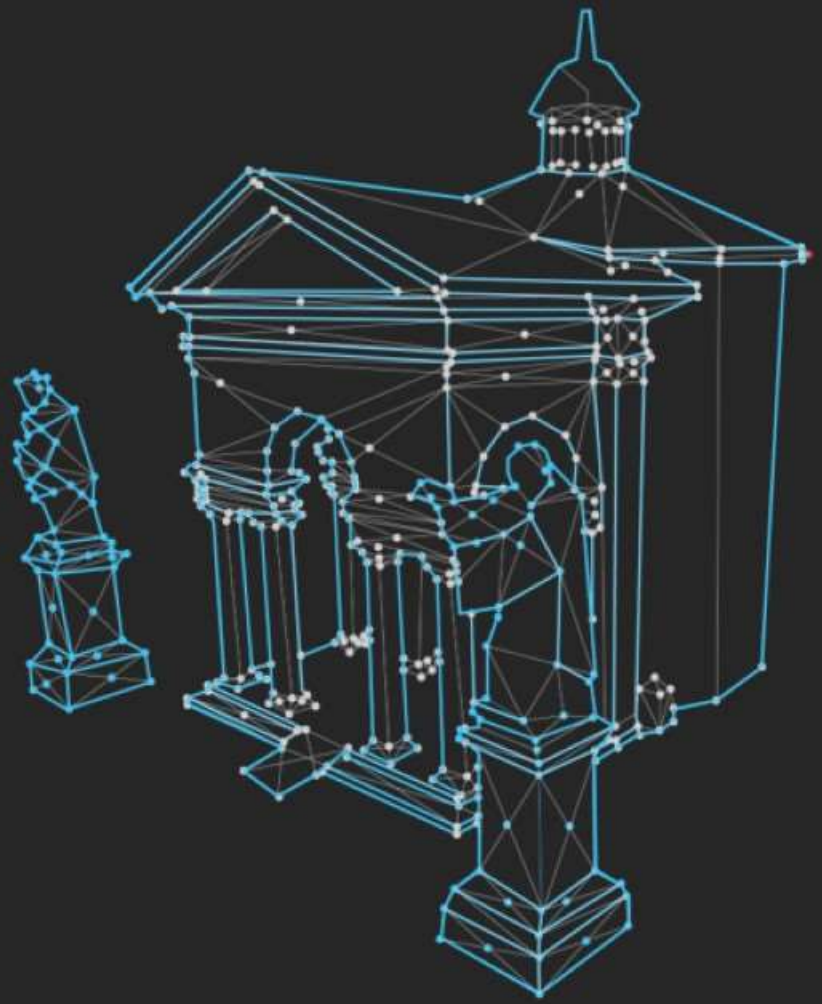


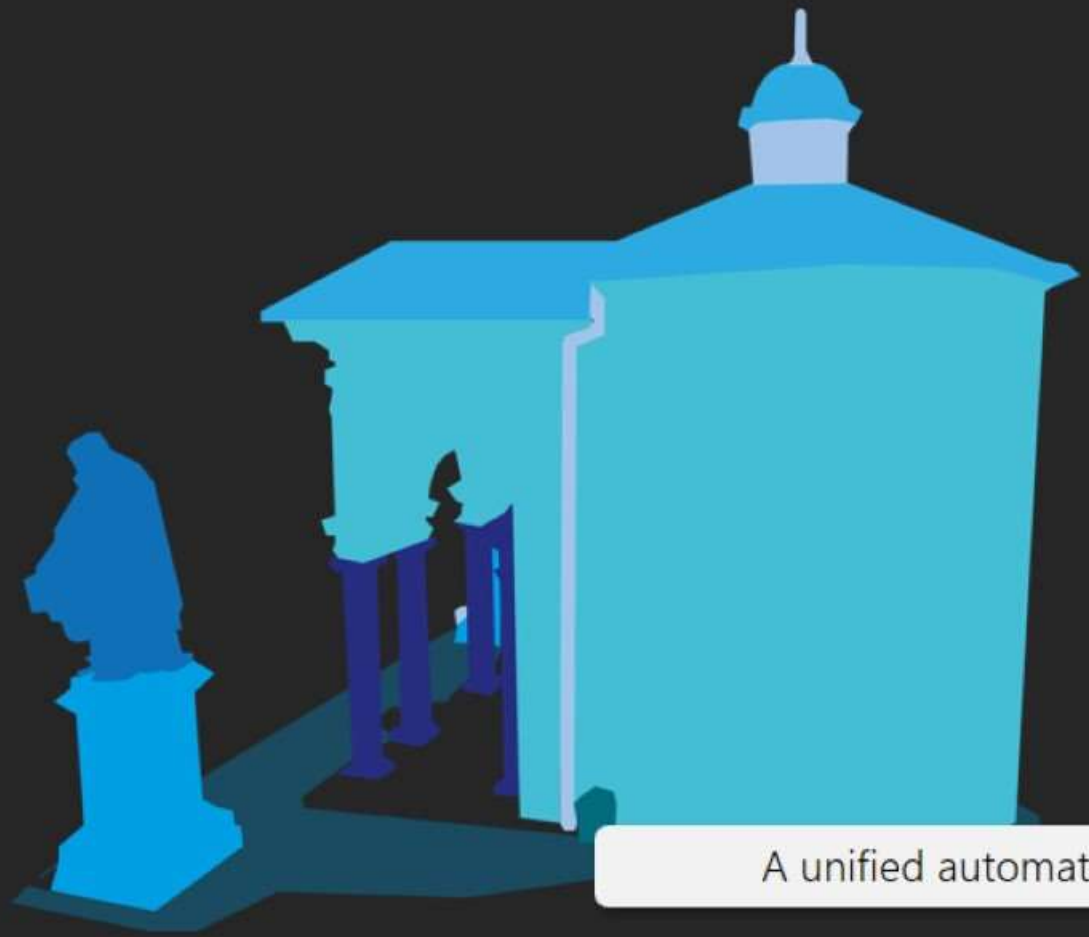


Precision, Geometry & Semantics ✓

Extended viewpoints & perspectives +

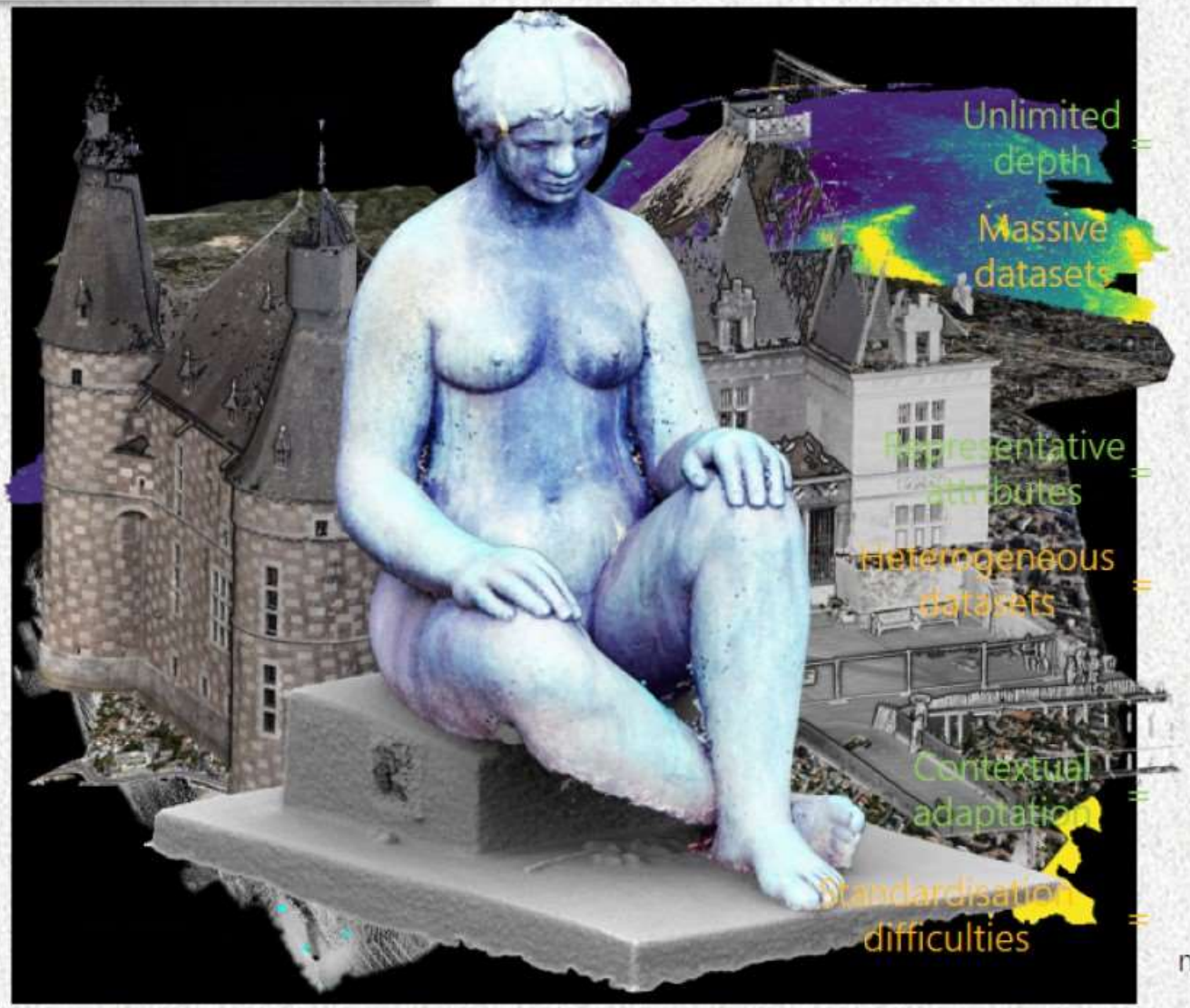
3. Can we address widely different applications and concepts?





A unified automatic processing?

Acquisition Adaptation



3D REALITY CAPTURE

Multi-scale context

Multitude of sensors

Multi methodologies

For Acquisition & Processing

A(N)I vs AGI vs ASI

Artificial Narrow Intelligence (ANI)

Stage-1

Machine Learning

- Specialises in one area and solves one problem

Siri

Alexa

Cortana

Artificial General Intelligence (AGI)

Stage-2

Machine Intelligence

- Refers to a computer that is as smart as a human across the board

Artificial Super Intelligence (ASI)

Stage-3

Machine Consciousness

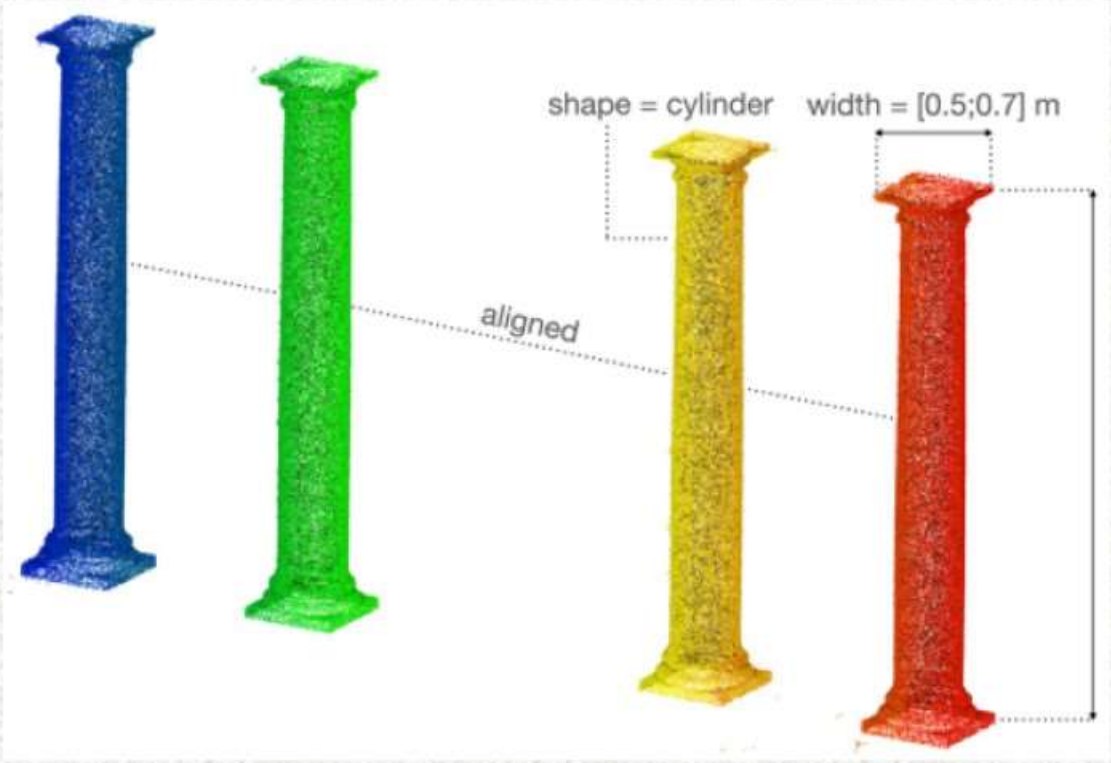
- An intellect that is much smarter than the best human brains in practically every field

3D Segmentation Taxonomy

Classification

Semantic Segmentation

A BENCHMARK FOR LARGE-SCALE HERITAGE POINT CLOUD SEMANTIC SEGMENTATION, Matrone et al., 2020



Instance segmentation

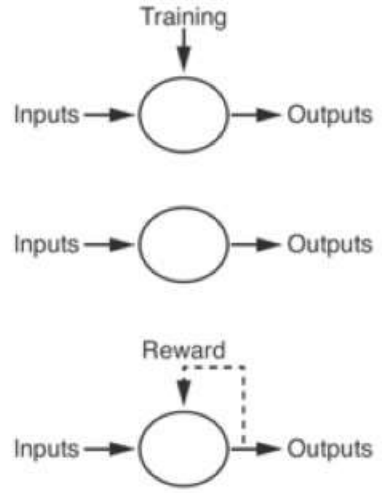
From Acquisition to Presentation—The Potential of Semantics to Support the Safeguard of Cultural Heritage, Ponciano et al., 2021

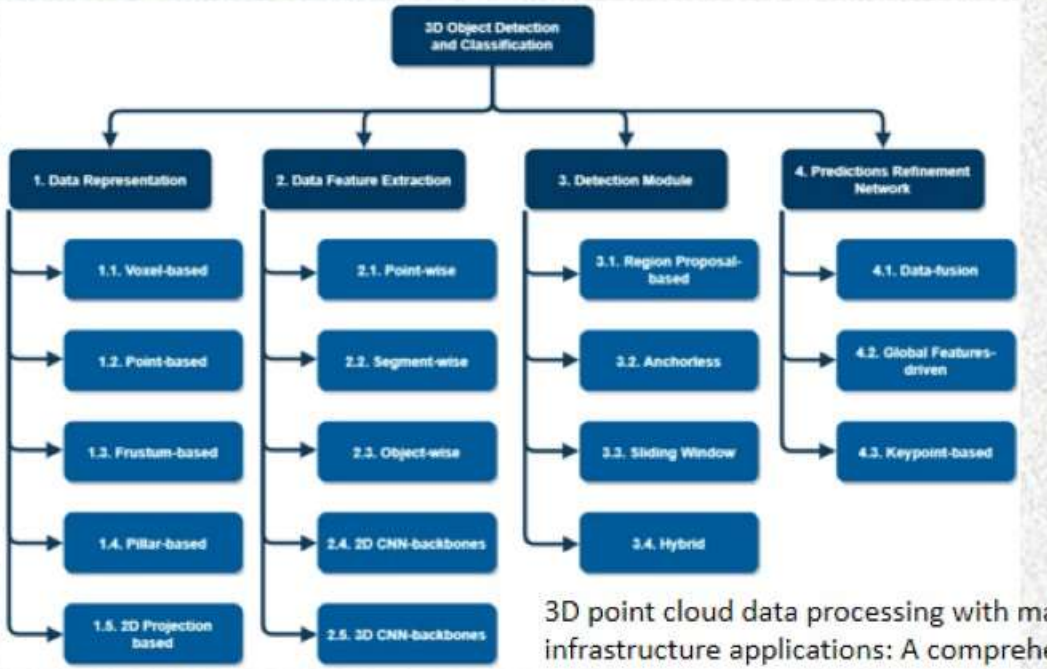
Semantic Augmentation

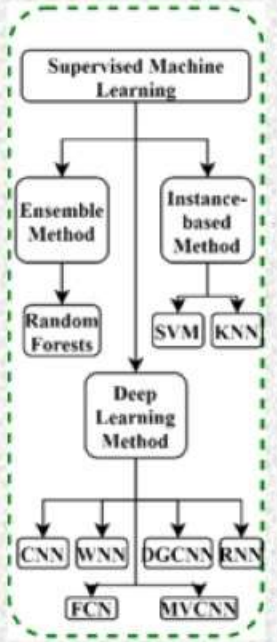
Supervised learning
Learns known patterns
Takes labeled input data
Predicts outcome/future

Unsupervised learning
Learns unknown patterns
Takes unlabeled input data
Finds hidden patterns

