Chair of Circular Engineering for Architecture

Automating Scan-to-BIM for Telecom Site Planning

Jeffrey Leisi

Final Presentation
Bachelor's Thesis
26.05.2025

Agenda

Research Foundation

1. Motivation
2. State of the Art
3. Problem Statement
4. Proposed Solution
5. Research Question
6. Methodology (DSRM)

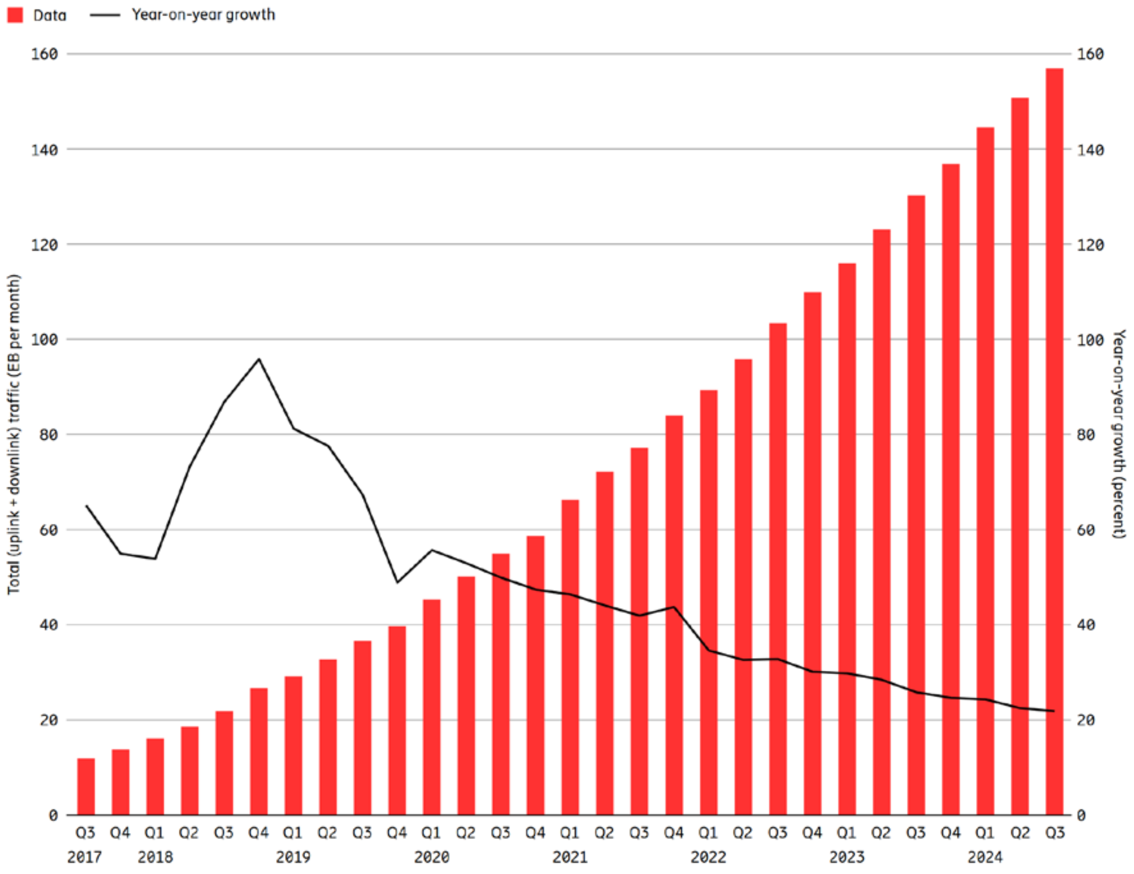
Research Activities

1. Problem Identification & Objectives
2. Design and Development
3. Demonstration
4. Evaluation
5. Communication

Part 1: Research Foundation

Motivation

Mobile data traffic increases



Source: Ericsson Mobility Report (November 2024)

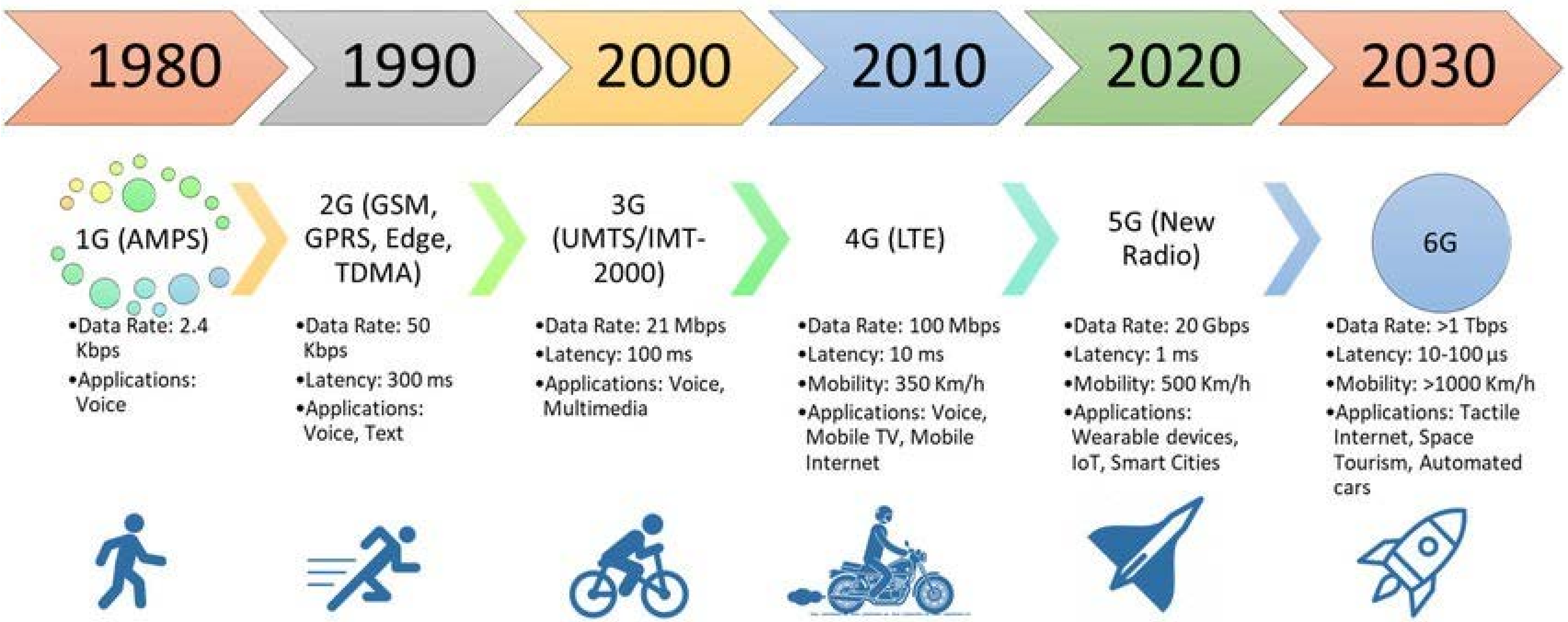
Motivation

Mobile data traffic increases

↓

New technologies
(shift toward higher frequency bands)

Currently relevant



Source: https://www.linkedin.com/pulse/understanding-5g-glimpse-6g-evolution-connectivity-dr-manpreet-puri

Motivation

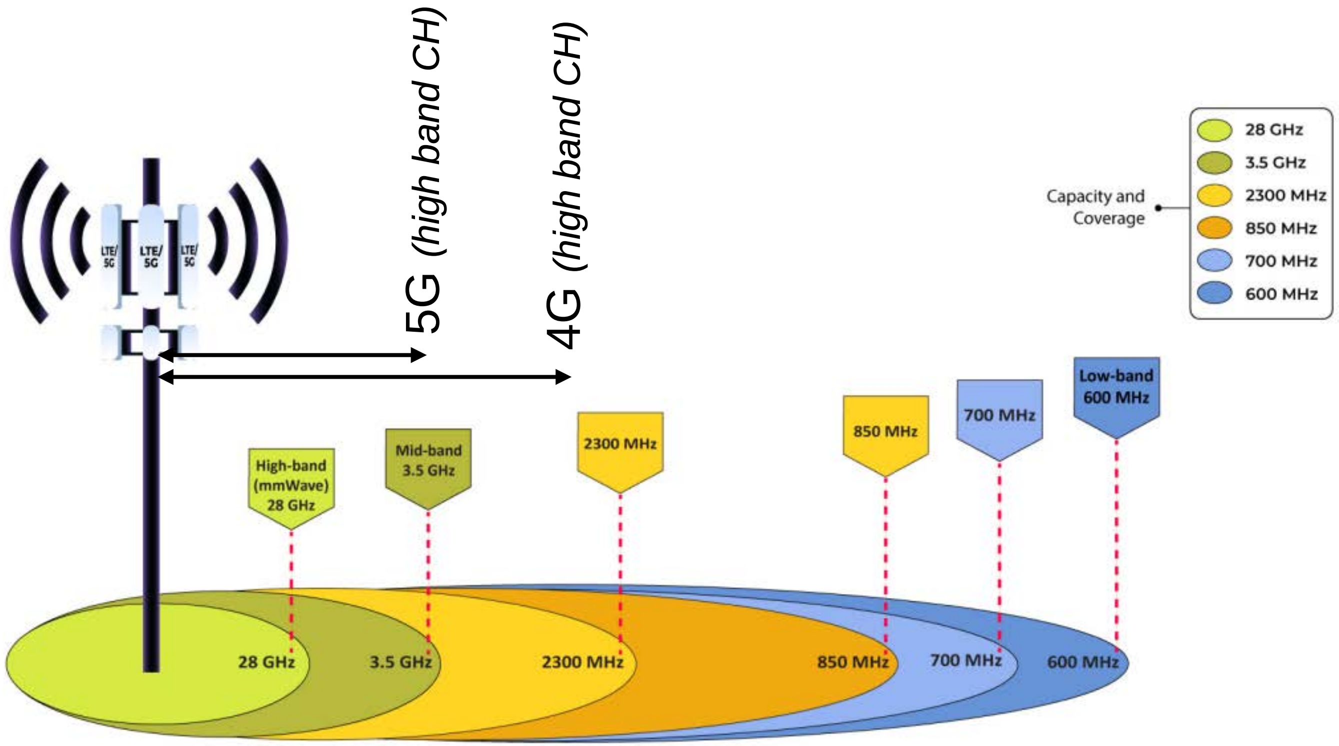
Mobile data traffic increases

↓

New technologies
(*shift toward higher frequency bands)*

↓

Decrease in range
(*stronger atmospheric attenuation)*



Source: https://jethrojeff.com/

Motivation

Mobile data traffic increases

↓

New technologies
(*shift toward higher frequency bands)*

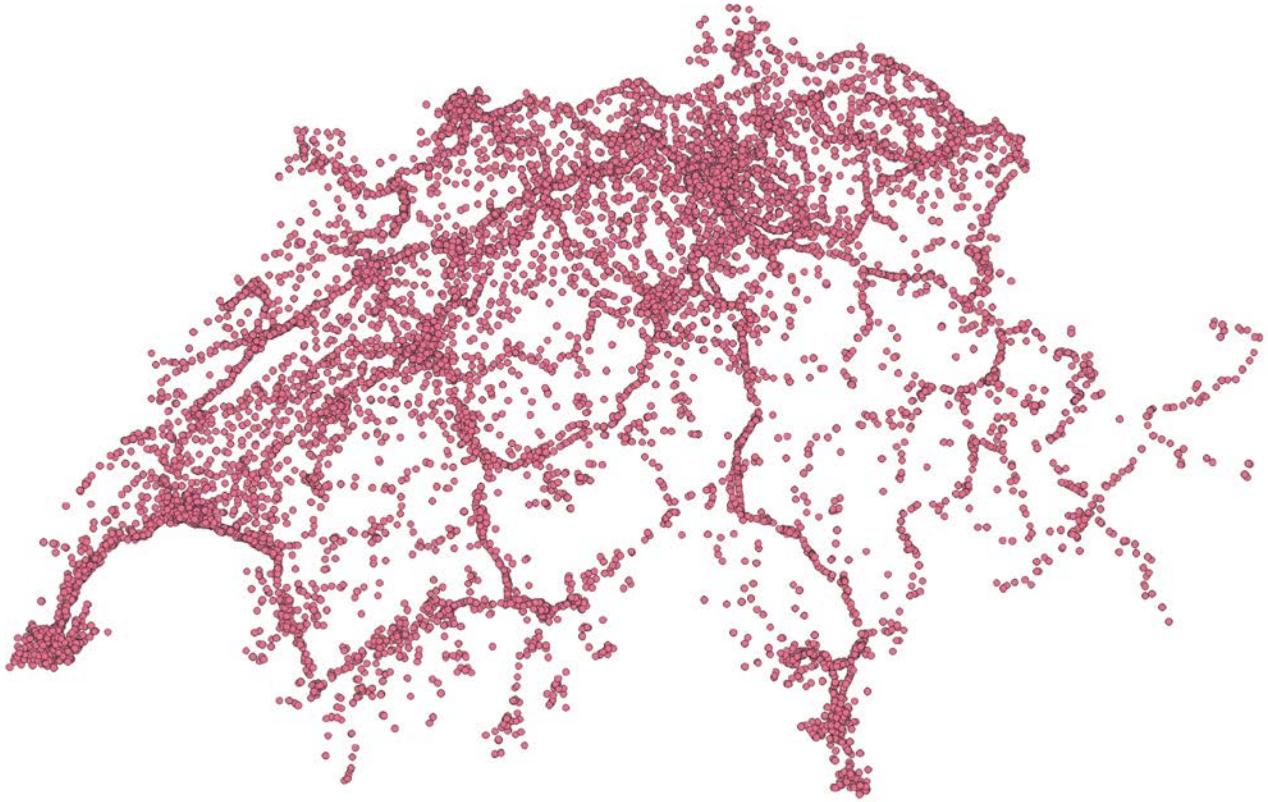
↓

Decrease in range
(*stronger atmospheric attenuation)*

↓

More antenna sites required
~(7,500 new 5G sites: CHF 3.2 bn)

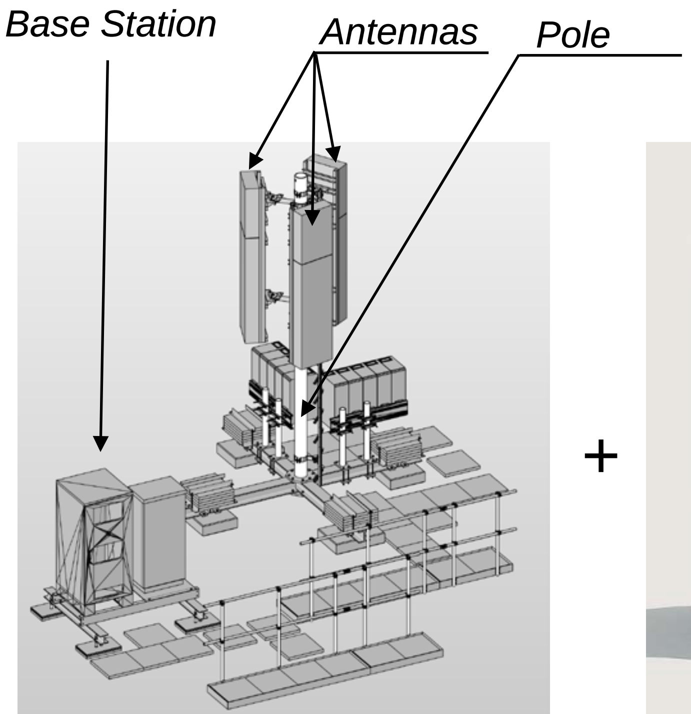
Large-scale deployment calls for **efficient** planning strategies.



Status quo: ~15,000 sites *(> 5 W)*

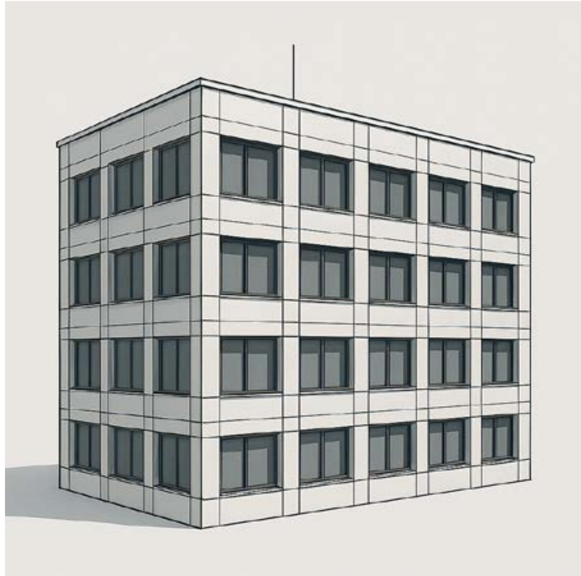
Source: Own GIS analysis based on data from https://data.geo.admin.ch/browser/index.html#/collections/ch.bakom.standorte-mobilfunkanlagen?.language=en

Definition: Cellular Site



- Steel structures
- Radio Access Network (RAN) Equipment

+



Building

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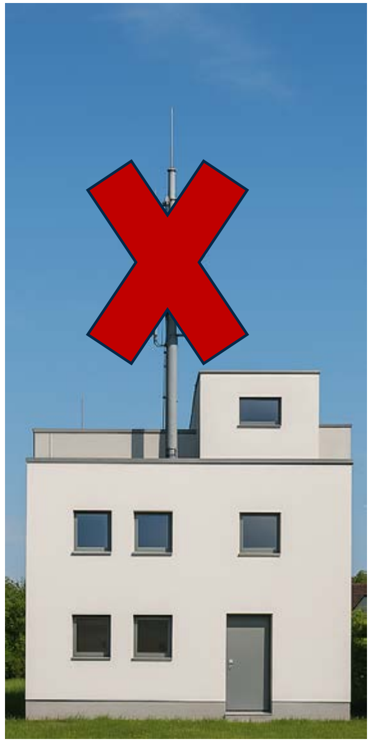
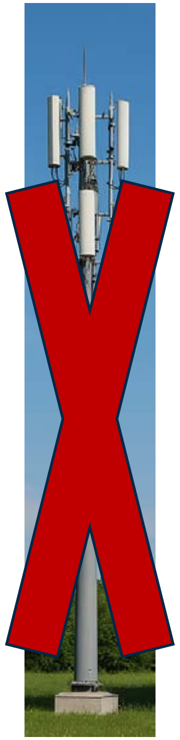


Rooftop Site
mainly urban areas

Thesis focus



Greenfield Site
mainly rural areas

State of the Art: Conventional Site Planning

Site Survey → Schematic Design → Technical Design → Execution & Operations

Building Permit

Tasks

Inspection of the site:

- **Drone capture**
- Geodetic survey (GNSS, total station)
- Organize existing building drawings

GNSS: Global Navigation Satellite System, positioning system

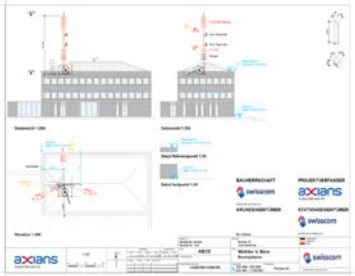
Total Station: Instrument for precise spatial measurement