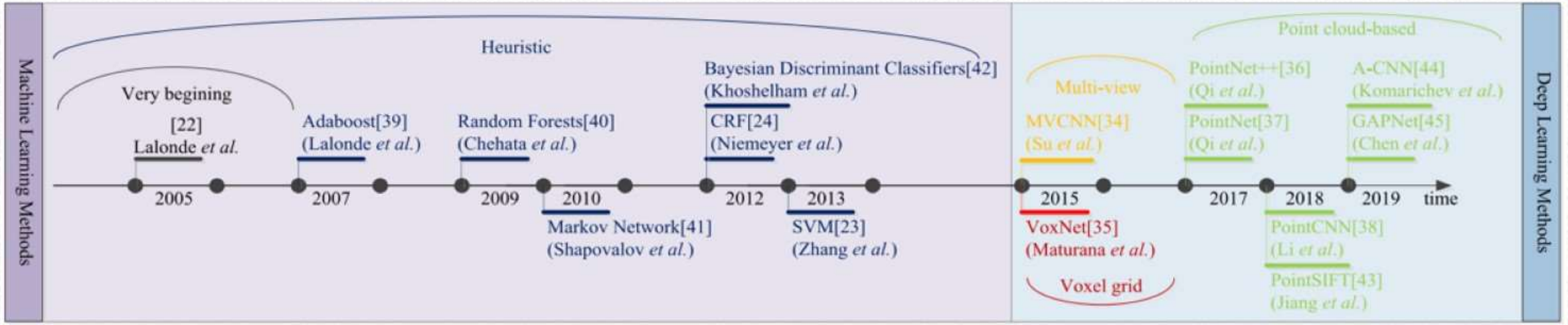
Reinforcement learning
Generates data
Takes labeled input data
Interacts with environment
Learns series of actions







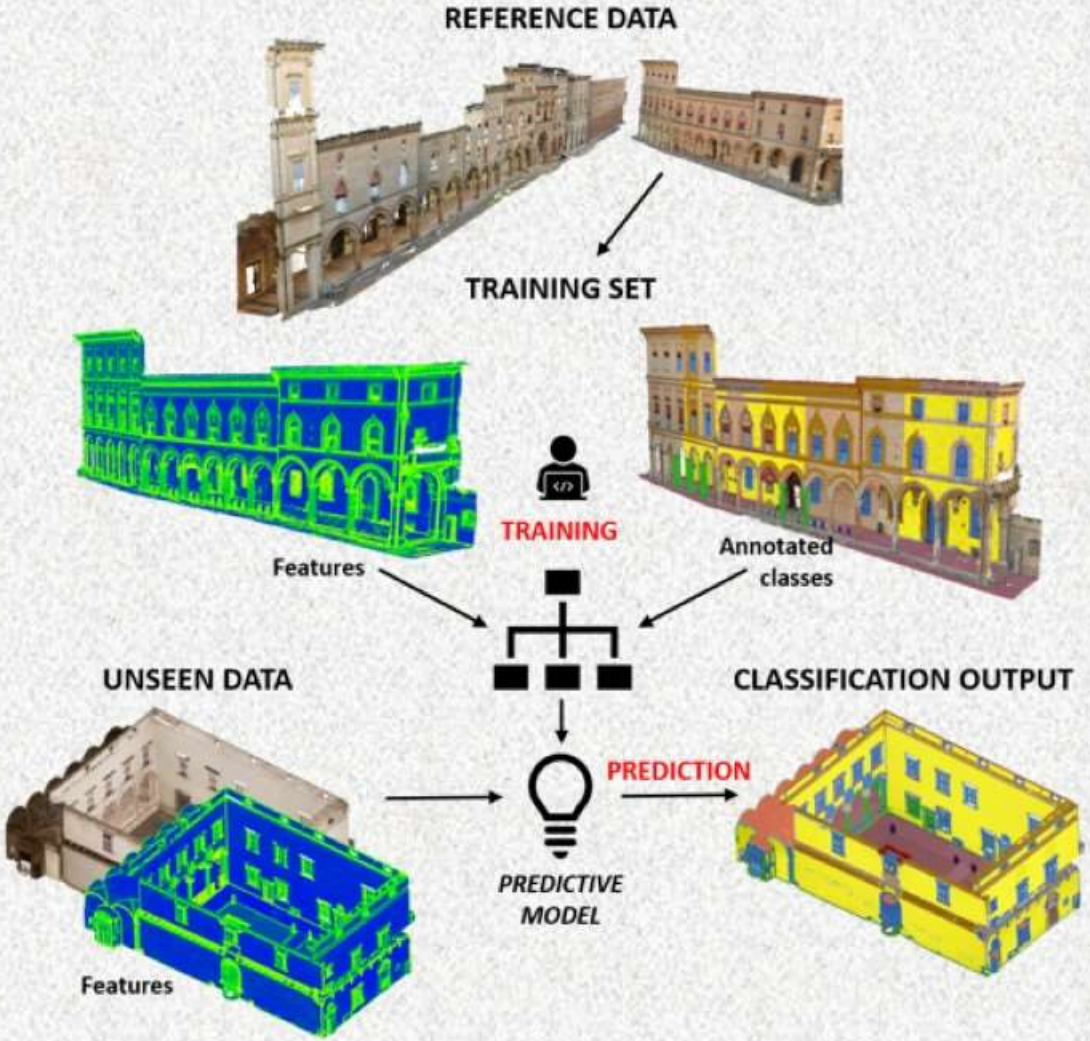
3D point cloud data processing with machine learning for construction and infrastructure applications: A comprehensive review, Mirzaei et al., 2021



Review of Deep Learning-Based Semantic Segmentation for Point Cloud, Zhang et al., 2020

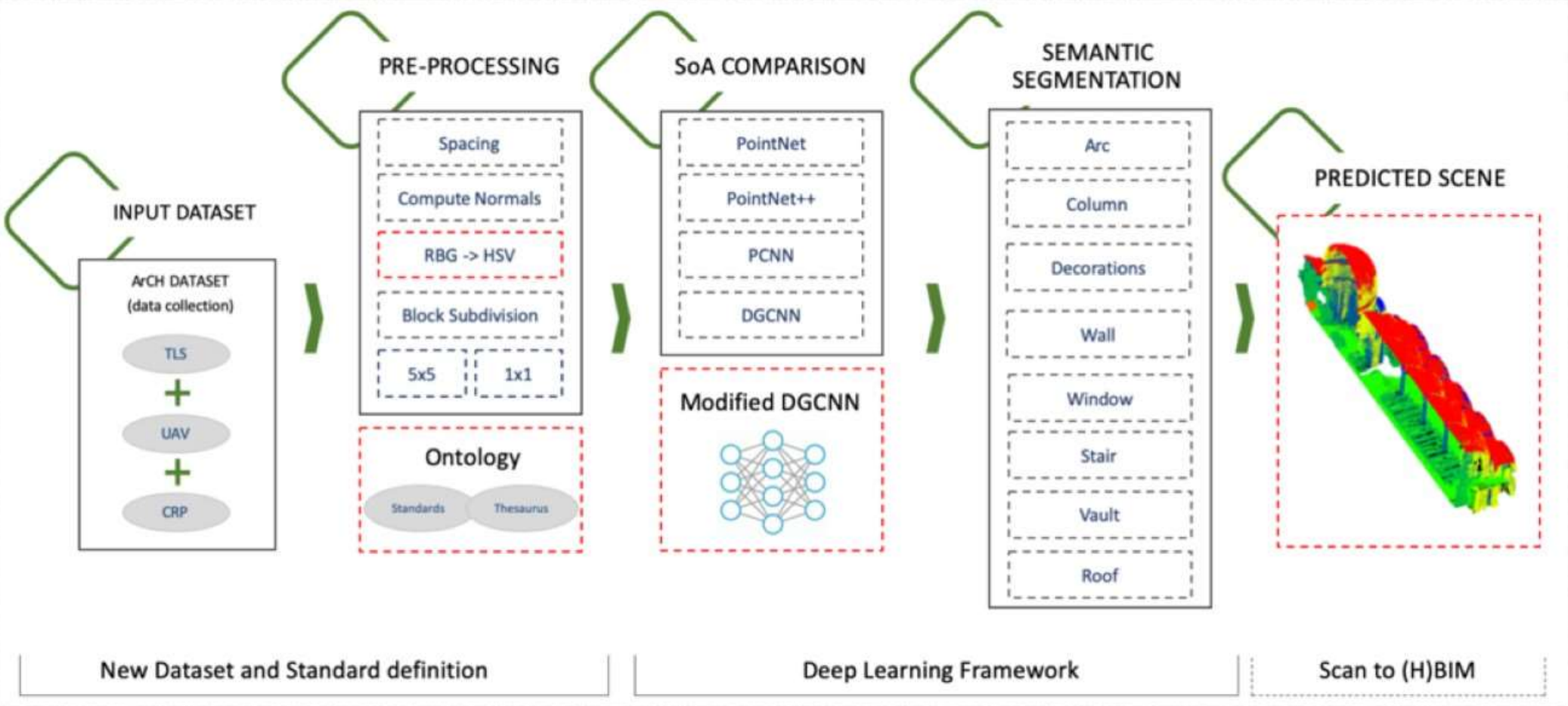
SL: Hand-engineer features

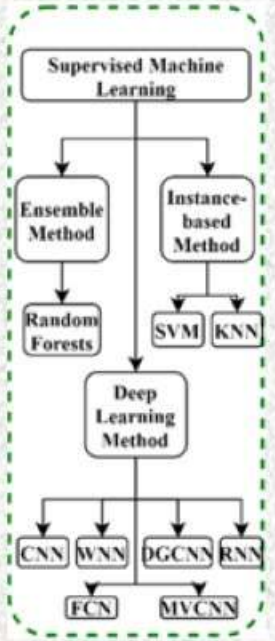
Point Cloud Tutorials: https://medium.com/@florentpoux



Machine Learning Generalisation across Different 3D Architectural Heritage, Grilli et Remondino, 2020

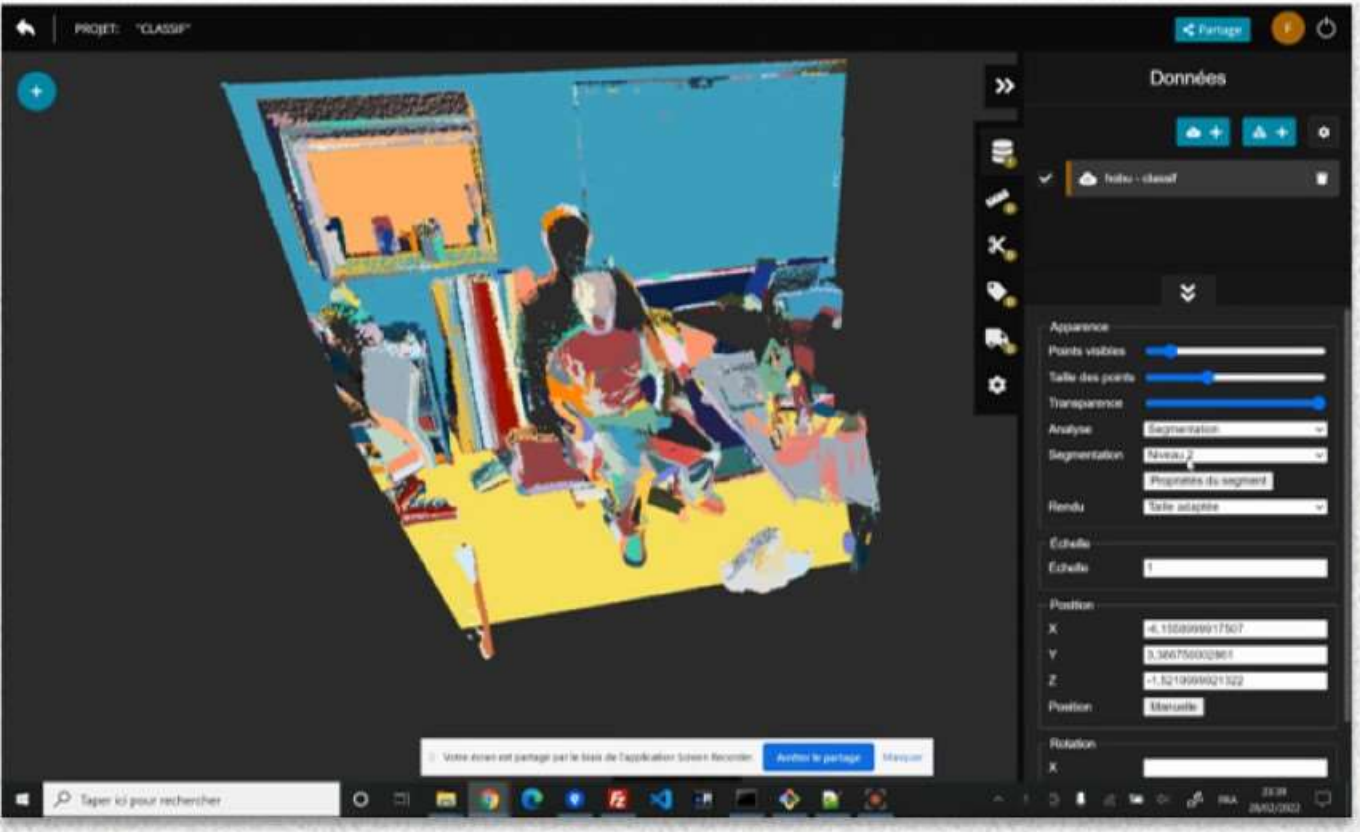
SL: Learned features

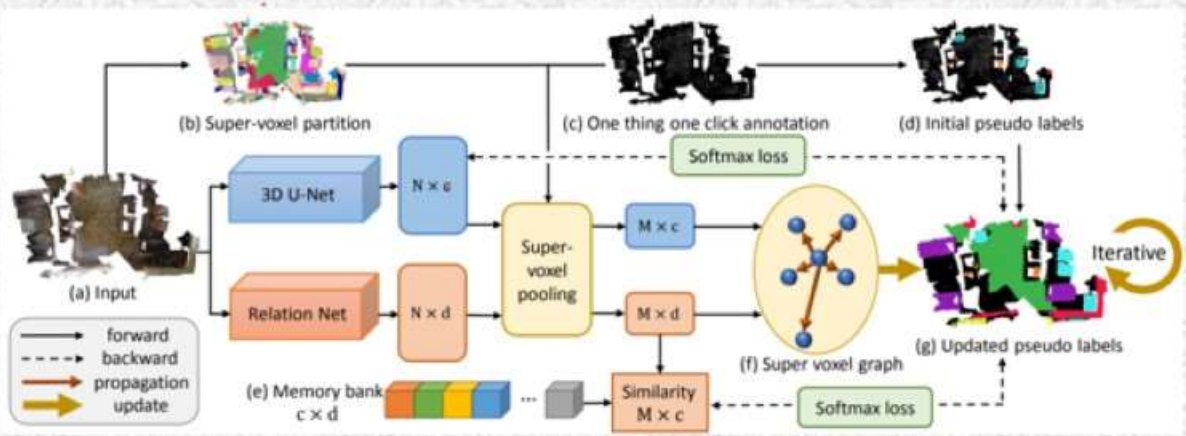




[Point Cloud Semantic Segmentation Using a Deep Learning Framework for Cultural Heritage](), Pierdicca et al., 2020