State of the Art: Conventional Site Planning

Site Survey → **Schematic Design** → Technical Design → Execution & Operations

Building Permit

→



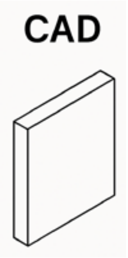
CAD

Tasks

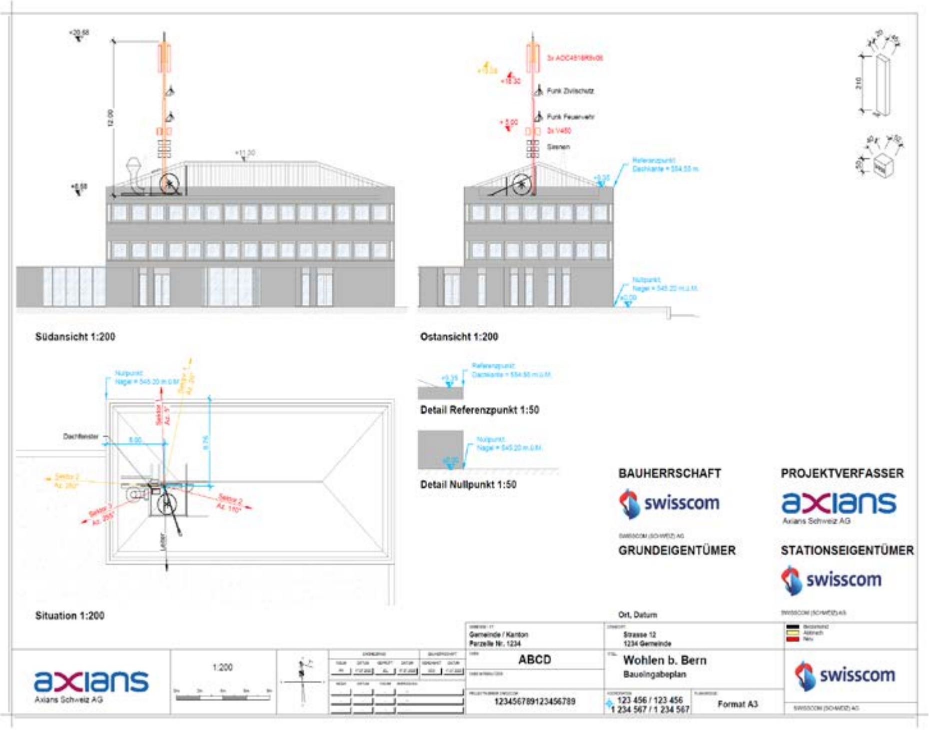
Create **CAD drawing** for building permit:

1. Scanning of paper building drawings
2. CAD-vectorization of digitalized building drawing (tracing)

CAD (Computer-Aided Design): Software for 2D/3D drawings



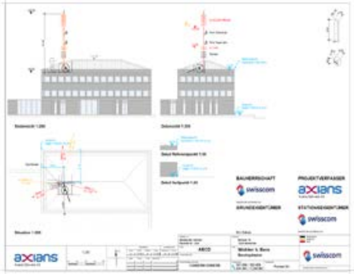
geometry



State of the Art: Conventional Site Planning

Site Survey → Schematic Design → **Technical Design** → Execution & Operations

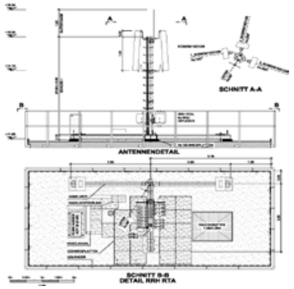
→



CAD

Building Permit

→



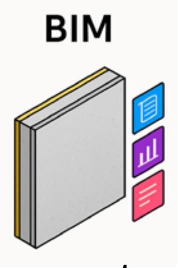
BIM

Tasks

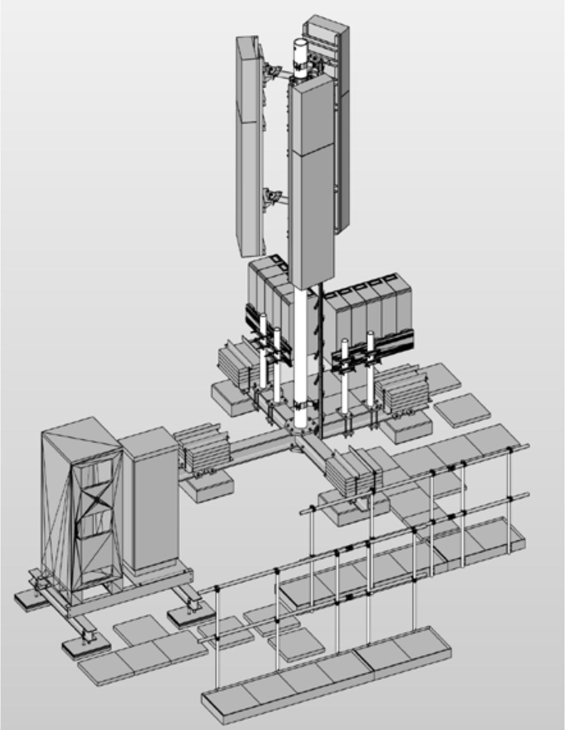
Create **BIM drawing** for execution**:**

1. Steel structure and RAN equipment
2. Derivation of bills of materials

BIM (Building Information Modeling):
Planning method with a **smart** 3D model



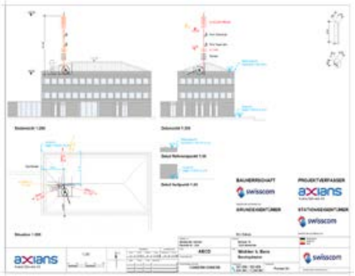
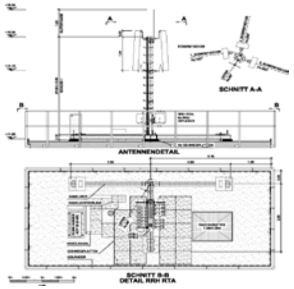
geometry + information



High component density → BIM

State of the Art: Conventional Site Planning

Site Survey → Schematic Design → Technical Design → **Execution & Operations**

 →  →  → 

CAD

Building Permit

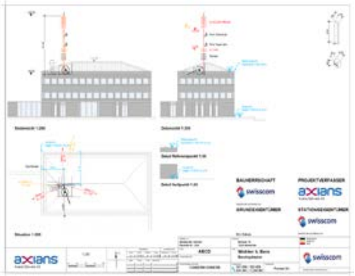
BIM

Tasks

- Site Construction
- Drawing adjustment (in case of changes)

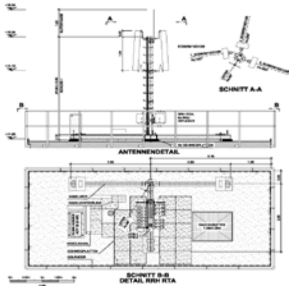
Problem Statement

Site Survey → Schematic Design → Technical Design → Execution & Operations



CAD

Building Permit



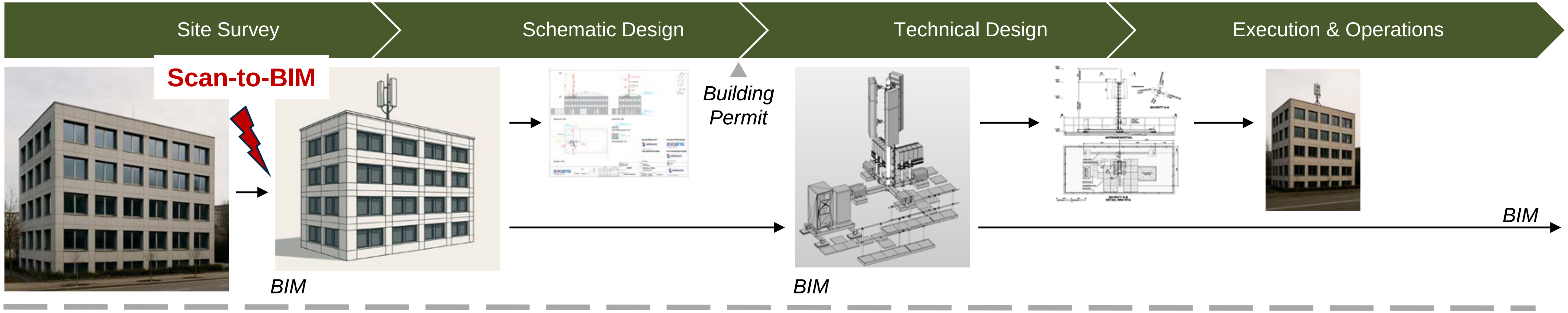
BIM

CAD

Challenges

1. Schematic design (CAD): **Labor-intensive** and **highly dependent** on third parties
2. Technical design (BIM): **No BIM context** available from the schematic design phase

Proposed Solution: Model-Based Site Planning



Proposed Tasks

1. Create schematic BIM model
2. Derivate permit drawings from schematic model
3. Use schematic model as basis for technical model
4. Derivate execution drawing from technical model
5. Use technical model throughout operations

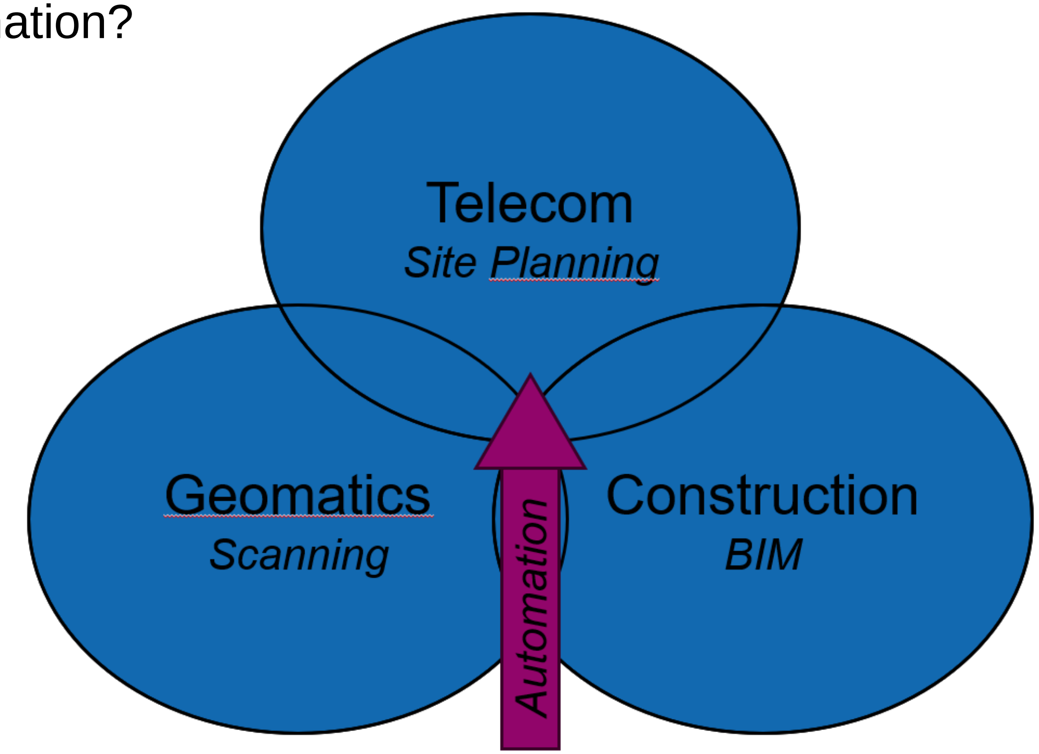
Research Questions

Main Research Question

- How can Scan-to-BIM be automated for telecom rooftop site planning?

Sub-Questions

- Which steps of Scan-to-BIM can be automated for rooftop site planning?
- Which tools enable rooftop Scan-to-BIM automation?



Design Science Research Methodology (DSRM)

Problem Identification → Objectives → Design and Development → Demonstration → Evaluation → Communication

Approach for solving **real-world problems** by Peffers et al. (2007)

Principles

- Structured in six defined steps
- Problem-solving through artefact creation

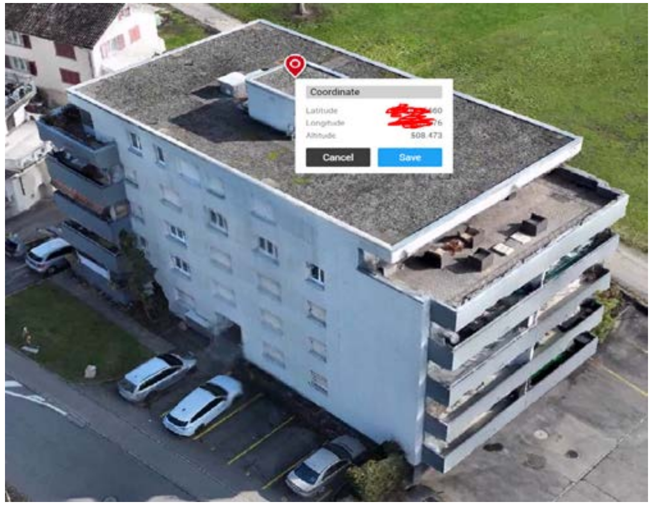
Design and Development

- Artefact **(tactical level):** Framework (from literature)

Demonstration

- Application **(operational level):** Pipeline (from framework)
- Case Study in collaboration with axians

Literature → Artefact → Application →



Part 2: Research Activities

Problem Identification & Objectives

Use of **Exchange Information Requirements (EIR)** to identify problems and objectives

Problems

- Inefficiency of conventional site planning
- Lack of commercial solutions for automation

Objectives

- Application that converts point clouds into a BIM model

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

axians

Jeffrey Lei
Bachelor Thes
E

Assumptions

- Point clouds with sufficient accuracy, coverage, and density will be given. At least three known points (x, y, z) for georeferencing, with low extrapolation to improve the numerical stability of the Helmert transformation.

Limitations

The BIM workflow covers:

- rooftop locations only (no greenfield locations)
- building envelope model only (no interior, no poles, no telecom equipment)
- building permit phase only (no execution or operation phase)
- 3D BIM only (no construction sequencing (4D BIM), cost estimation (5D BIM) or facility management (6D))
- No suitability evaluation or comparison to conventional working methods
- No measurement techniques for quality assessment are planned

5. Requirements for Data and Information

This section defines the required deliverables, their specifications, and the Definition of Done (DoD). Furthermore, model guidelines are defined, consisting of the required building elements, the required level of detail (LoD), and the required non-geometric attributes[2].

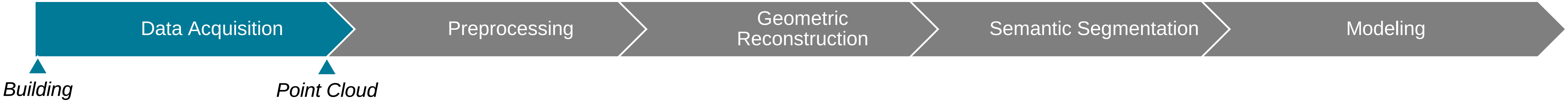
Deliverables	DoD
Mesh	?
Model	Enables the creation of plans without manual adjustments while ensuring compliance with the modeling guidelines.
Plans	confirmation from the Building Department of Zurich that all regulatory requirements are met. Retention of the existing plan layout with design flexibility.

Modeling guidelines

General Model

Requirde Level of Development (LoD)	Generally lowest required according to the Building Authority of Zurich (100-200).
Required Level of Geometry (LoG)	Pole area: approximate geometry (20 mm) Remaining area: conceptual (50 mm)
Model referencing	Georeferenced

Design and Development



Reality Capture (RC): Convert real-world objects into point clouds

Point cloud: Represent object surfaces as a set of 3D points

Photogrammetry: RC method that uses overlapping 2D photographs

Design and Development

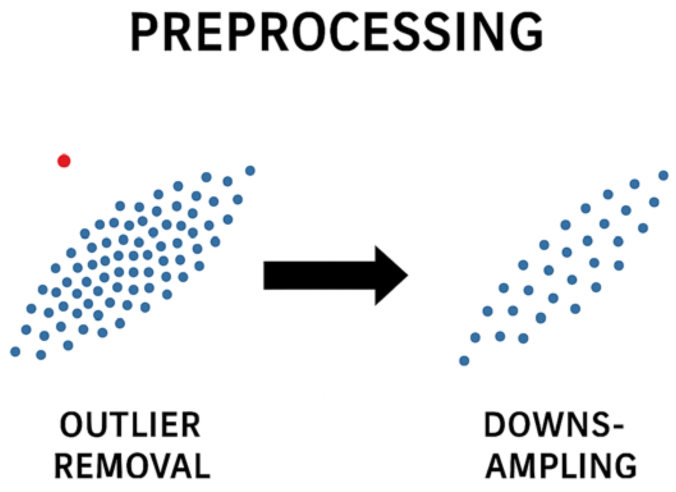
Data Acquisition → **Preprocessing** → Geometric Reconstruction → Semantic Segmentation → Modeling

Point Cloud   *Point Cloud*

Preprocessing: Prepare data for further processing

1. **Outlier Removal:** Remove far data points
   Statistical Outlier Removal (SOR)

2. **Downsampling:** Reduce the amount of data
   Voxel Grid Downsampling



Design and Development

Data Acquisition → Preprocessing → **Geometric Reconstruction** → Semantic Segmentation → Modeling

Point Cloud *Geometry*

Geometric Reconstruction: Extract building surfaces

Example: **PolyFit** by Nan & Wonka (2017) TU Delft – Delft University of Technology

1. **Candidate Face Generation:** Generate many planar faces
   RANSAC
2. **Face Selection:** Select optimal faces
   Optimization Problem (Integer Linear Programming)

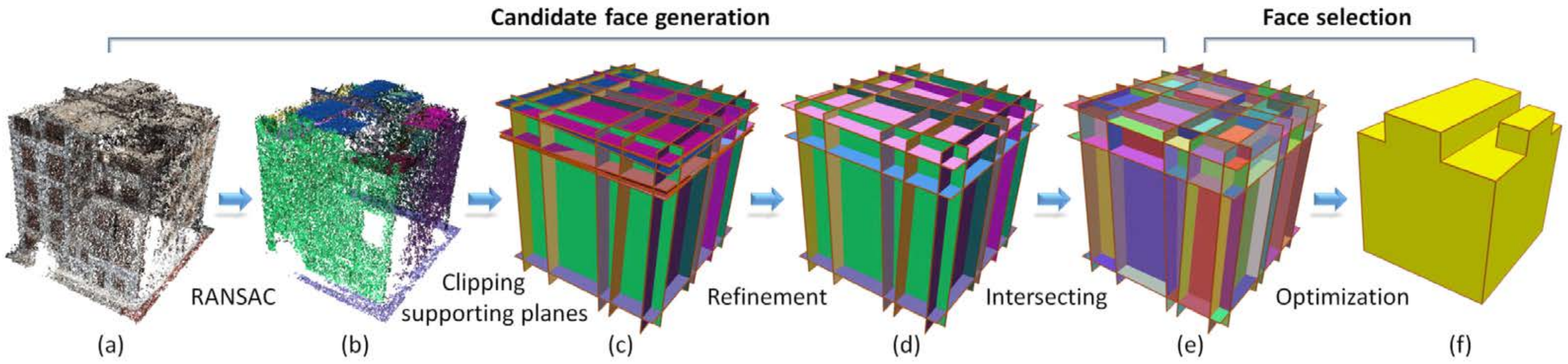
$$\min_{\mathbf{x}} \quad \lambda_f \cdot E_f + \lambda_m \cdot E_m + \lambda_c \cdot E_c$$

$$\text{s.t.} \quad \begin{cases} \sum_{j \in \mathcal{N}(e_i)} x_j = 2 \quad \text{or} \quad 0, & 1 \leq i \leq |E| \\ x_i \in \{0, 1\}, & 1 \leq i \leq N \end{cases}$$