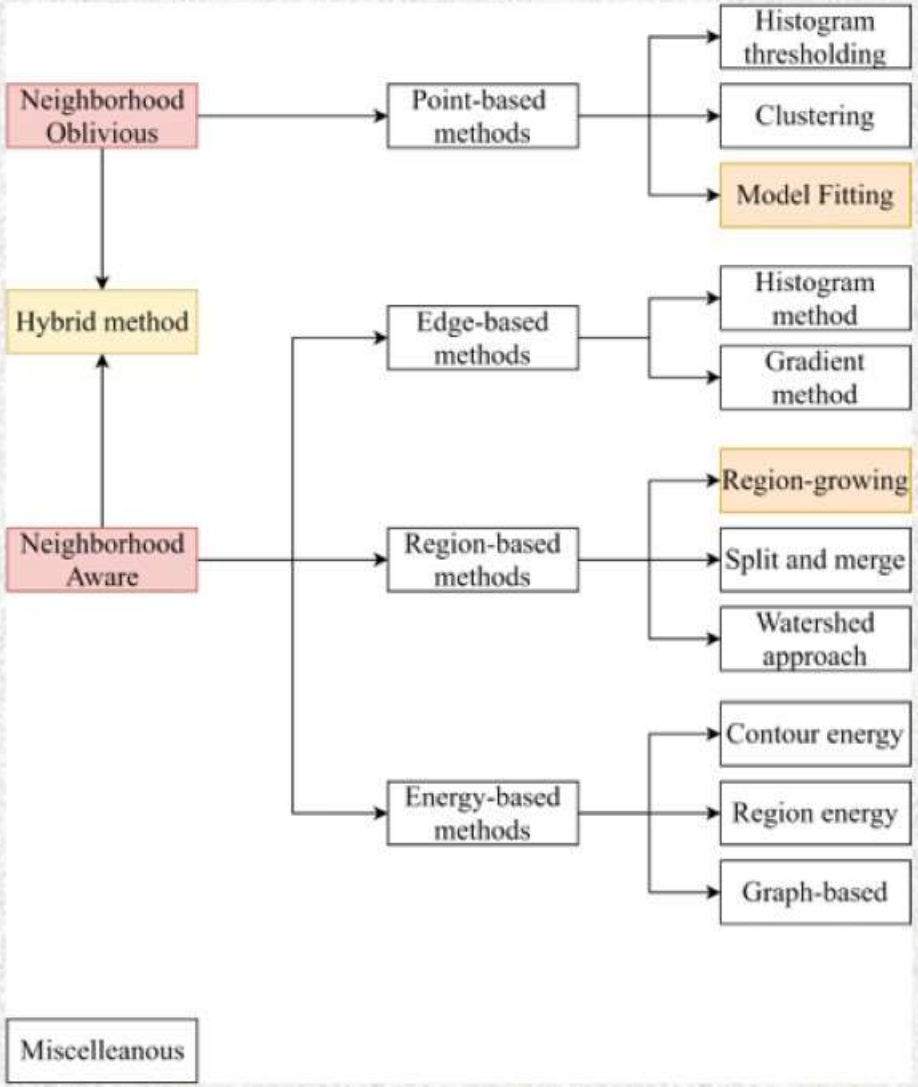
Weakly supervised





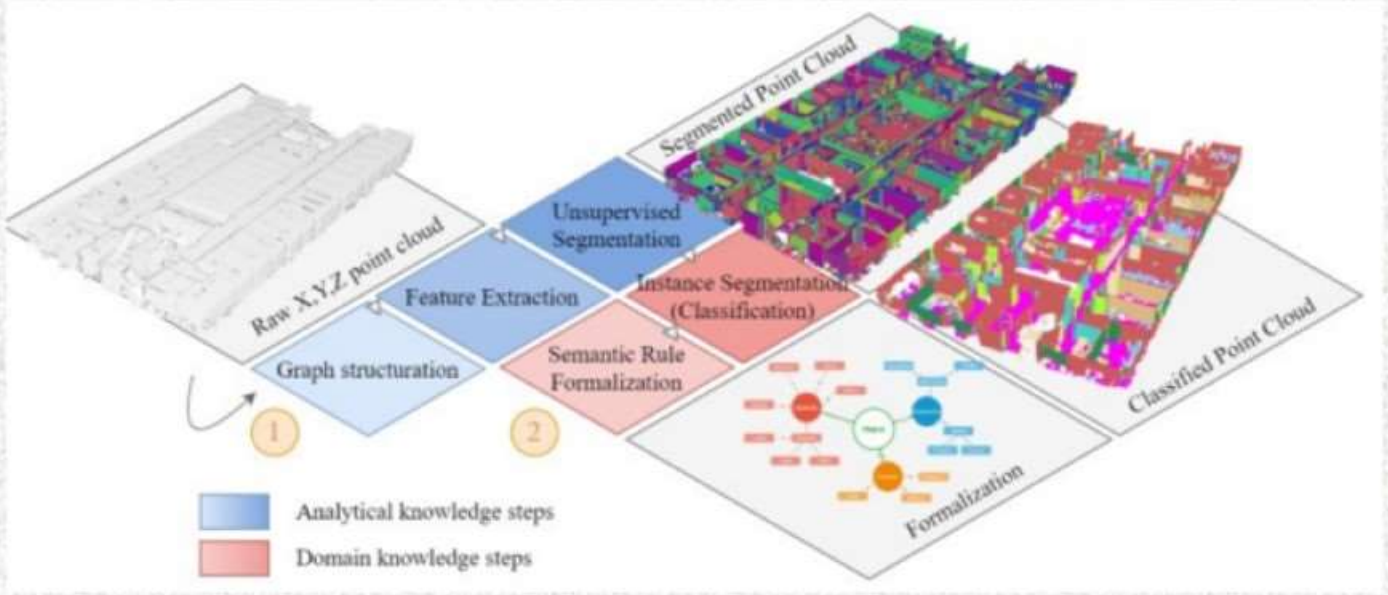
[One Thing One Click: A Self-Training Approach for Weakly Supervised 3D Semantic Segmentation](), Liu et al., 2021

Unsupervised segmentation



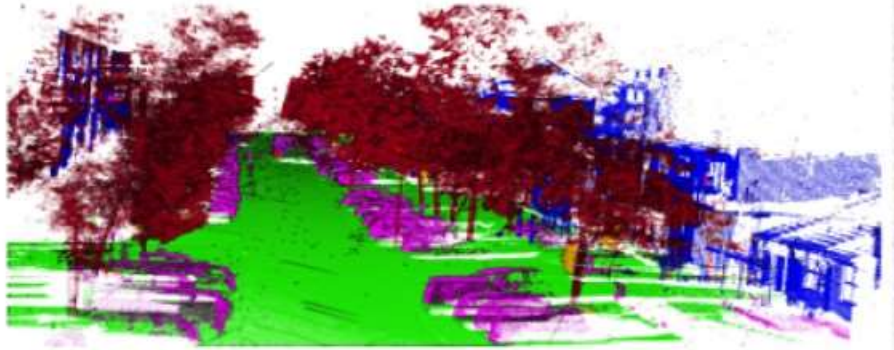
Unsupervised Point Cloud Segmentation for large point clouds, Poux et al., in press

Self-supervised learning

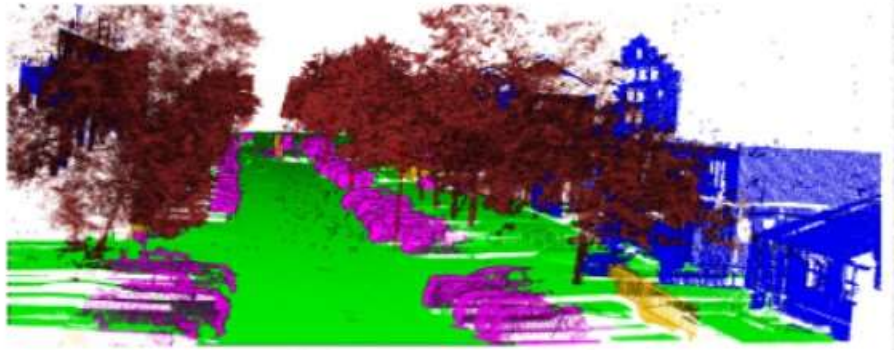


SELF-LEARNING ONTOLOGY FOR INSTANCE SEGMENTATION OF 3D INDOOR POINT CLOUD, Poux et Ponciano, 2020

(a) Original point cloud



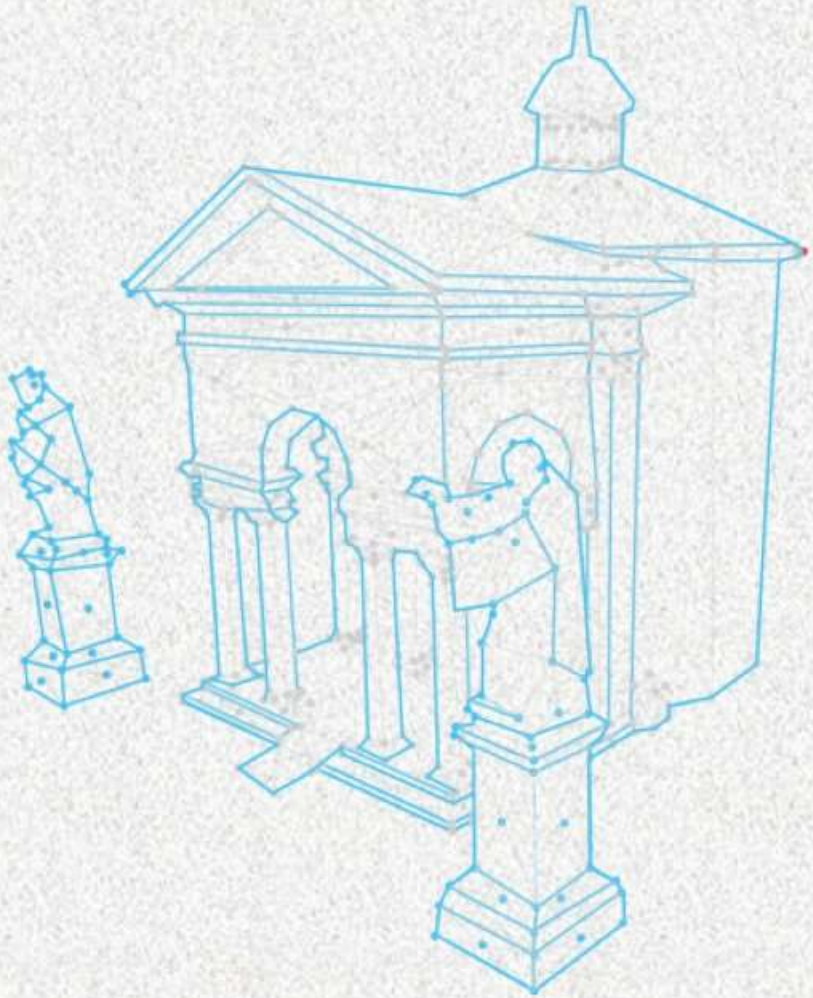
(b) DL semantic segmentation results

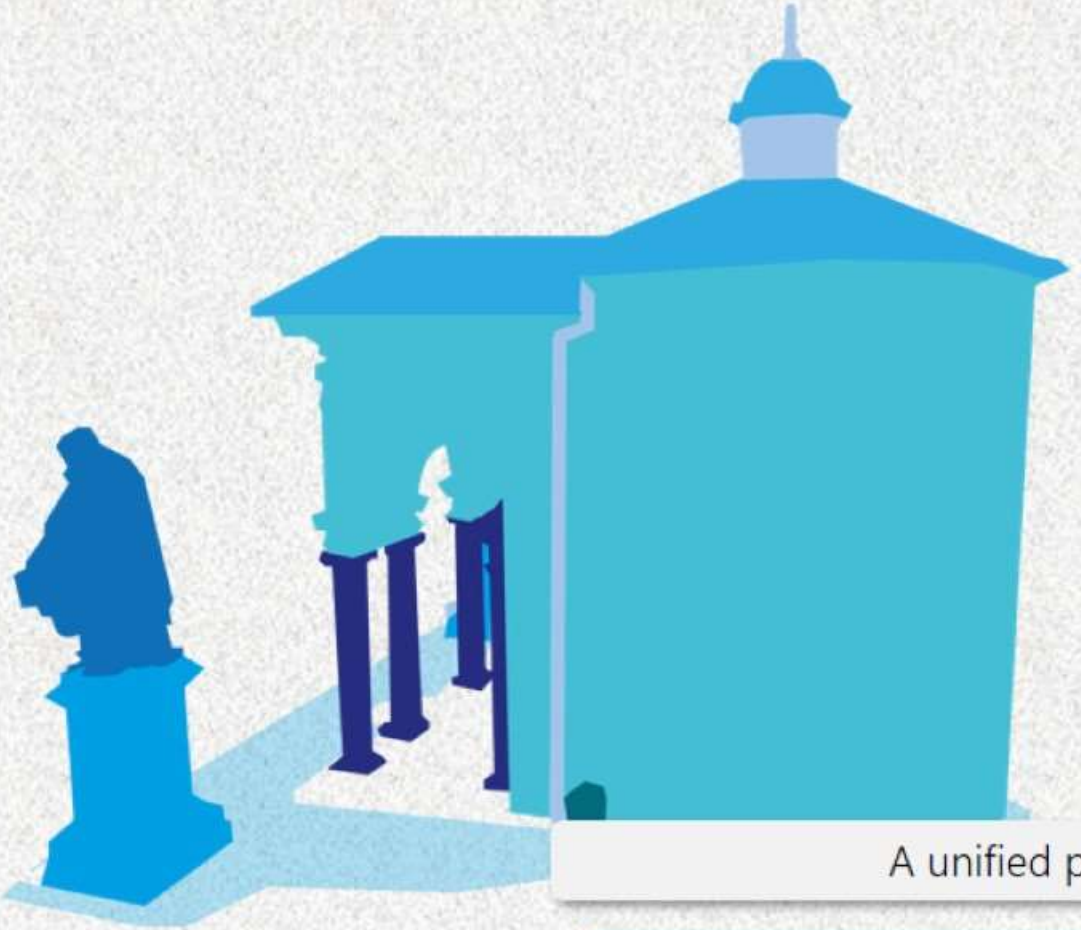


(c) KB semantic segmentation results

Object Semantic Segmentation in Point Clouds—Comparison of a Deep Learning and a Knowledge-Based Method, Ponciano et al., 2021