E_f: Point-to-face fitting error

E_m: Penalizes unnecessary complexity

E_c: Encourages clean topology and connectivity



Design and Development

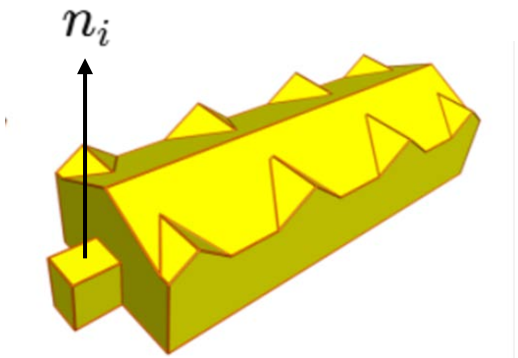
Data Acquisition → Preprocessing → Geometric Reconstruction → **Semantic Segmentation** → Modeling

Geometry *Semantic*

Semantic Segmentation: Classify building elements

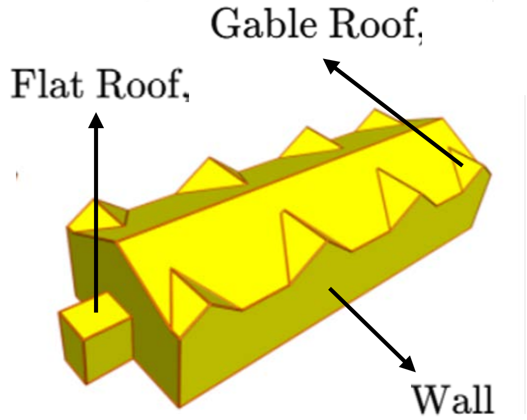
1. **Feature Extraction:** Select useful information from data
   Normal Vector

$$n_i = \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}, \quad \text{for } i \in \mathcal{I} \subset \mathbb{N}, \text{ the index set of all faces in the model}$$

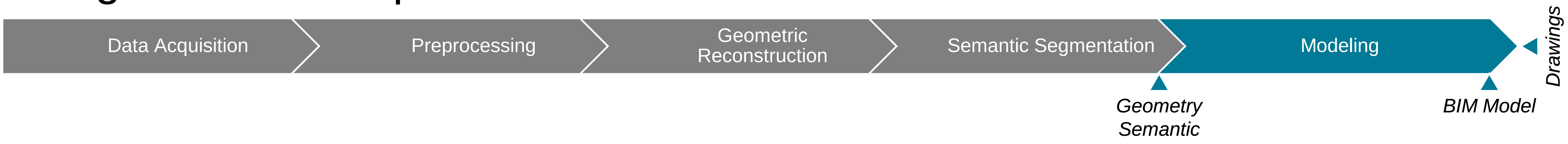


2. **Classification:** Label features
   Rule Based Classification

$$\mathrm{SurfaceType}(n_i) = \begin{cases} \text{Wall,} & \text{if } |z_i| \approx 0 \\ \text{Flat Roof,} & \text{if } \sqrt{x_i^2 + y_i^2} \approx 0 \\ \text{Gable Roof,} & \text{otherwise} \end{cases}$$



Design and Development



Modeling: Merge geometry and sematic into a BIM model

1. **Automated Modeling:** Convert mesh into a basic IFC model
   ifcopenshell

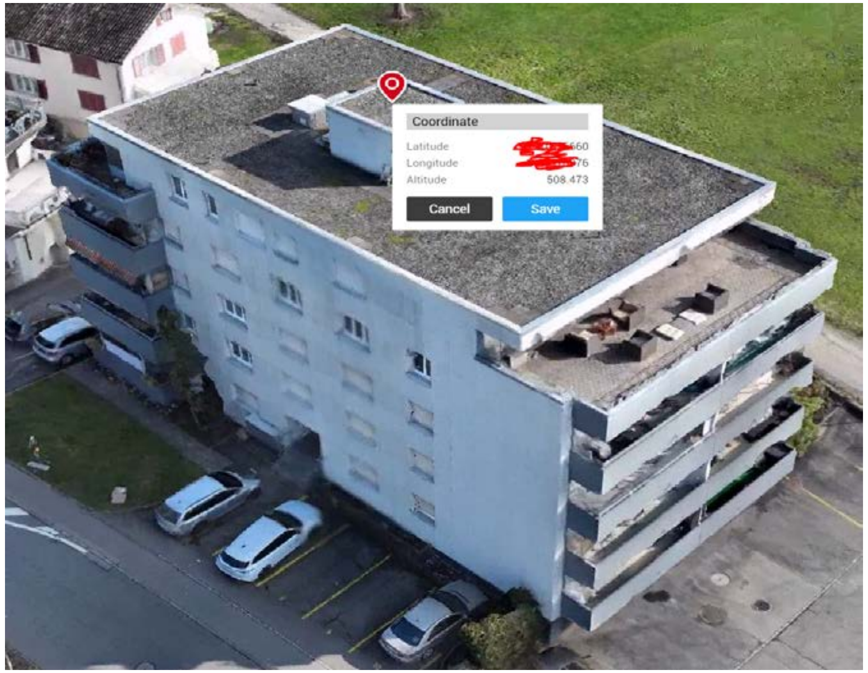
2. **Manual Modeling:** Add architectural elements in BIM software
   windows, doors, balconies, roof structures, topography, radio site components, …

3. **Drawing Generation:** Derivate and dimension 2D drawings
   plan view, front elevation, side elevation

Demonstration

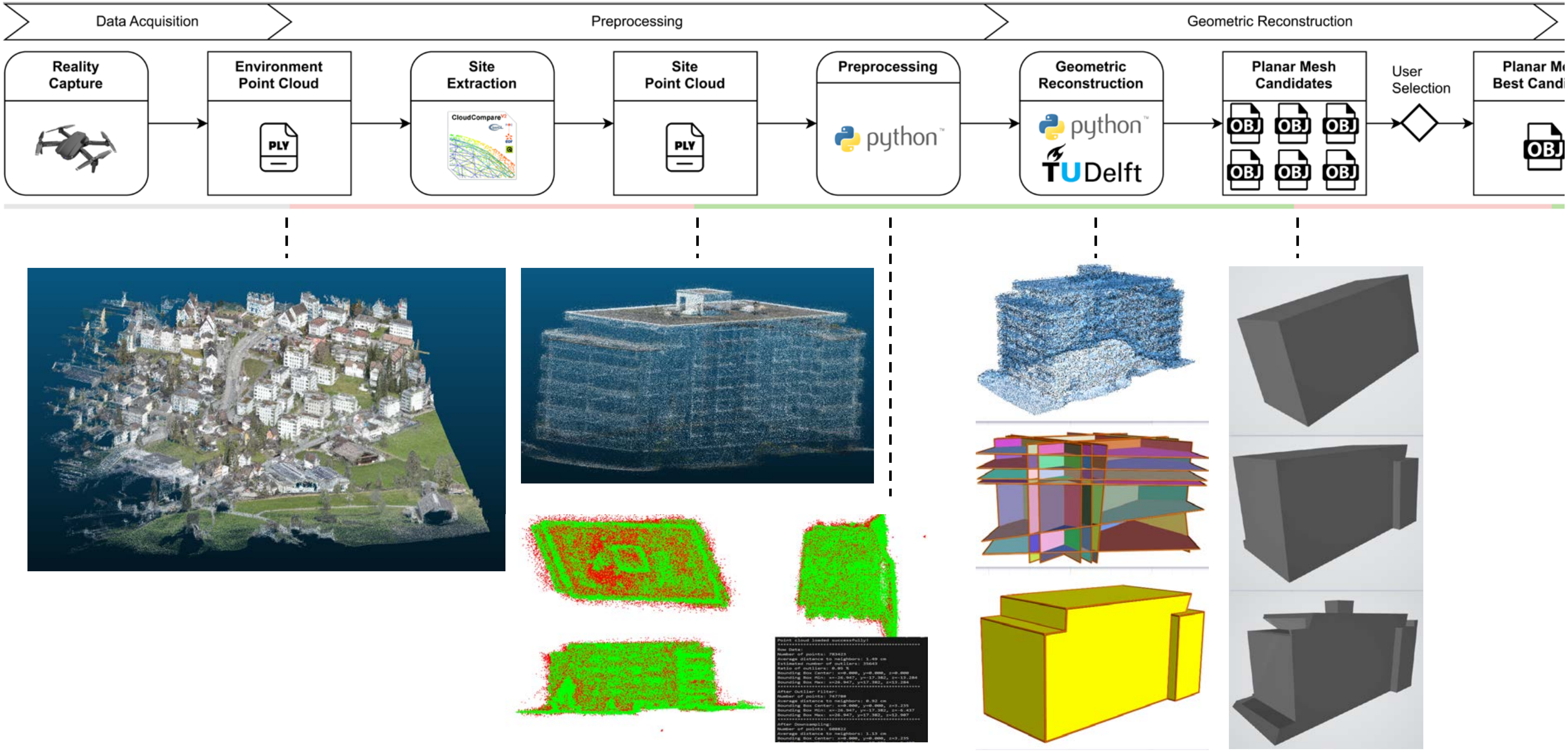
Applying the developed framework to a real-world project.