3. Can we address widely different applications and concepts?

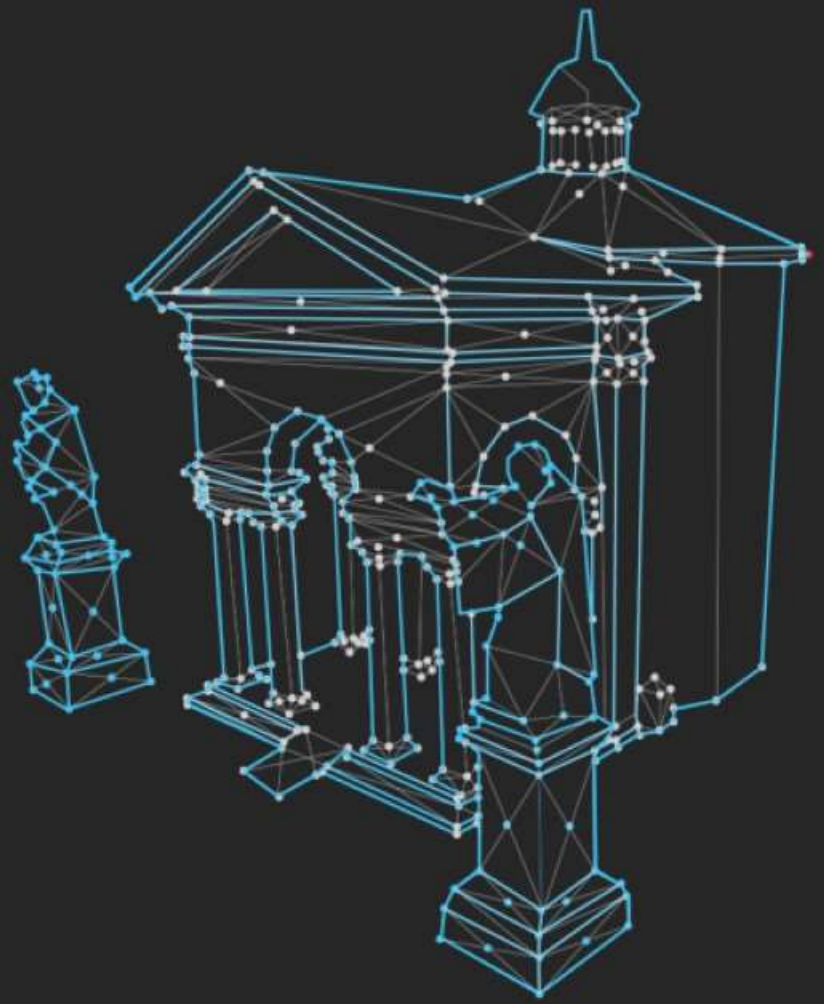


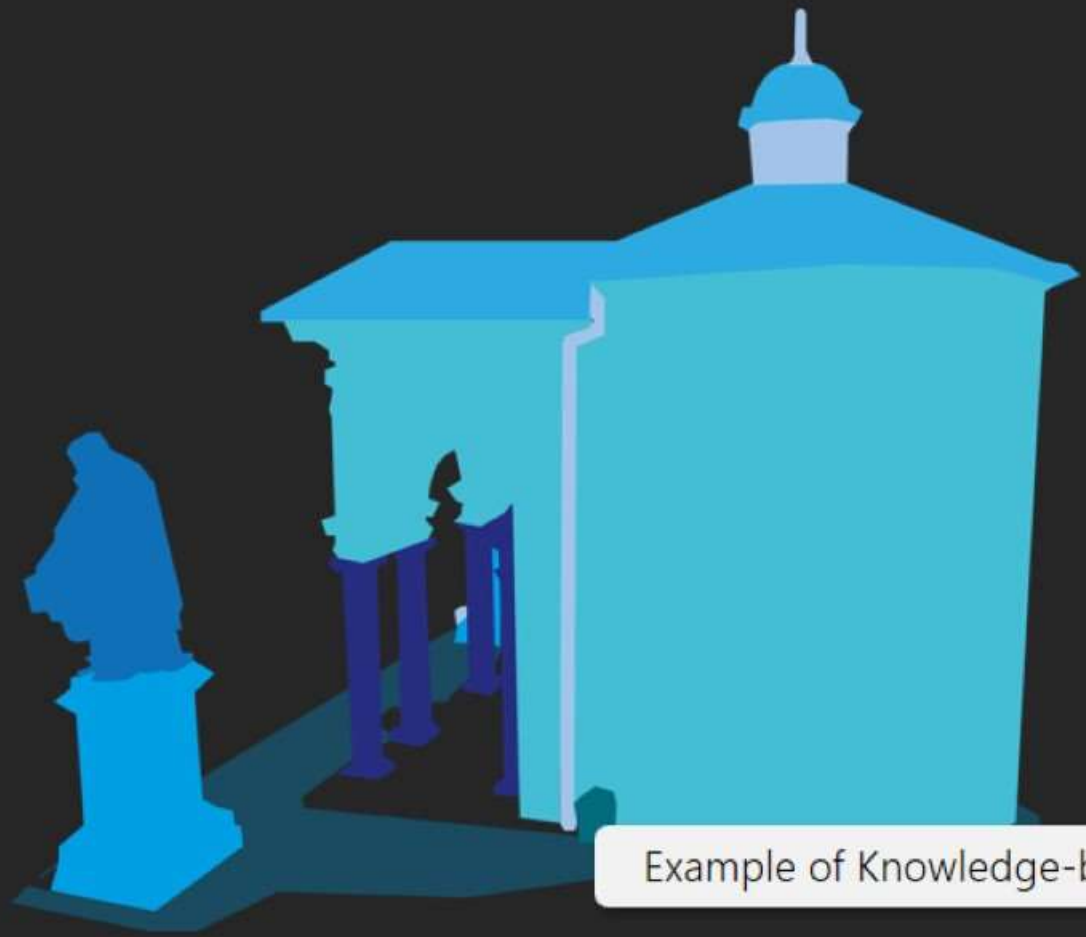


A unified processing? ✗

System 2 Cognition Research

4. Can we generalize our ARCH-approaches?

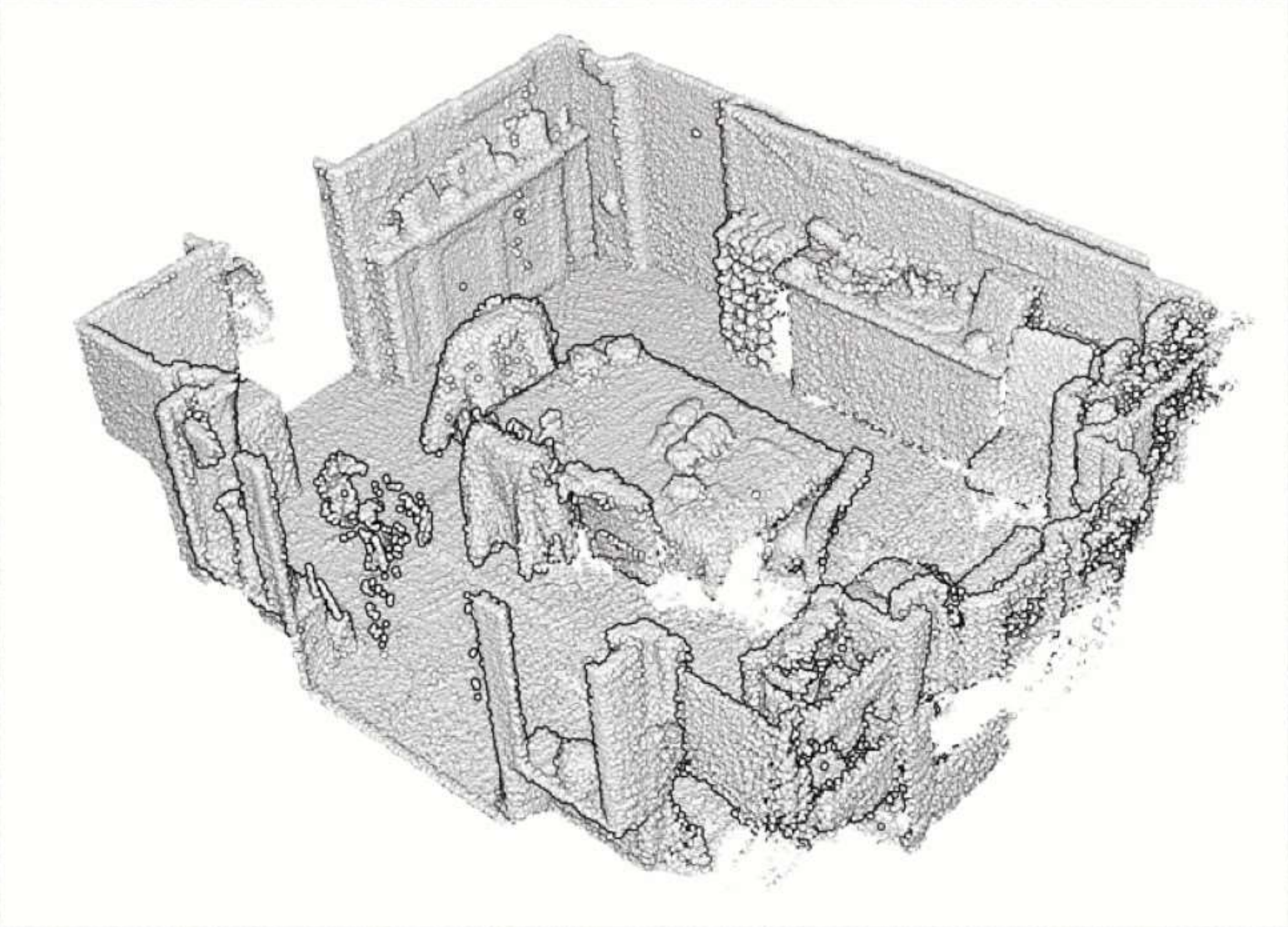




Example of Knowledge-based learning

Labelling datasets

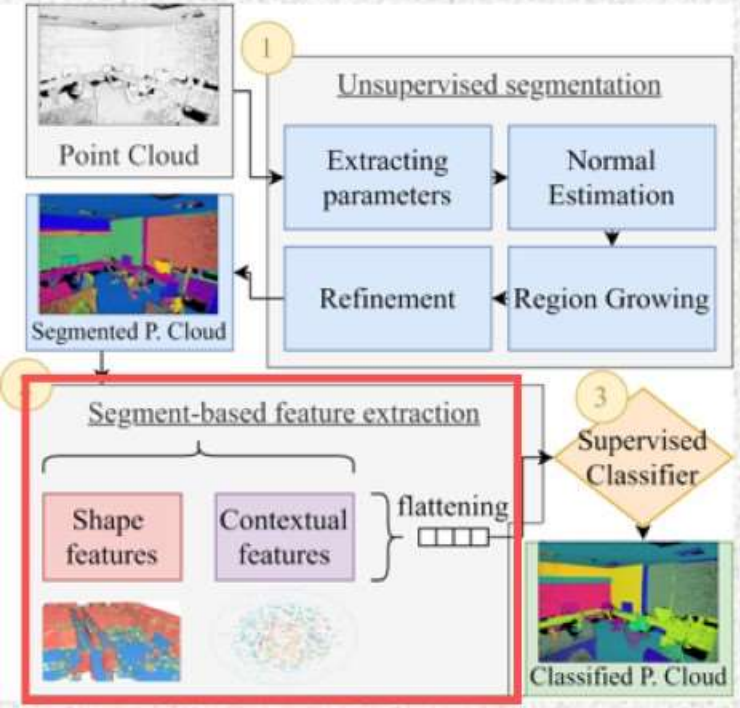
Unspervised direction

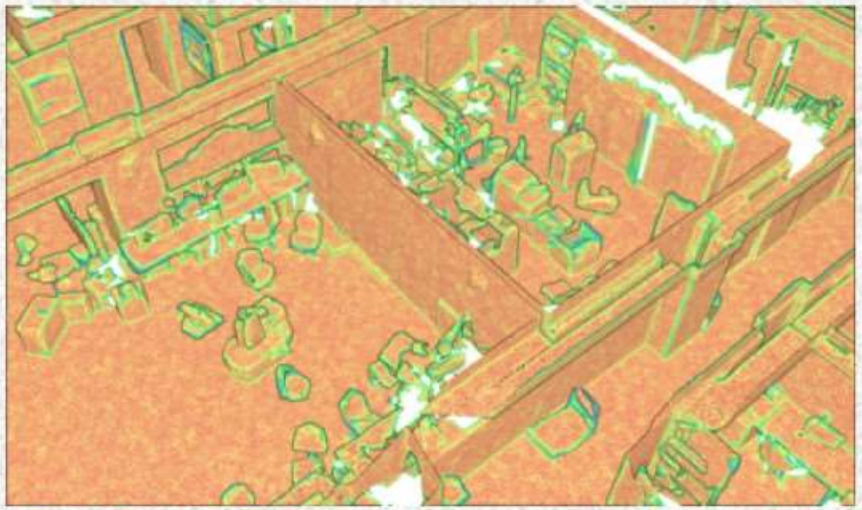


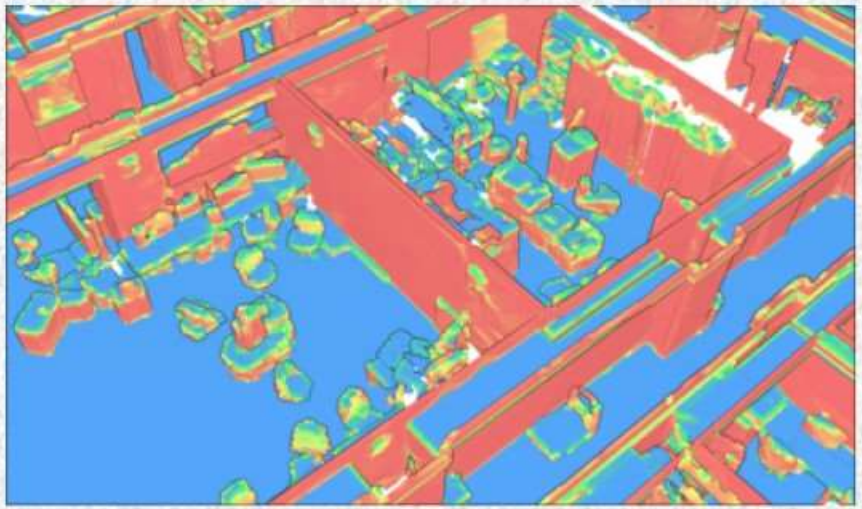
Segmentation (unsupervised)

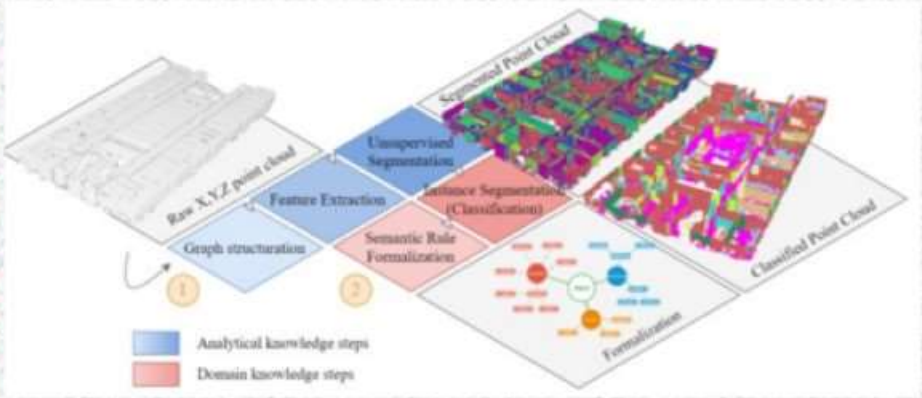
S-based feature extraction

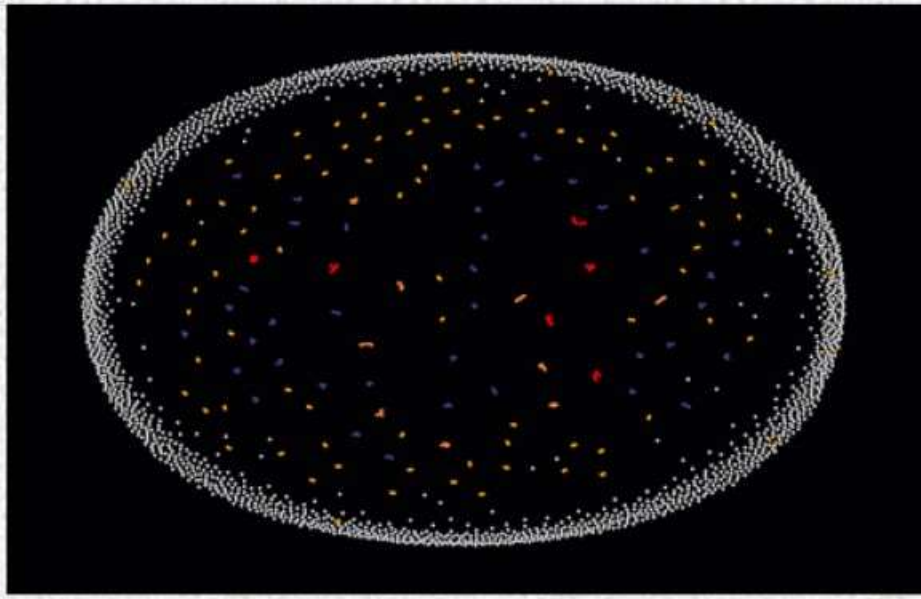
SELF-LEARNING ONTOLOGY FOR INSTANCE SEGMENTATION OF 3D INDOOR POINT CLOUD, Poux et Ponciano, 2020





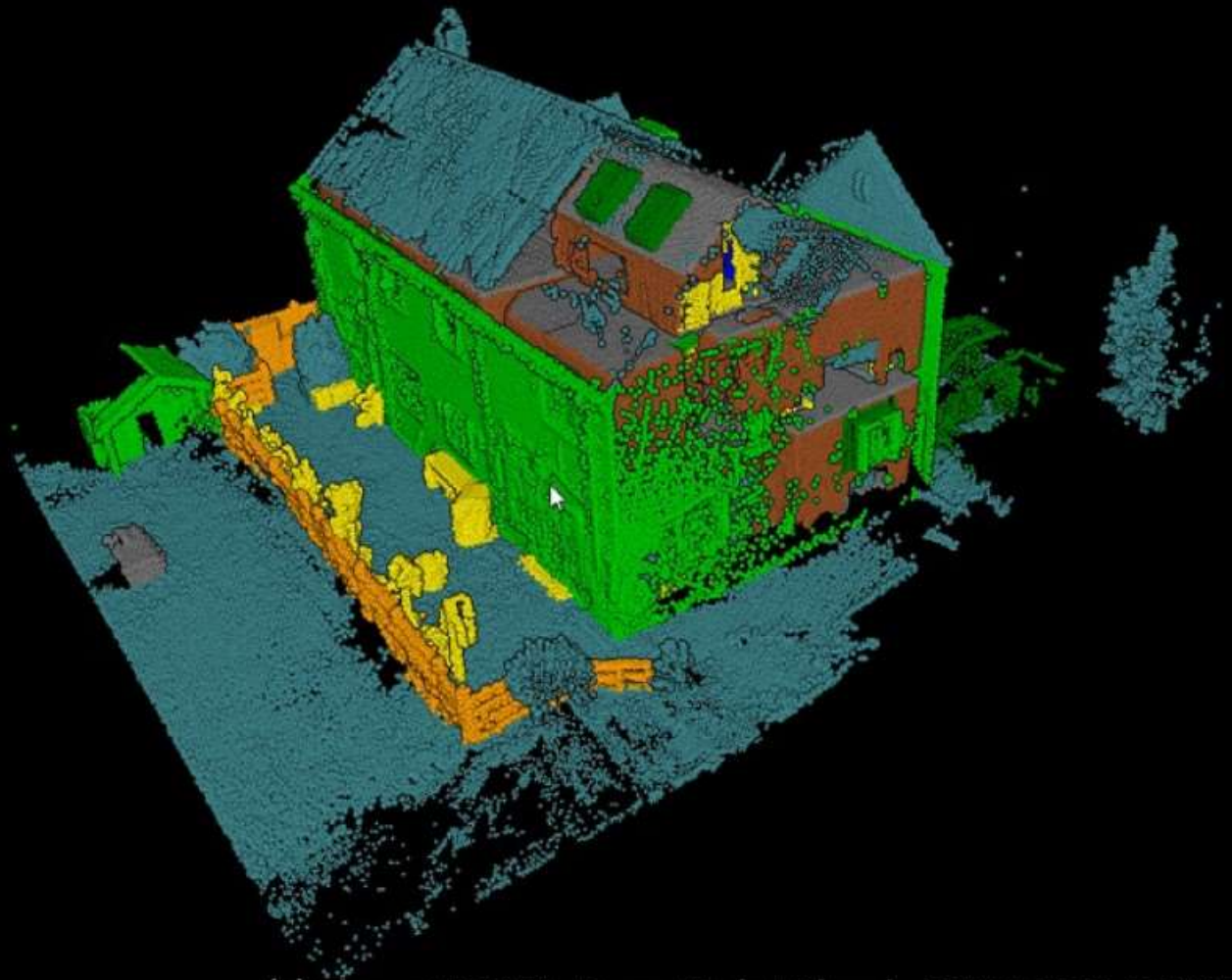






UNSUPERVISED OBJECT-BASED CLUSTERING IN SUPPORT OF SUPERVISED POINT-BASED 3D POINT CLOUD CLASSIFICATION, Grilli et al., 2021

Geometry, Semantics



Double right-click to select a point.

Activate selection mode :

OFF

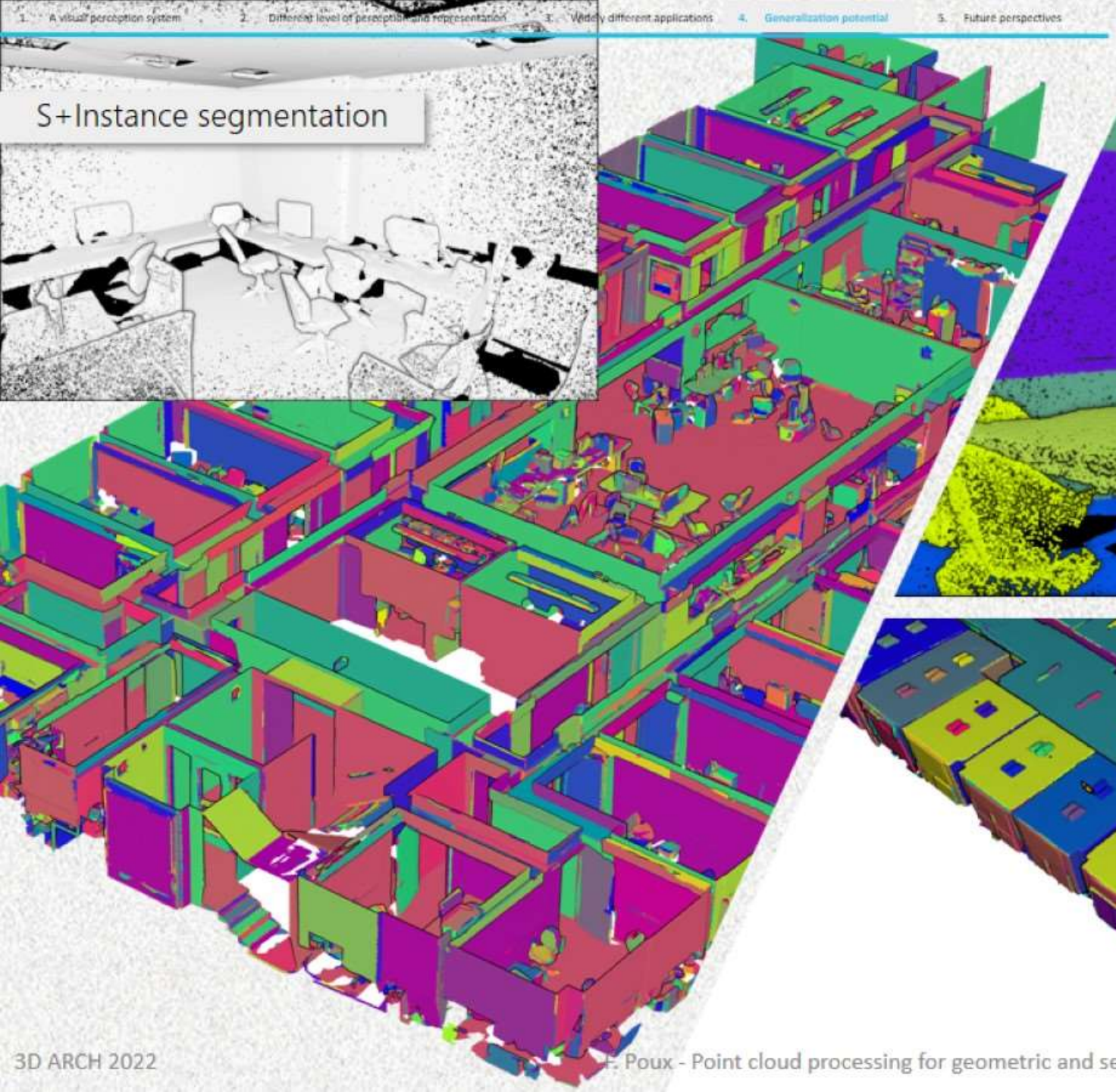
MULTIPLE SELECTION

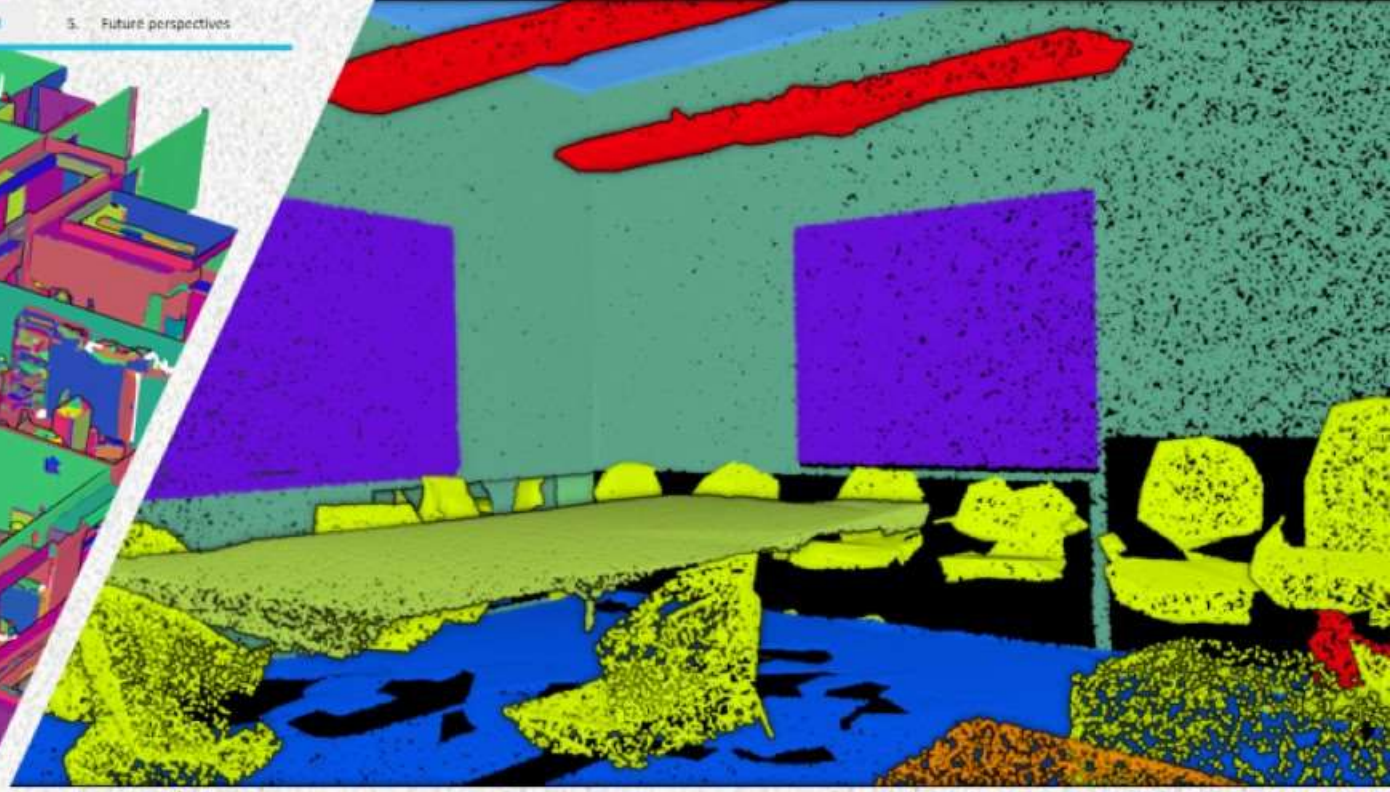
VALIDATE

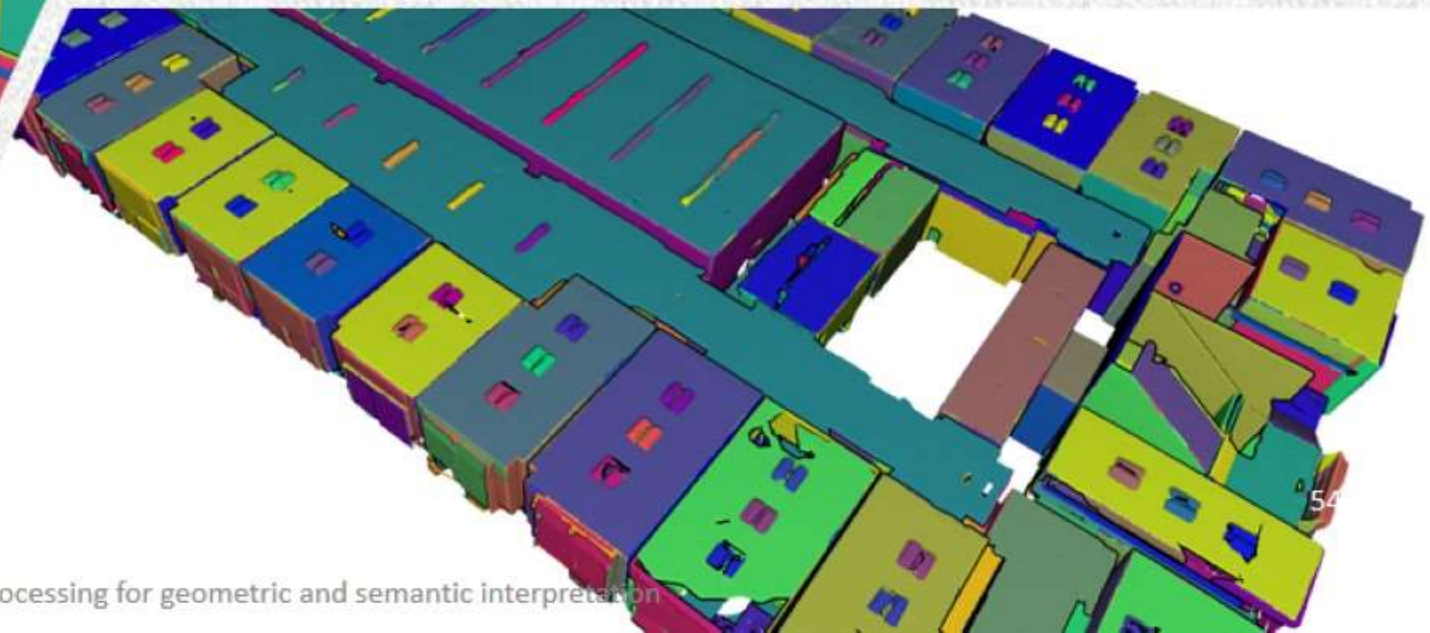
Query Form

(c) Florent POUX - Smart Point Cloud - BUILD PRE-ALPHA

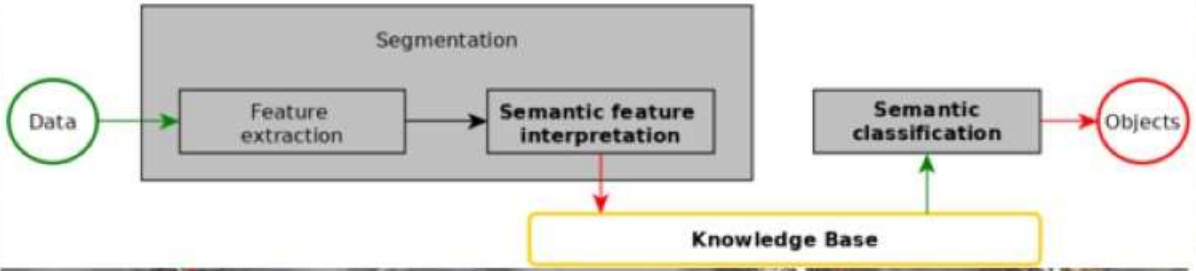
S+Instance segmentation



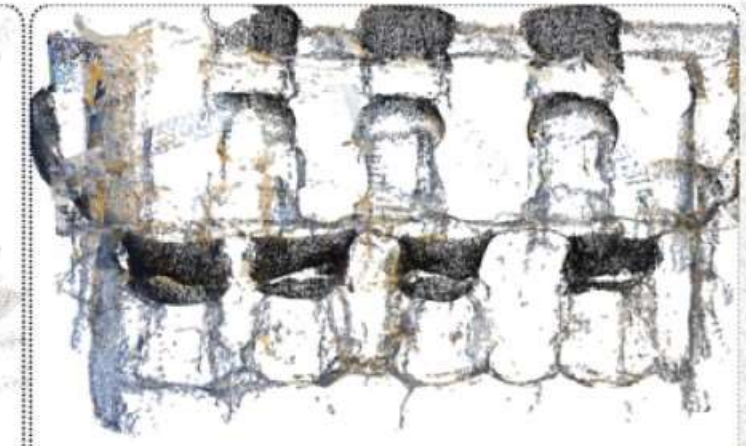




Introducing the context



(a) Results of chairs detection in red.



Circular shape

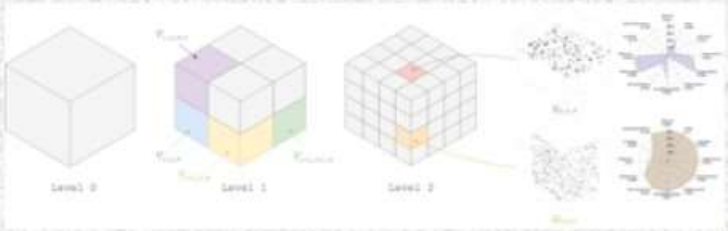
Rectangular shape

ge room context

Work room context

Source: Ranzato et al. 2020

Knowledge-Driven

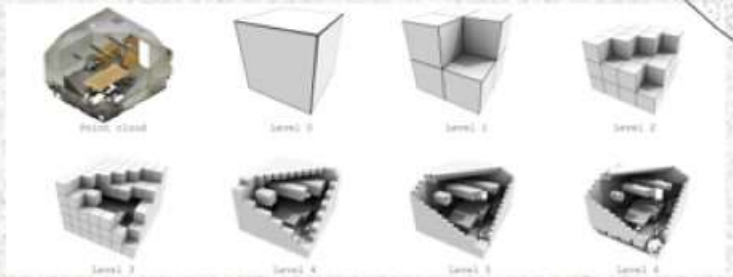


Context / Proximity

Local Features

Relationships / Topology

Geometries Generalizations



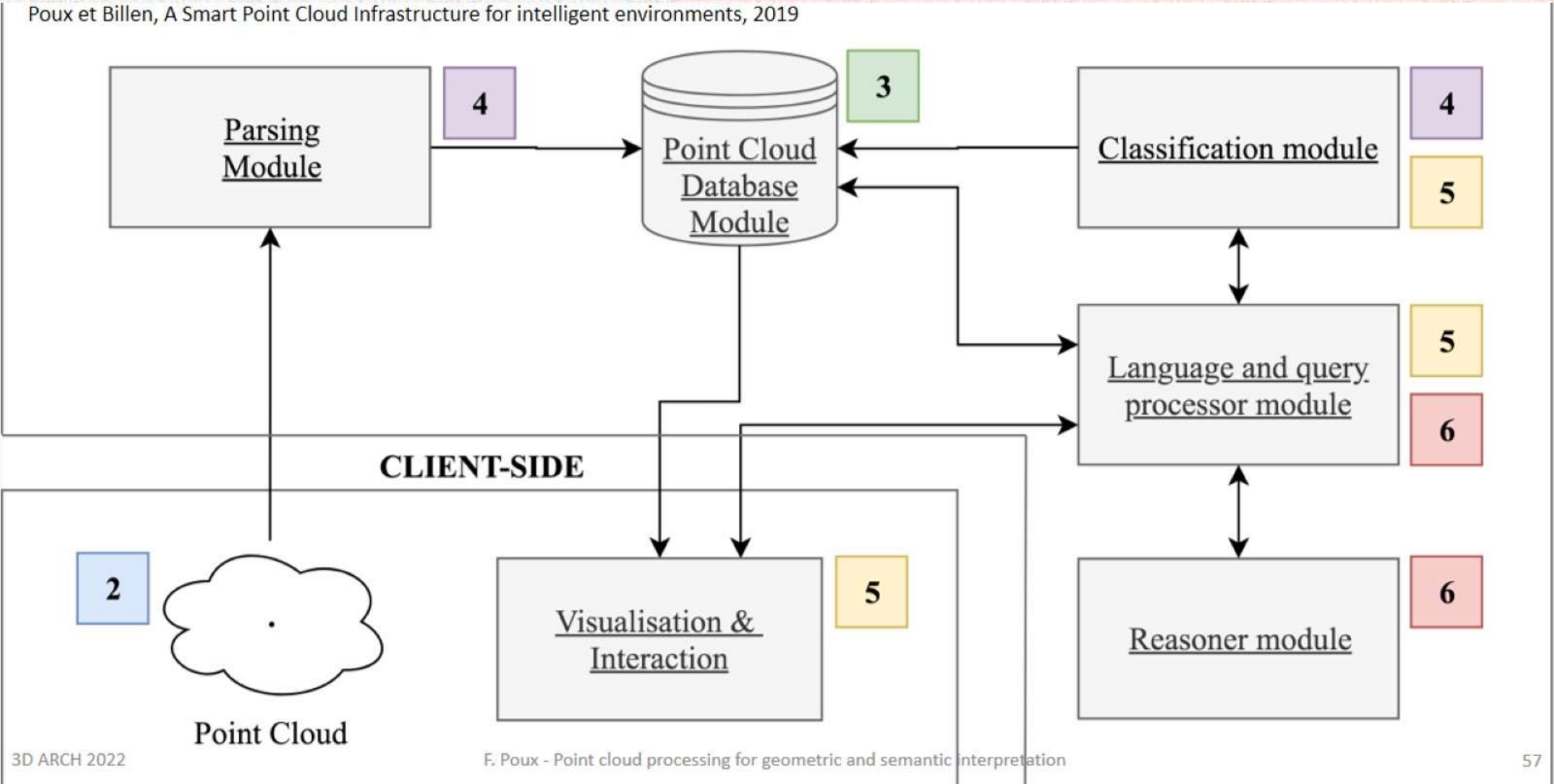
Isolation

Relation « host/guest »

Extract

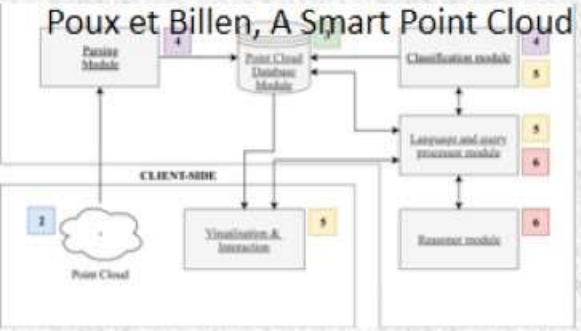
Acquisition | Pre-processing | Registration | Segmentation | Classification | Structuration | Application

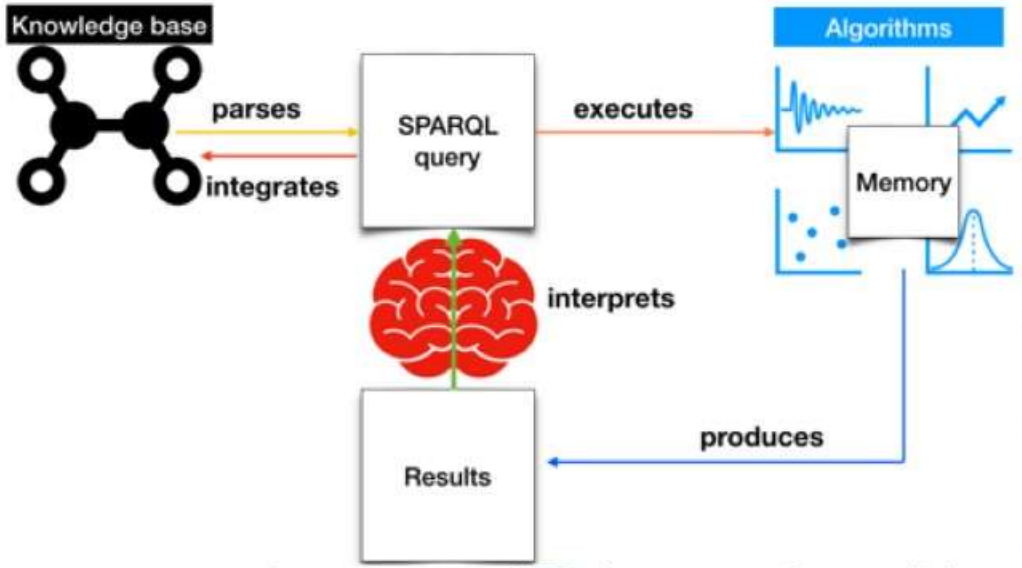
Poux et Billen, A Smart Point Cloud Infrastructure for intelligent environments, 2019