Provided point cloud

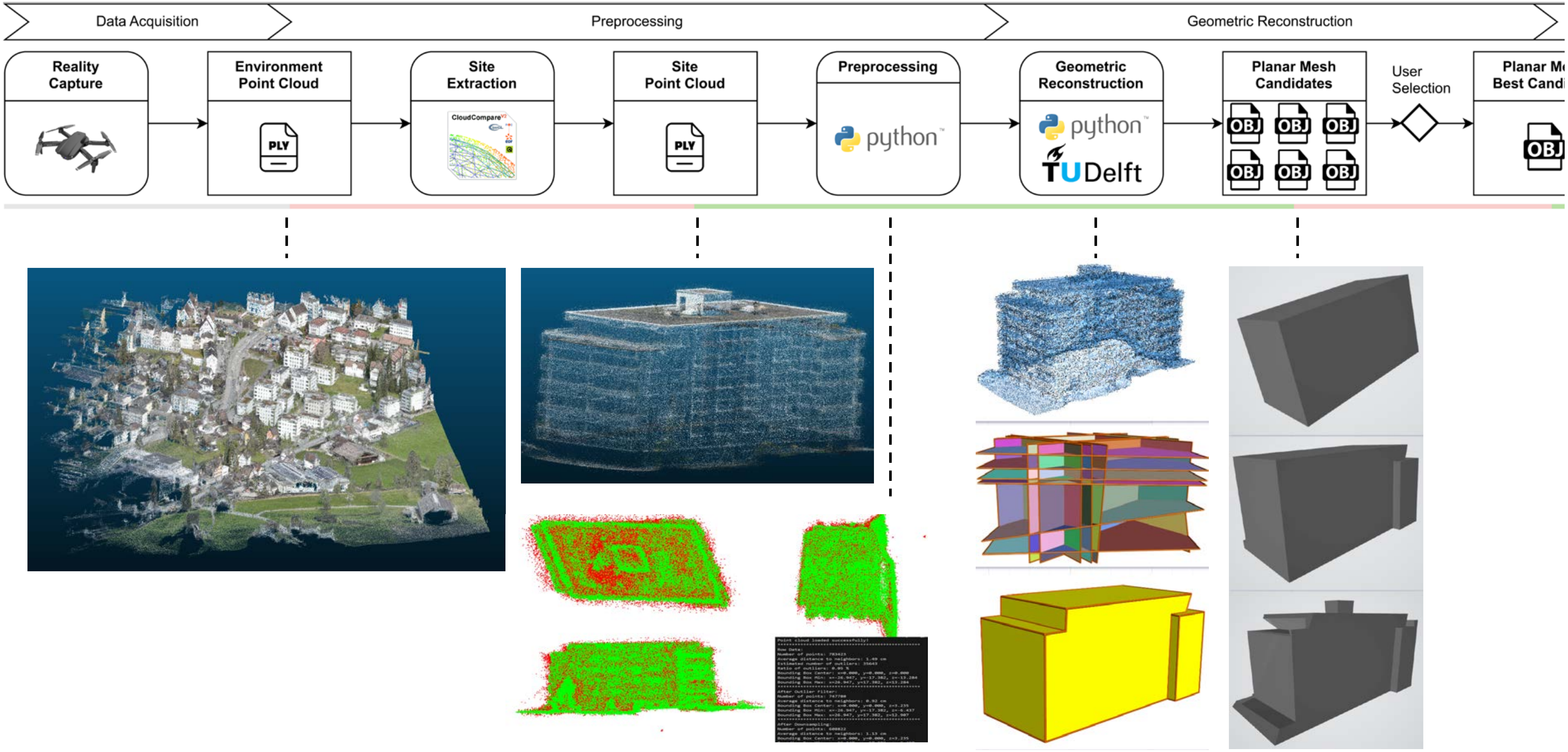


Site

Demonstration



Demonstration



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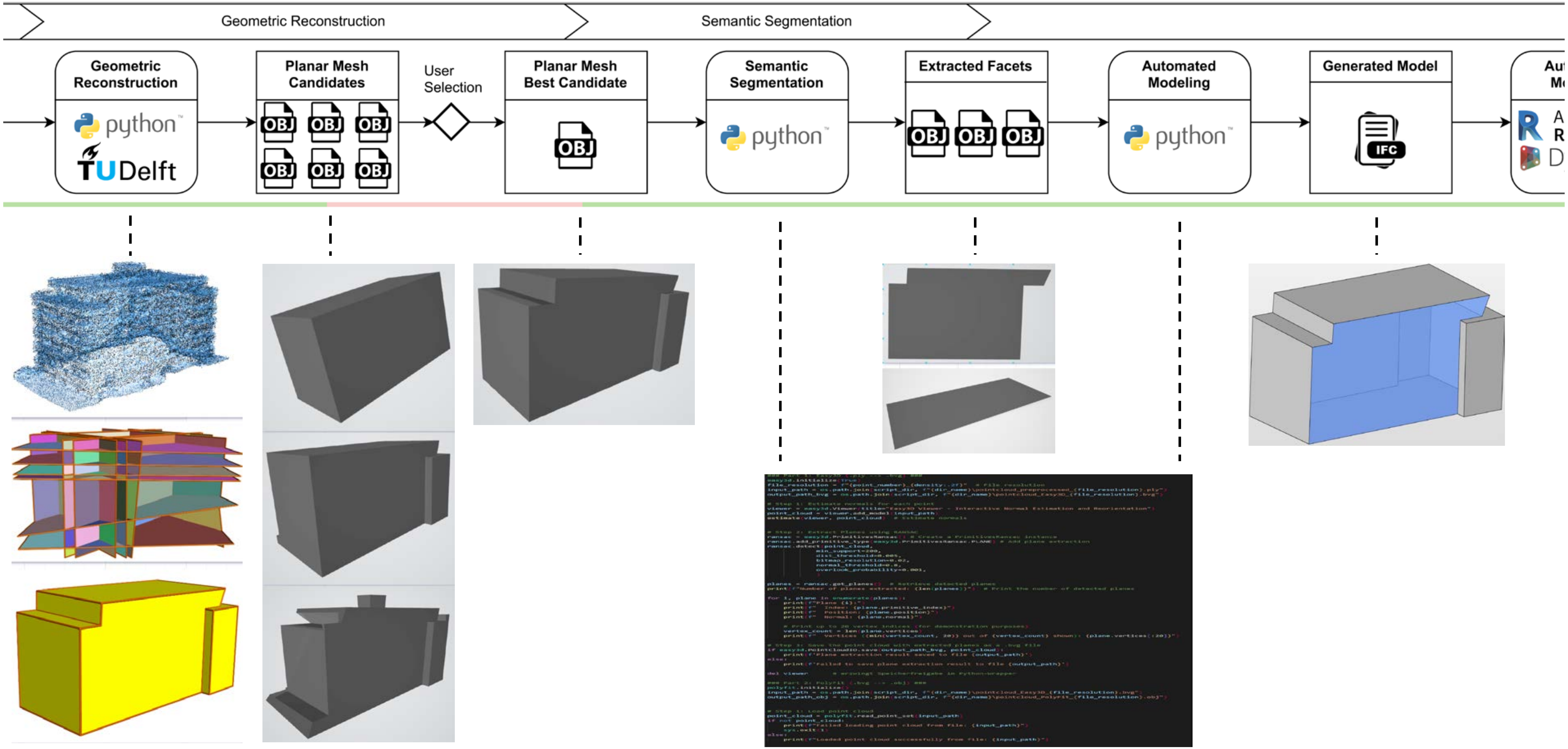

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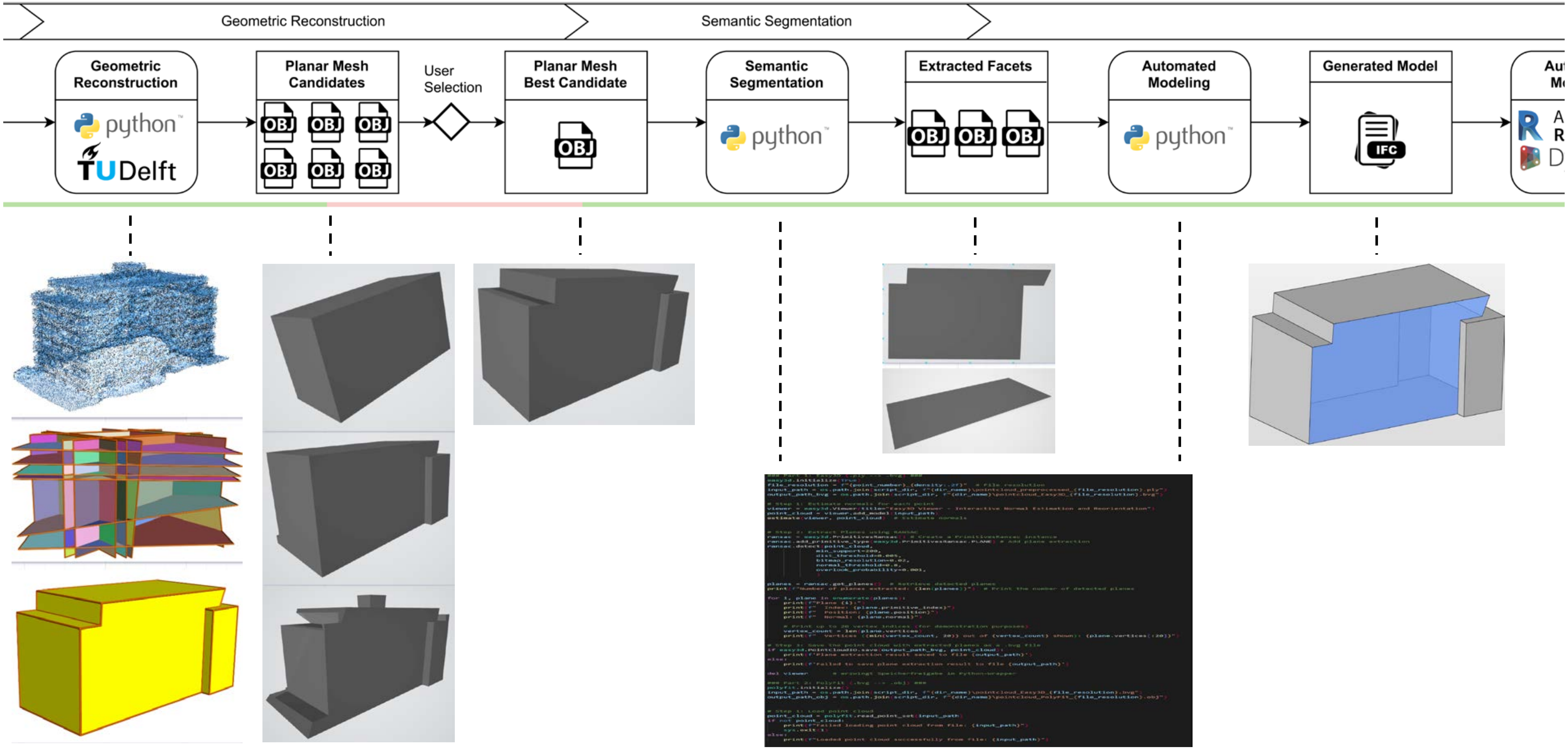