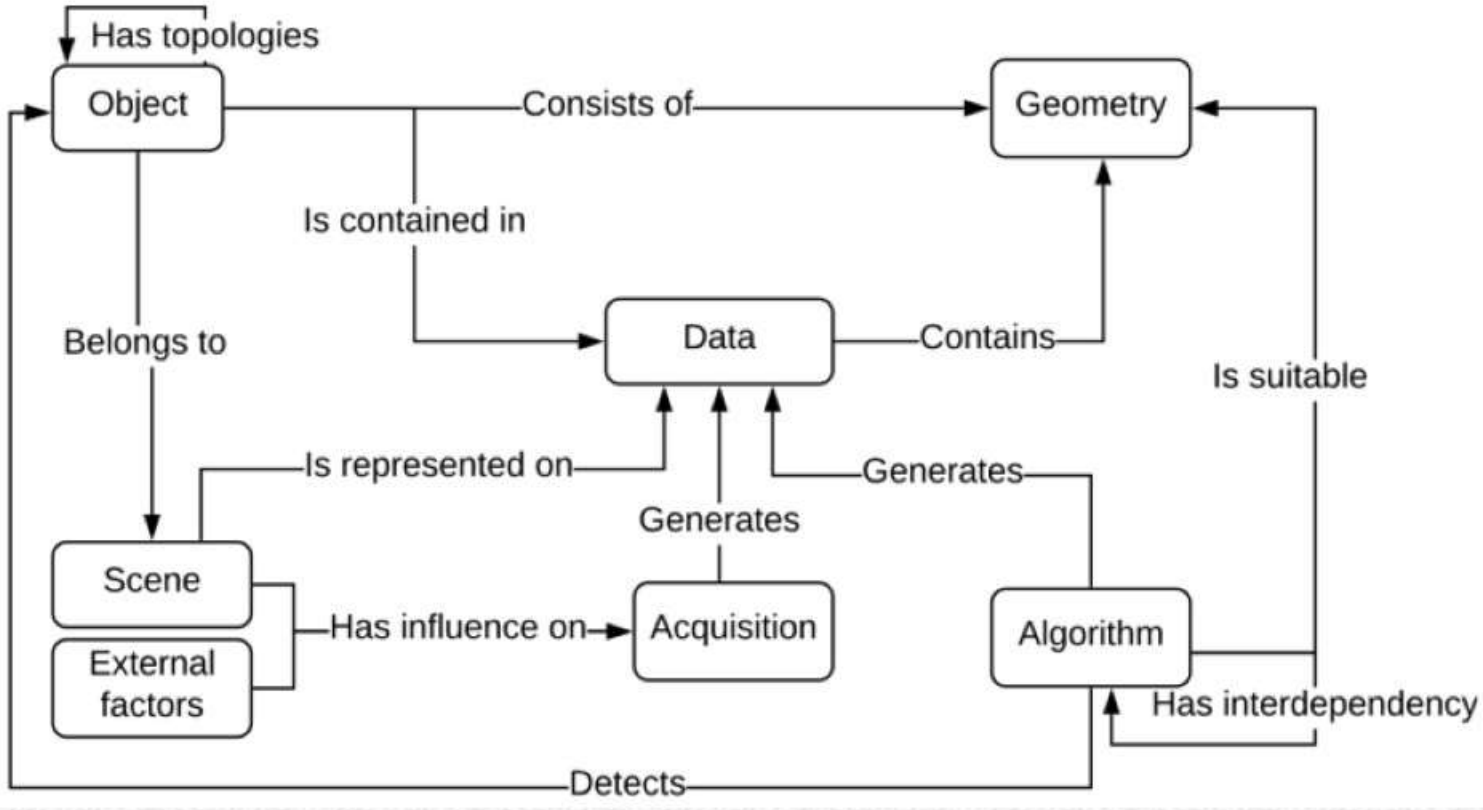


Acquisition | Pre-processing | Registration | Segmentation | Classification | Structuration | Application

Poux et Billen, A Smart Point Cloud Infrastructure for intelligent environments, 2019



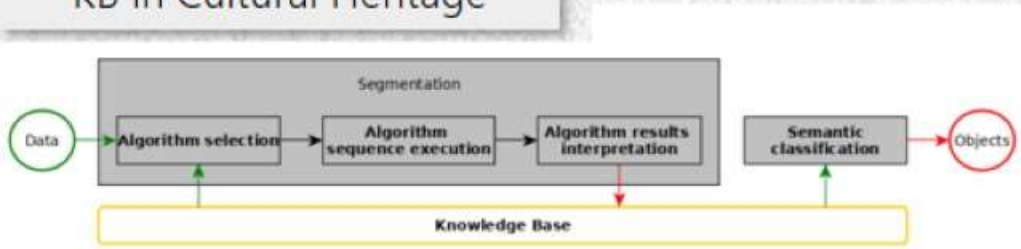


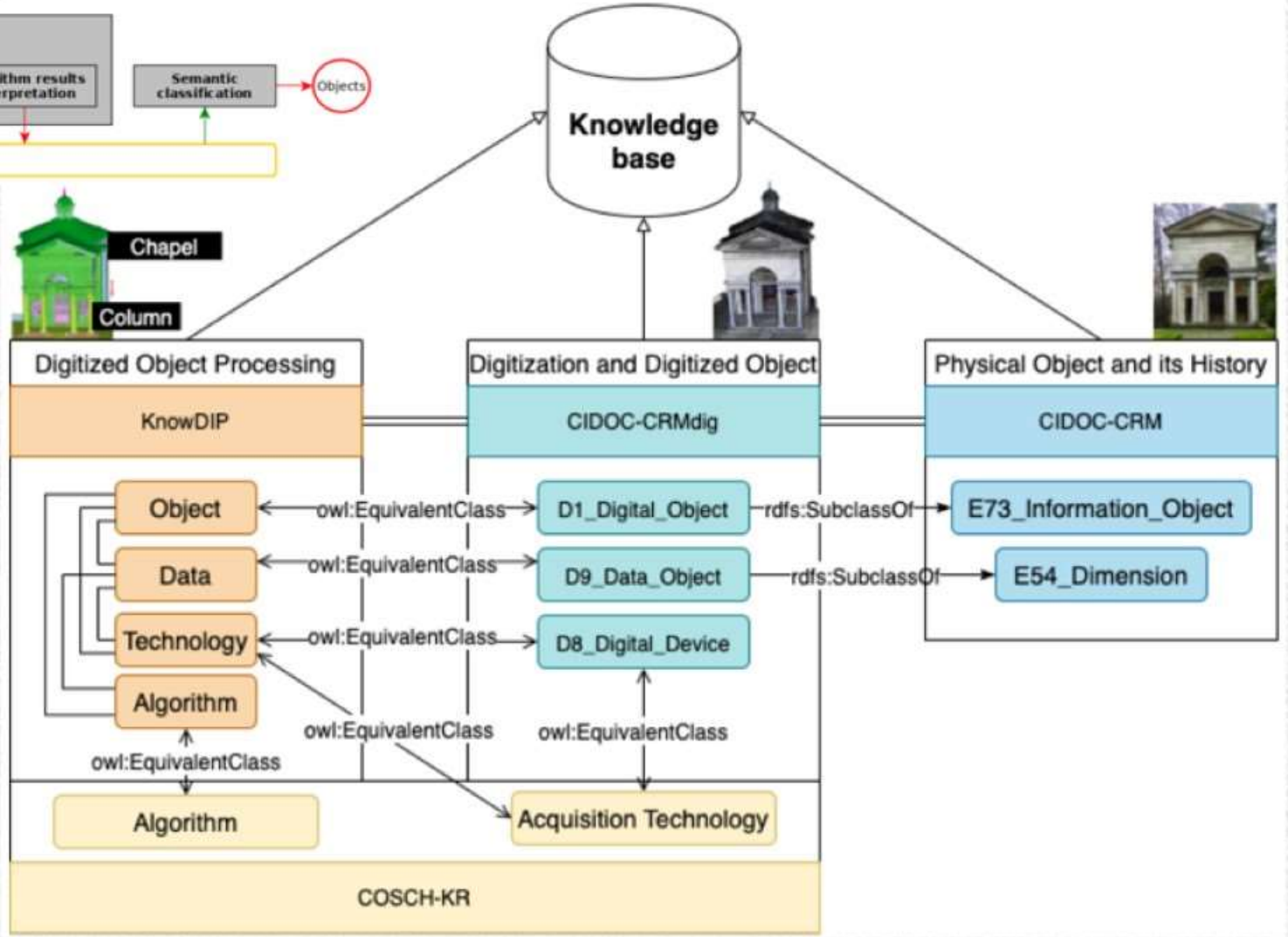


Object Detection in unstructured 3D data sets using explicit semantics, Ponciano, 2019

Poux & Ponciano, 2020

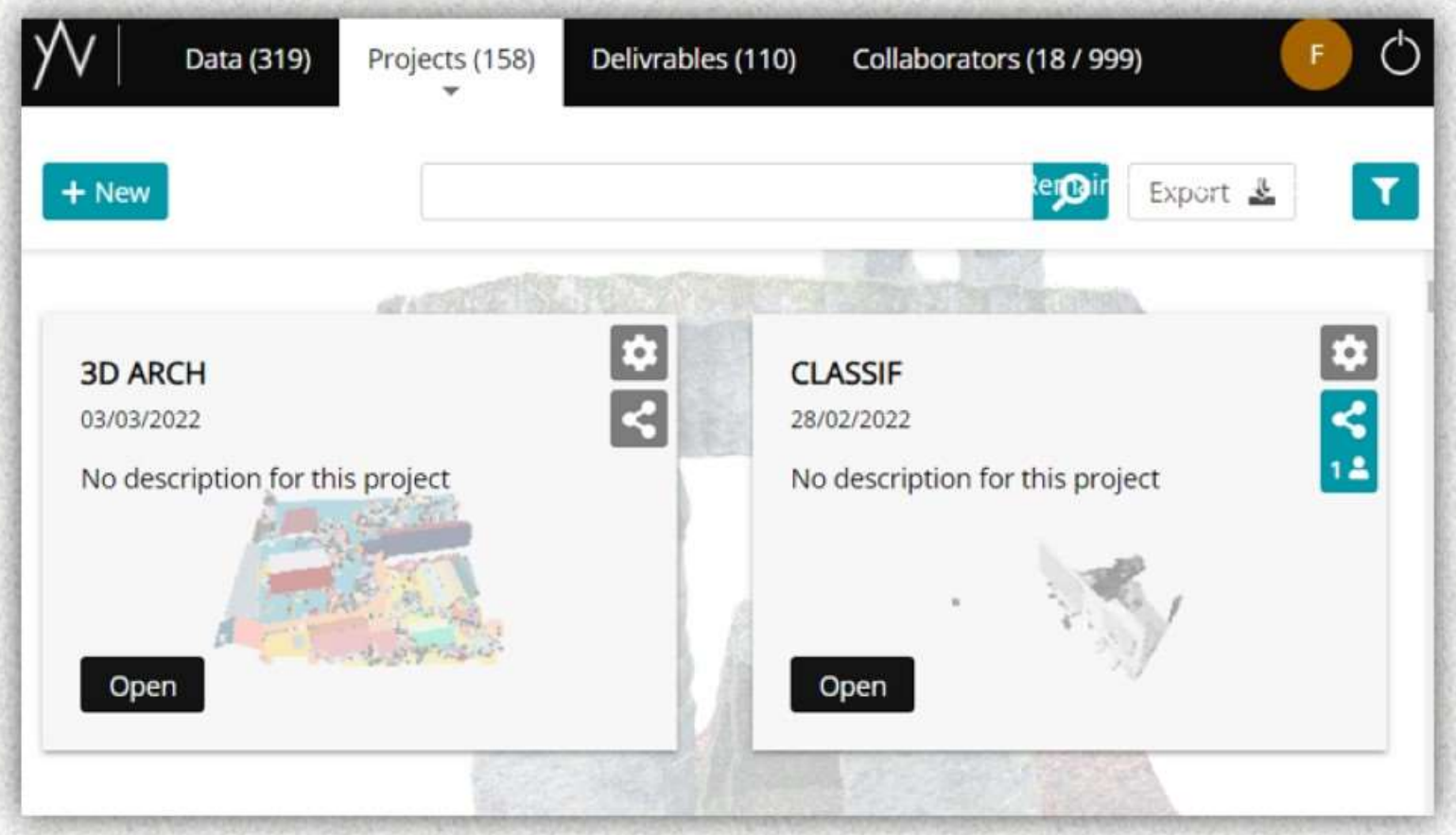
KB in Cultural Heritage



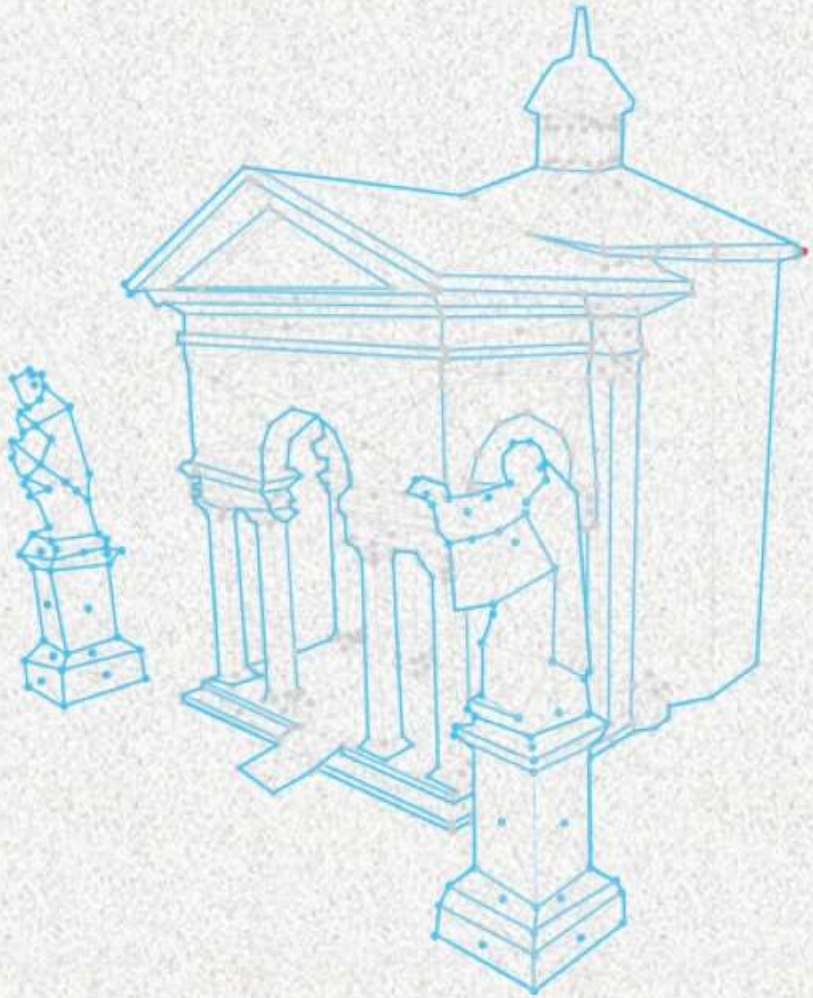


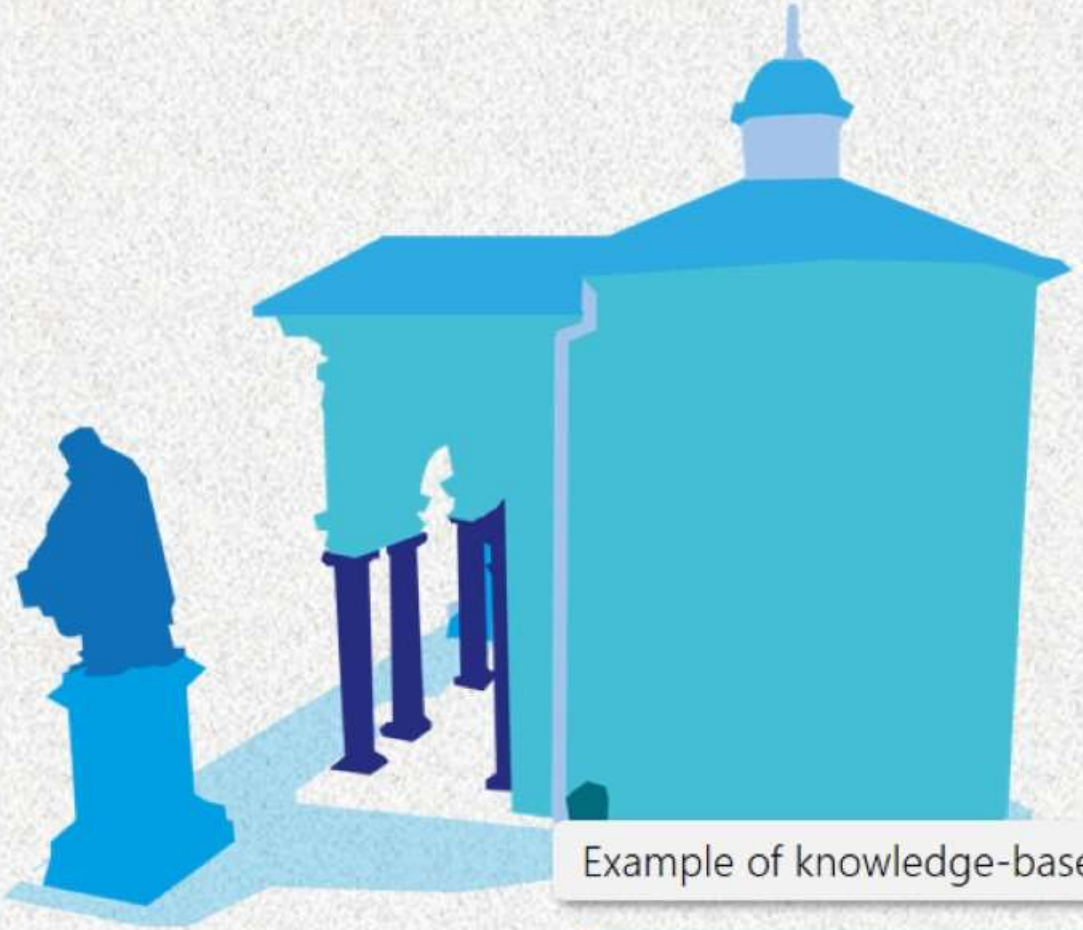
From Acquisition to Presentation—The Potential of Semantics to Support the Safeguard of Cultural Heritage, Ponciano et al., 2021

Towards innovation



4. Can we generalize our ARCH-approaches?

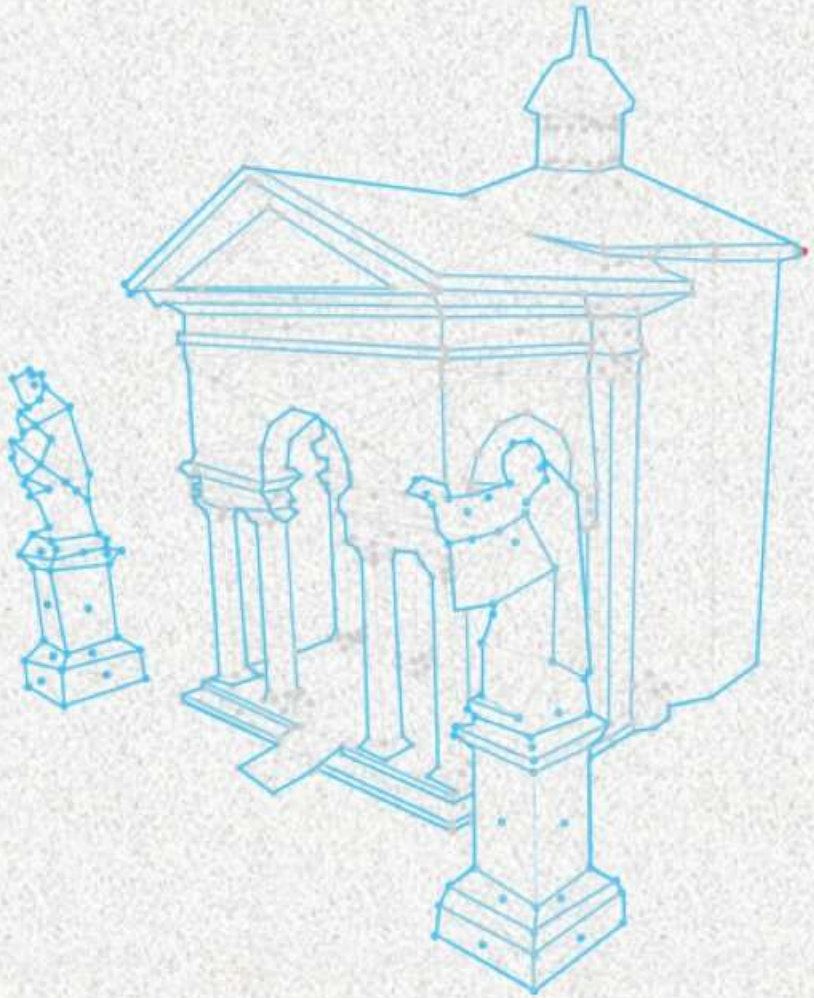


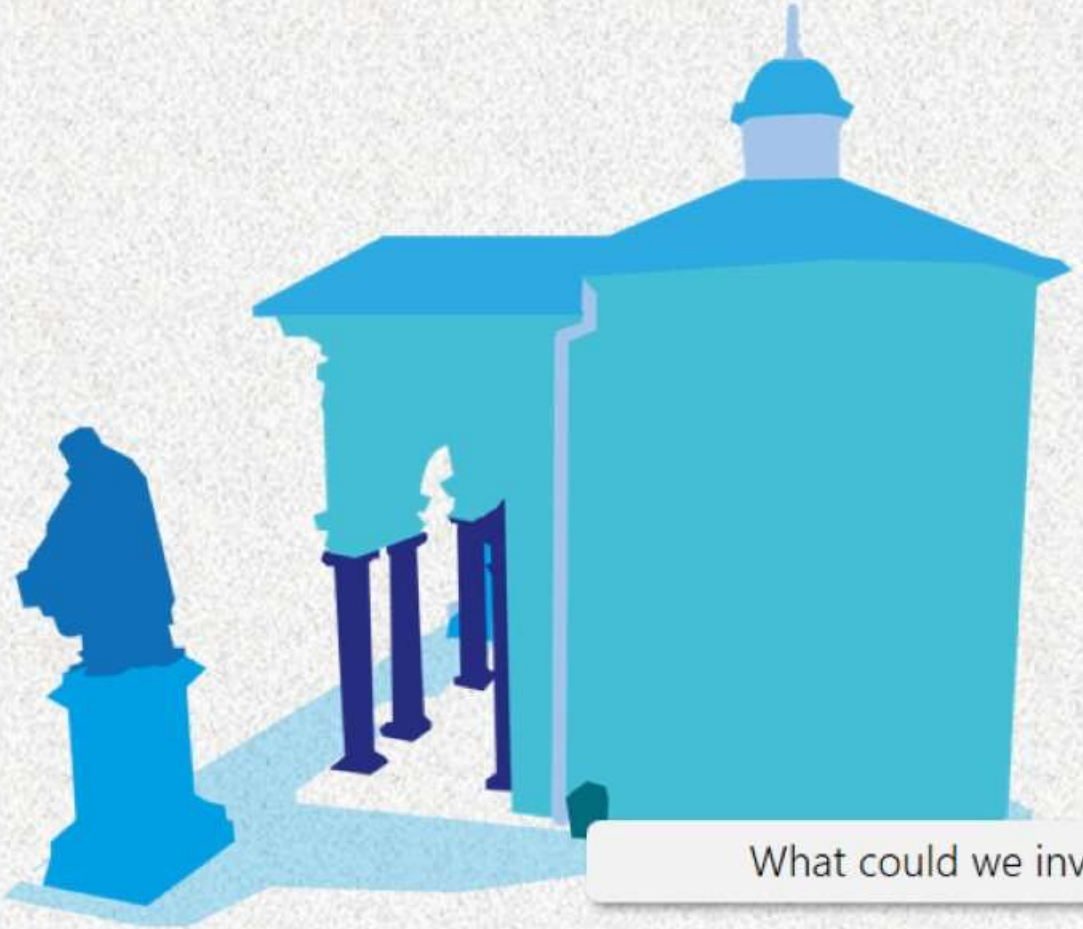


Example of knowledge-based learning ✓

Bypassing the human memory limits +

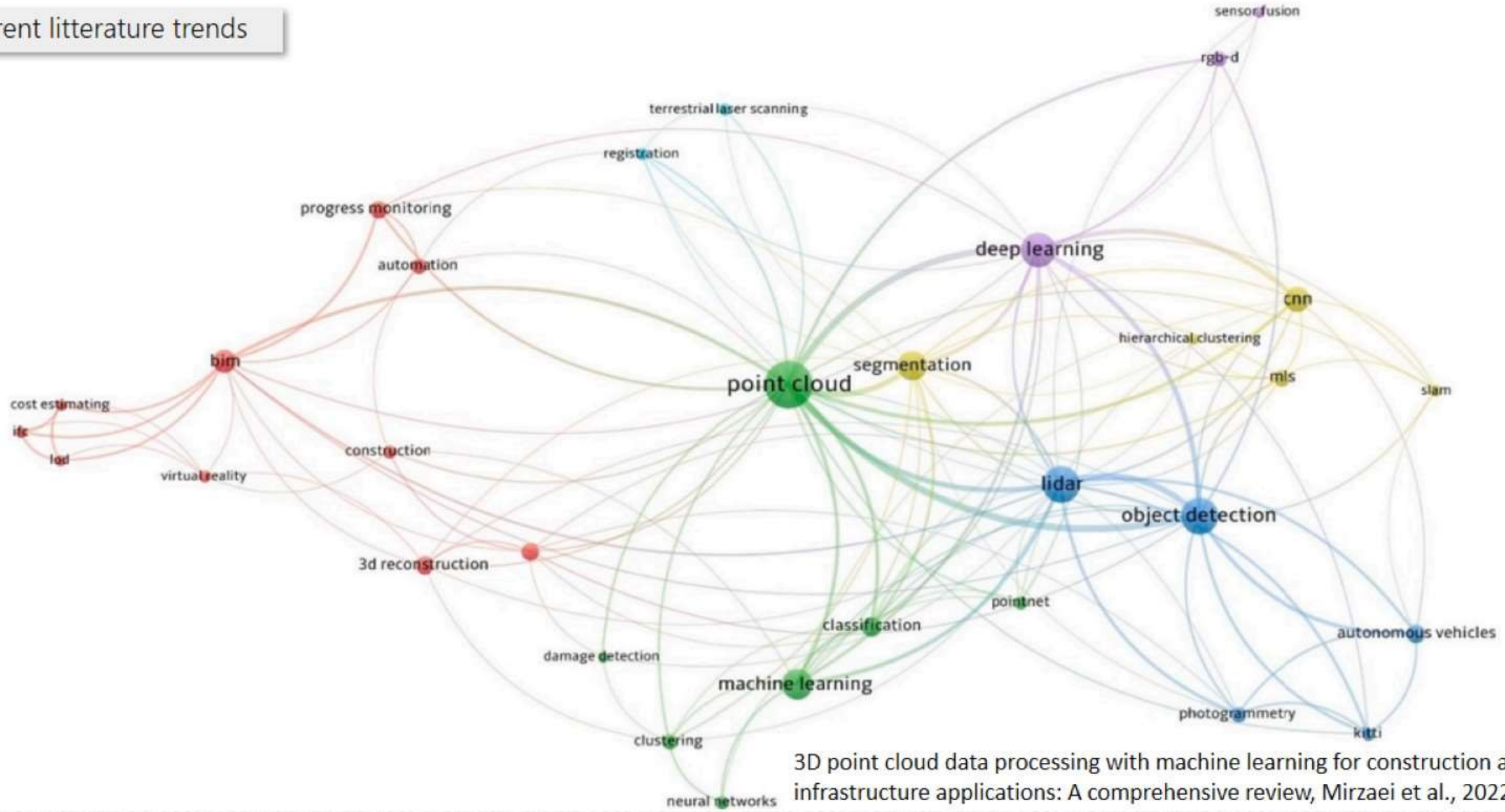
5. Perspectives





What could we investigate next?

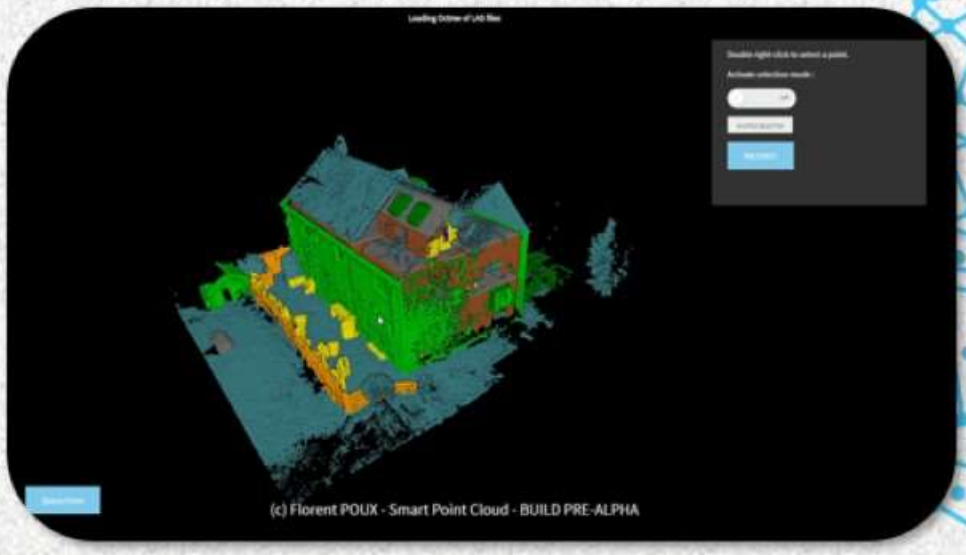
Current litterature trends



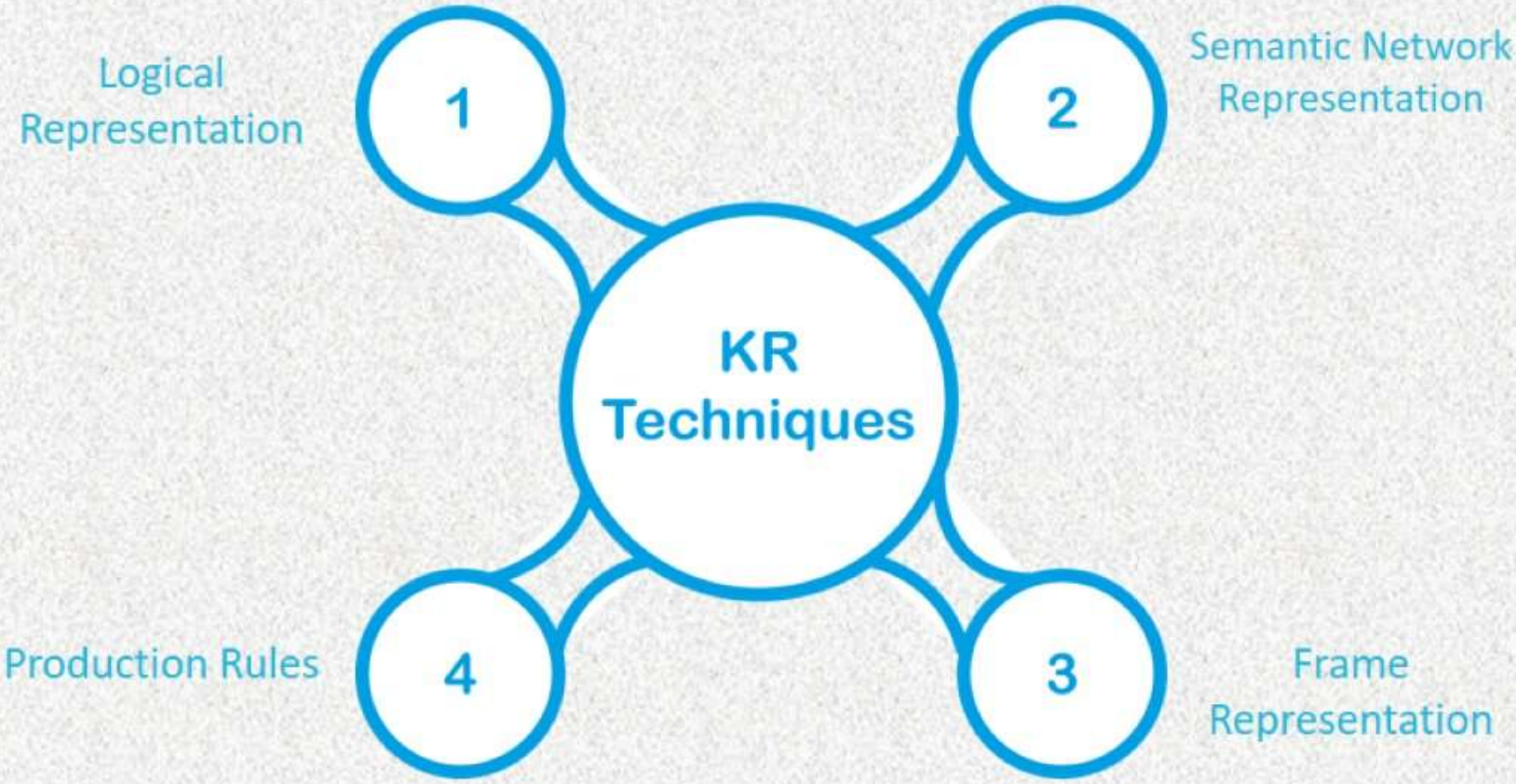
3D point cloud data processing with machine learning for construction and infrastructure applications: A comprehensive review, Mirzaei et al., 2022