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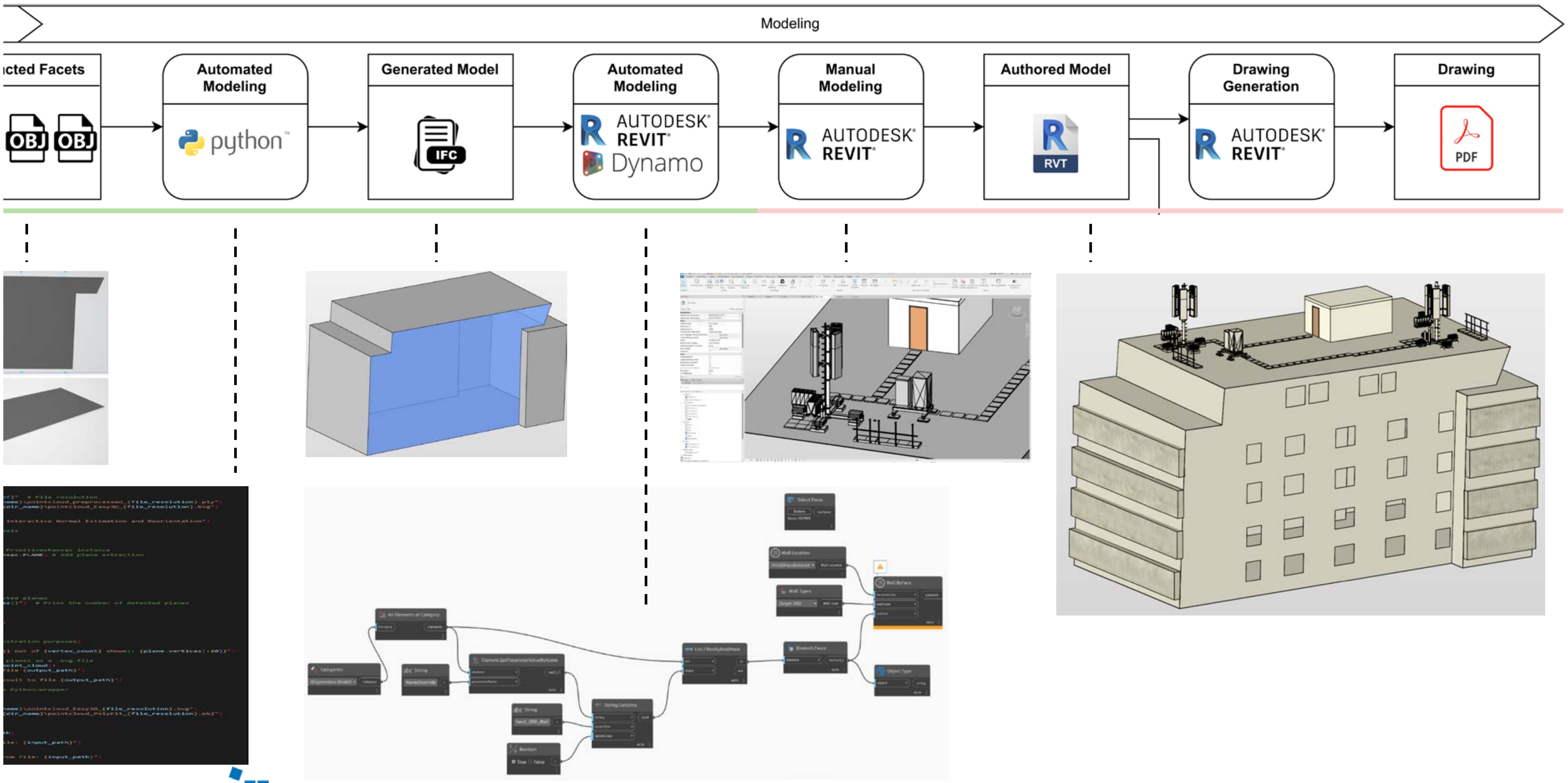

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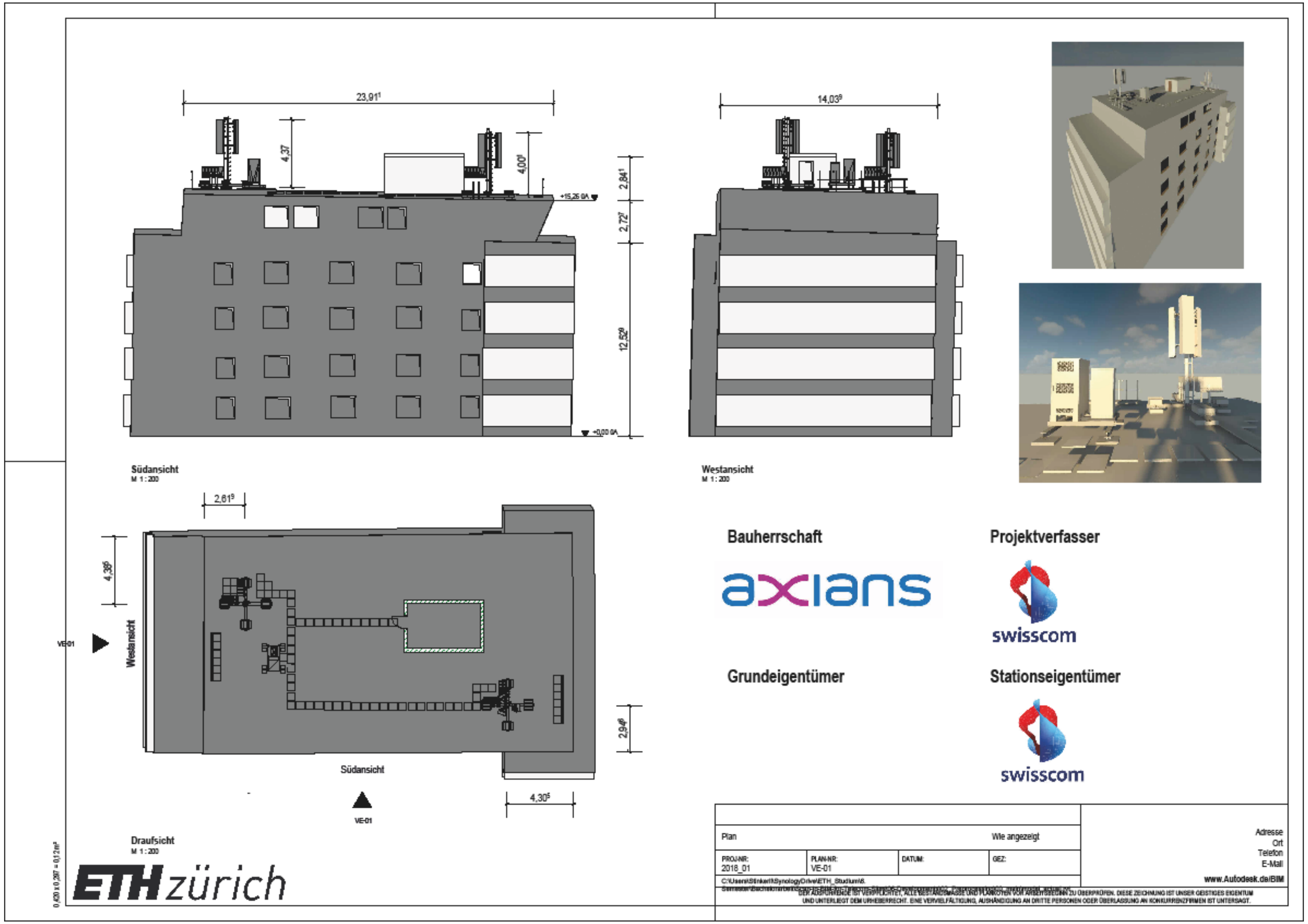