First pass perspectives

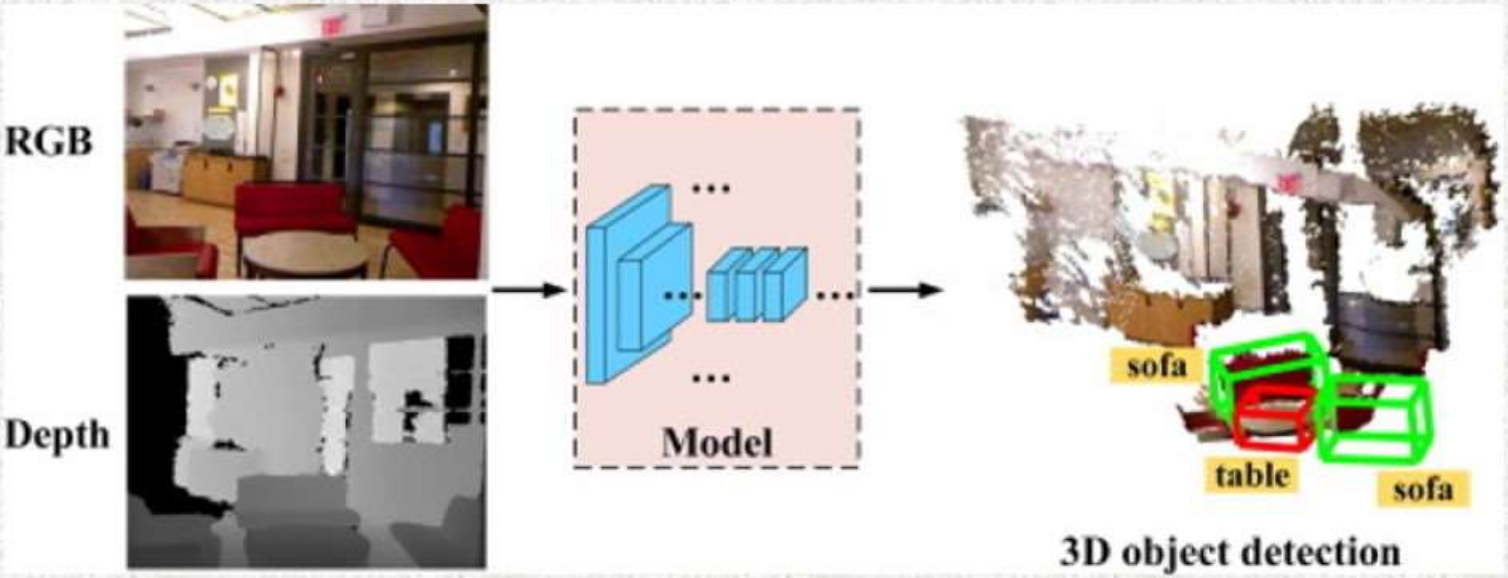
- Define powerful SPC-based AI Agents
- Increase generalization / specialization
- Dynamic data and LoD management
- Enhance unsupervised segmentation
- Enhance classification



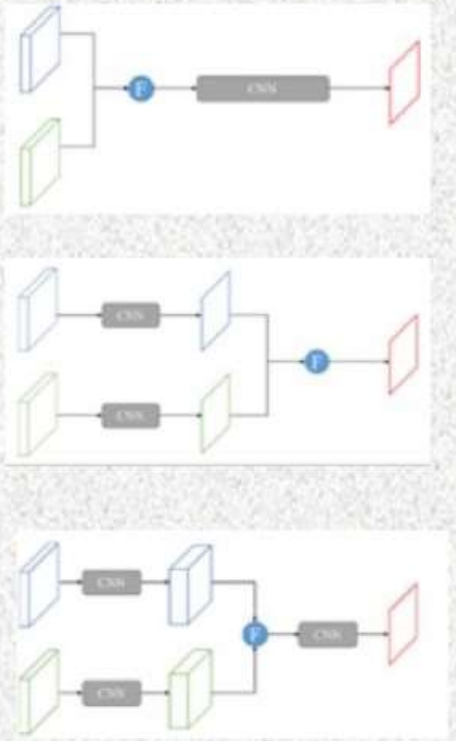
Knowledge Representation



Information fusion

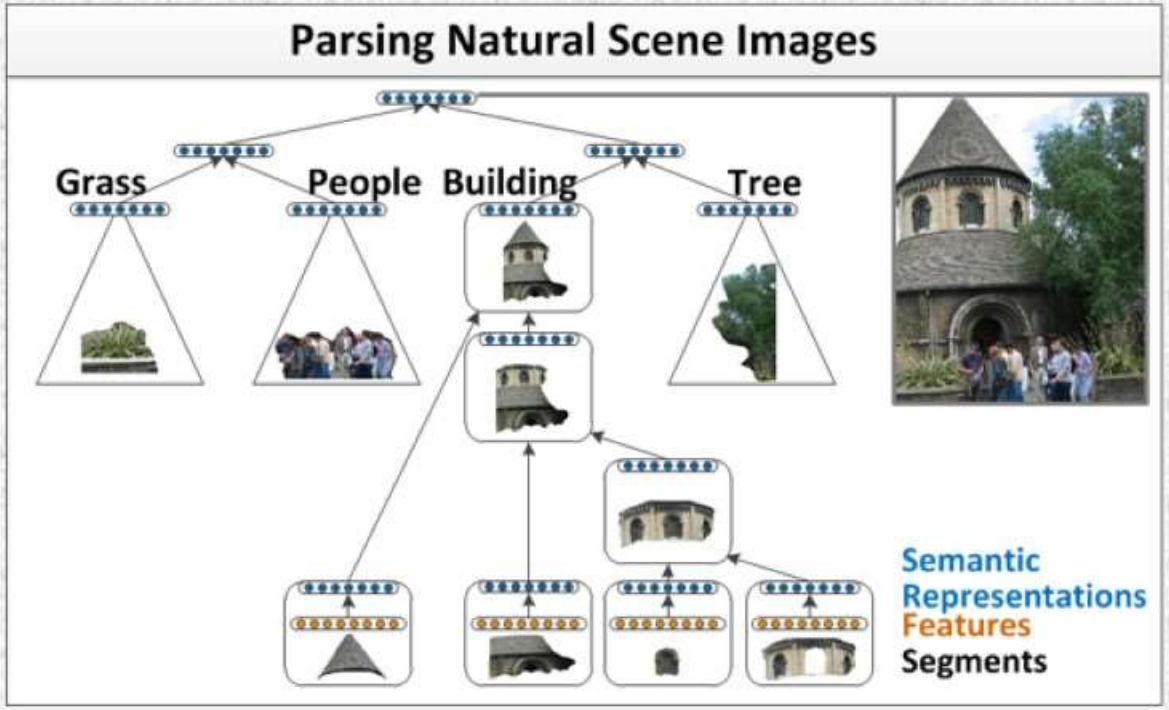


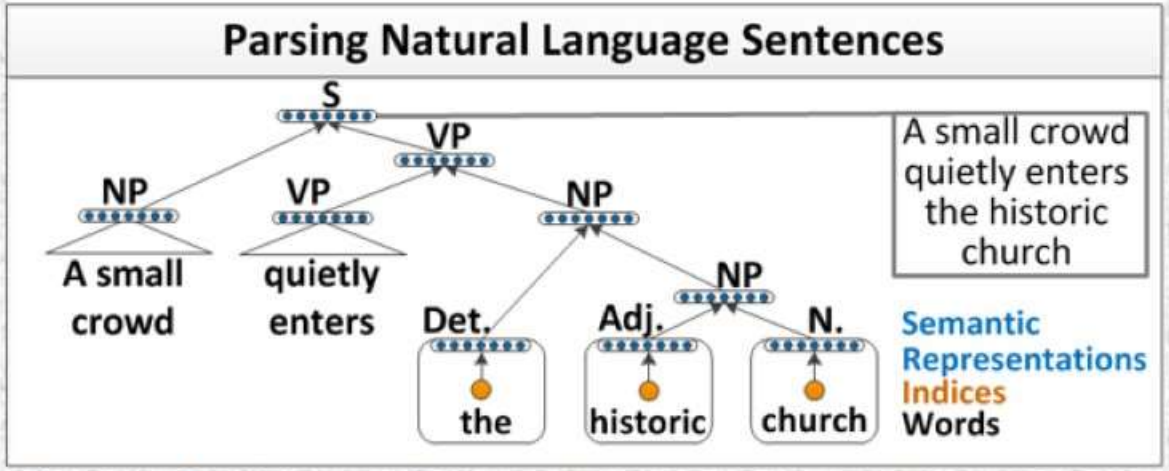
A multilevel fusion network for 3D object detection, Xia et al., 2021



C. Maurice, Sattelite photogrammetry for 3D tasks, 2022

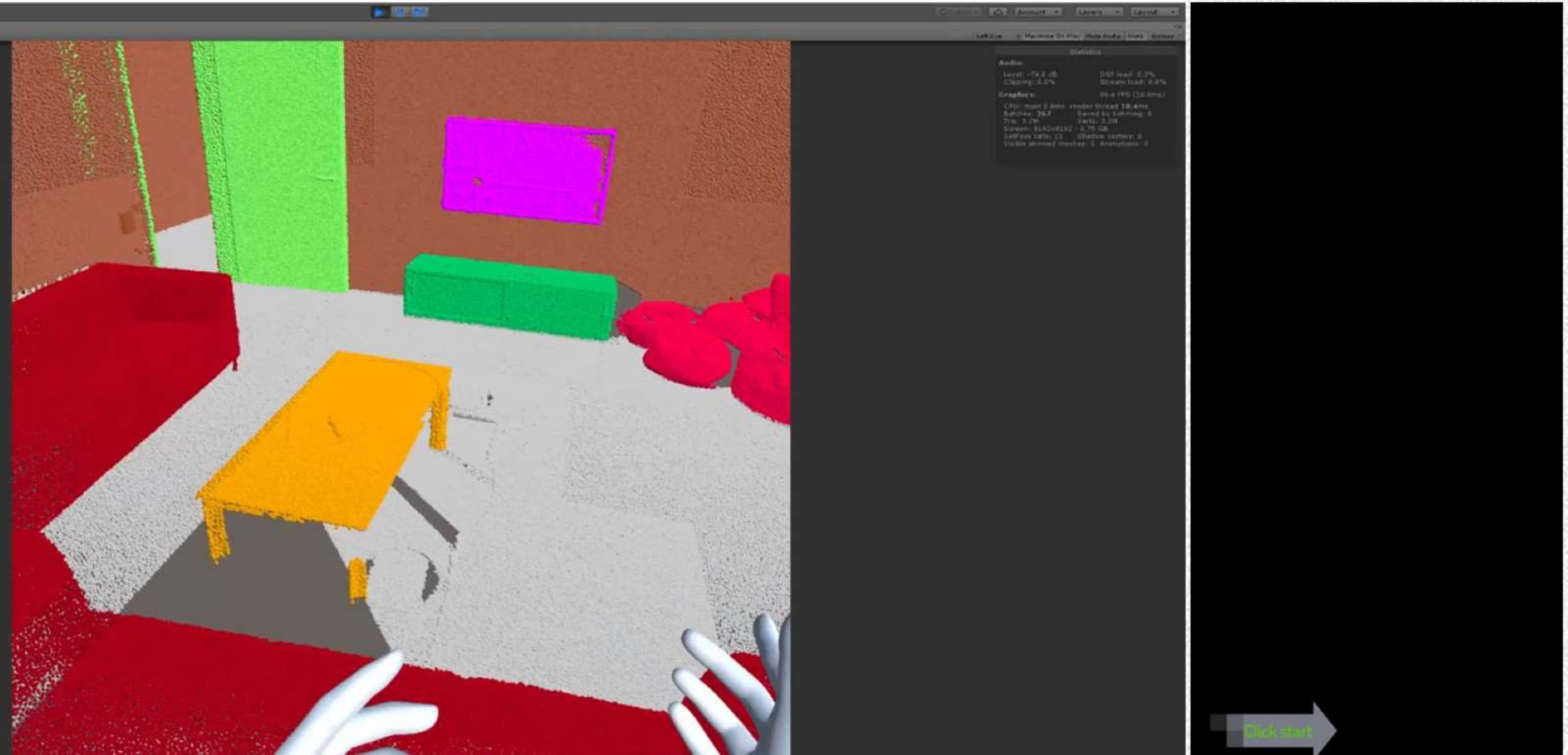
Natural language processing

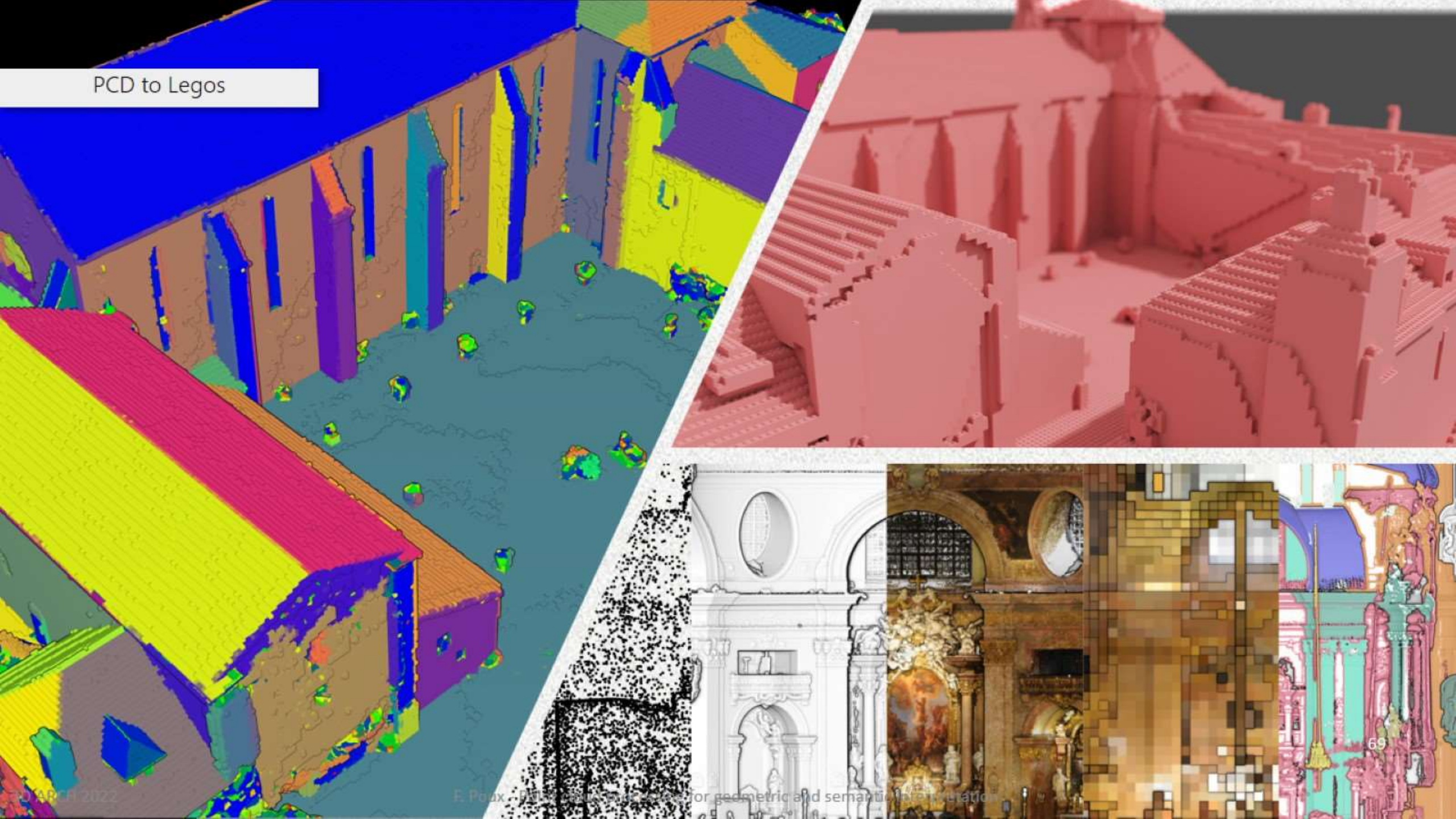




[The Stanford Natural Language Processing Group]

Interaction & Meta




PCD to Legos

E-Learning Center

Teaching & Sharing Ideas

3D Geodata Academy

LIÈGE université

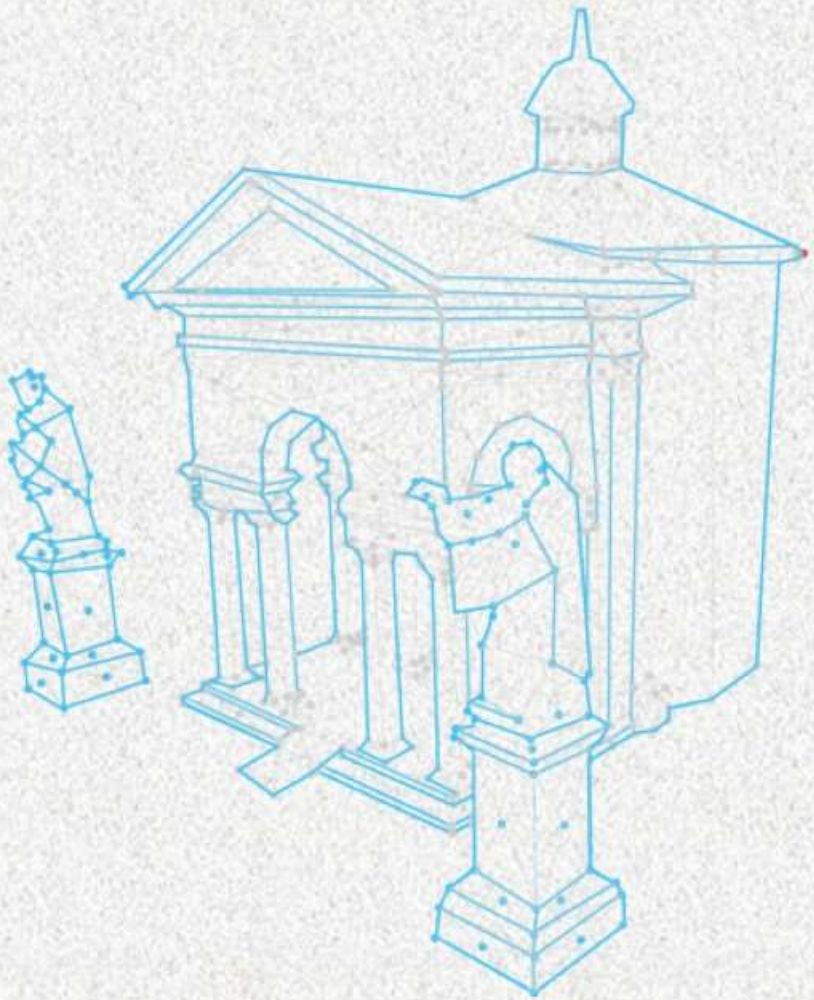
Research Articles

Innovations, R&T and 3D Projects

GEOSAT

La FRENCH TECH FT120

Thank you !



fpoux@uliege.be

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