Demonstration

Animation

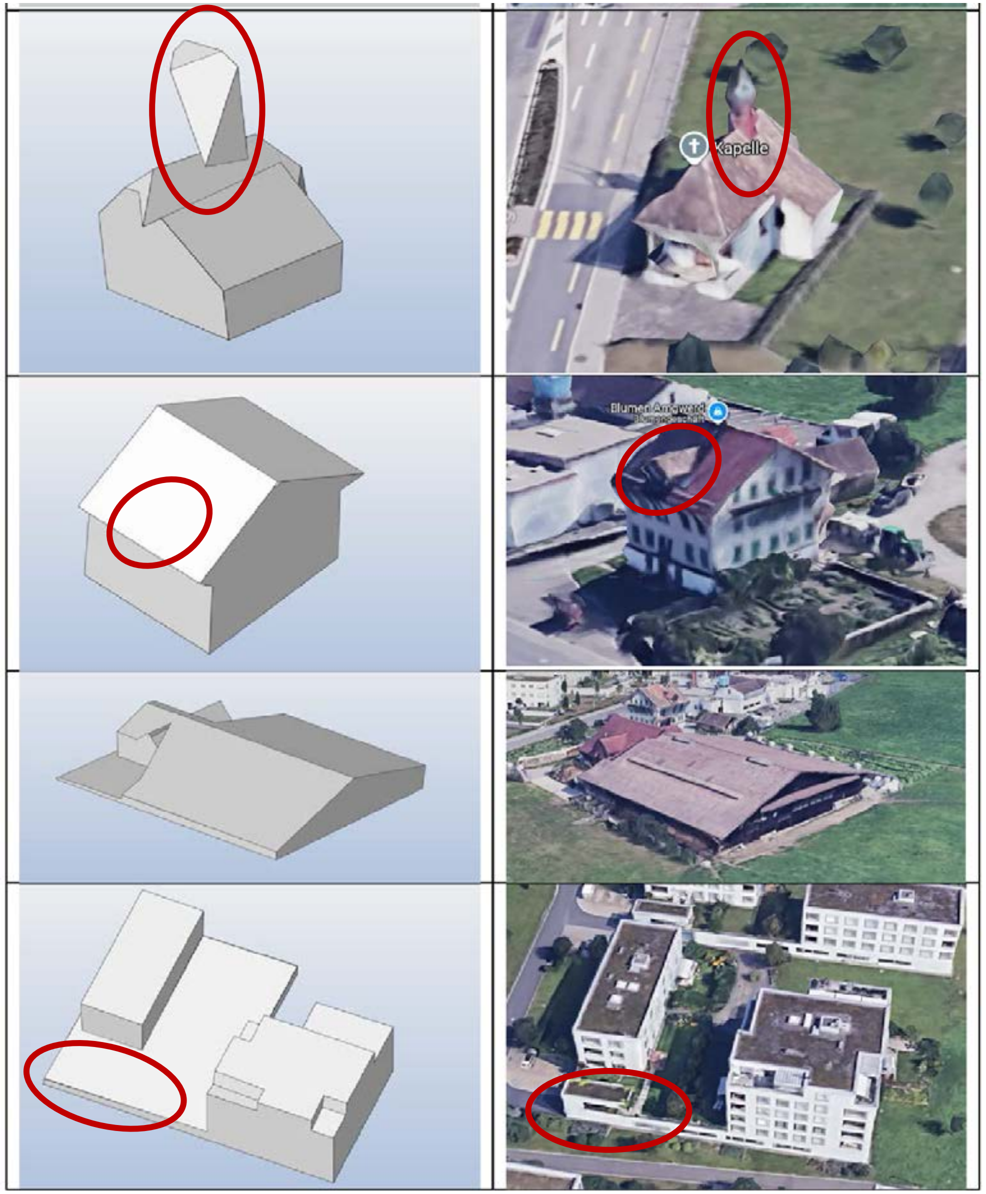
Evaluation

Study Design Limitations:

No **comprehensive evaluation** (excluded from beginning due time constraints).

Following aspects were assessed:

- **PolyFit Runtime** (for different conditions)
- **Generalizability** (for different buildings)
- **Model quality** (based on subjective observations)



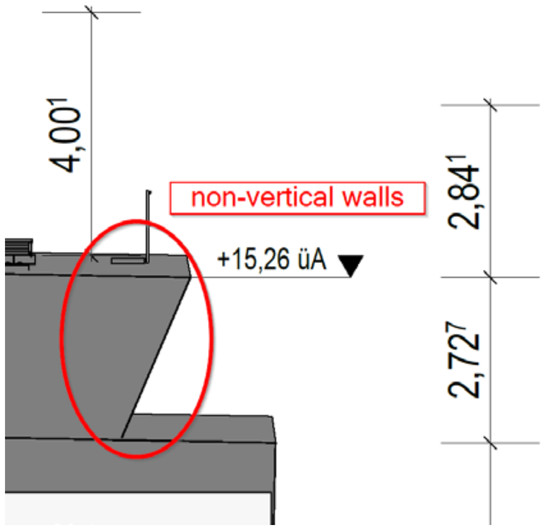
Generalizability

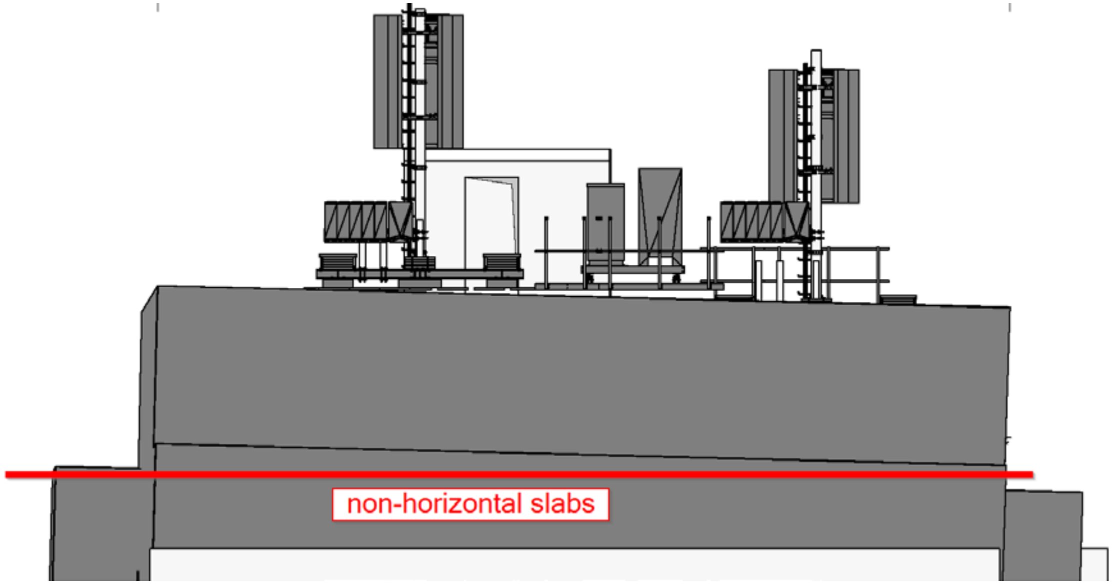
Evaluation

Limitations

Geometric Reconstruction

- No curved geometries possible
- Low precision (high variability in results) → low accuracy (not validated)
- Geometric imperfections (non-orthogonality) increase modeling effort





Evaluation

Limitations

Geometric Reconstruction

- No curved geometries possible
- Low precision (high variability in results), questionable accuracy (not validated)
- Geometric imperfections (non-orthogonality) increase modeling effort

Level of automation

- Details (windows, roof structure, …) still require manual modeling

Deployment

- Python-based algorithm requires significant setup effort (many dependencies)

Evaluation

Results

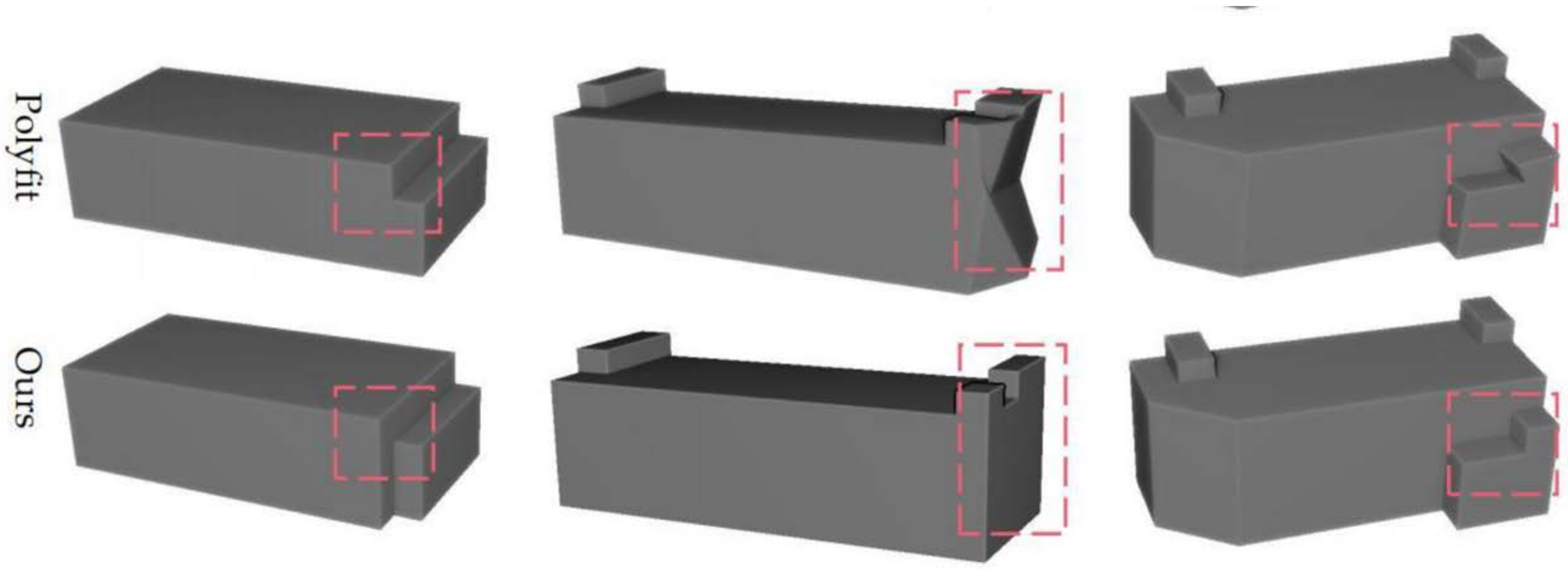
1. A Scan-to-BIM framework was **successfully** developed and implemented.
2. A **high degree of automation** could be achieved.
3. Due to current limitations, practical use remains unlikely without **additional refinements**.

Evaluation

Future Work

Geometric Reconstruction

- Ground truth validation of main surfaces is necessary
- Evaluate other promising geometric reconstruction algorithms (accessibility remains unclear)



Wang Feng et al. Reconstruction of LoD-2 Building Models Guided by Façade Structures from Oblique Photogrammetric Point Cloud (2023)

Evaluation

Future Work

Geometric Reconstruction

- Ground truth validation of main surfaces is necessary
- Evaluate other promising geometric reconstruction algorithms (accessibility remains unclear)

Level of automation

- Use of neural networks for automatic object detection (Master’s thesis incoming ☺)

Deployment

- deploying as a web application (.ply to .ifc)

Communication

Sharing Results
The results were presented to project stakeholders on **26.05.2025** at **ETH Zürich**.

Further resources are publicly available via GitHub:

- **Final thesis** *(available from 15.06.2025)*
- **Final source code** *(expected end of July)*

GitHub

Questions or suggestions?
Feel free to contact me at: leisij@student.ethz.ch

Q&A

Thank you for your attention

Many thanks to my supervisors for their guidance during this project:

- Oceane Durand-Maniclas (ETH)
- Kasimir Forth (ETH)
- Jean-Charles Schaegis (Axians)