Chair of Circular Engineering for Architecture

Automating Scan-to-BIM for Telecom Site Planning

Jeffrey Leisi

Midterm Presentation
Bachelor’s Thesis
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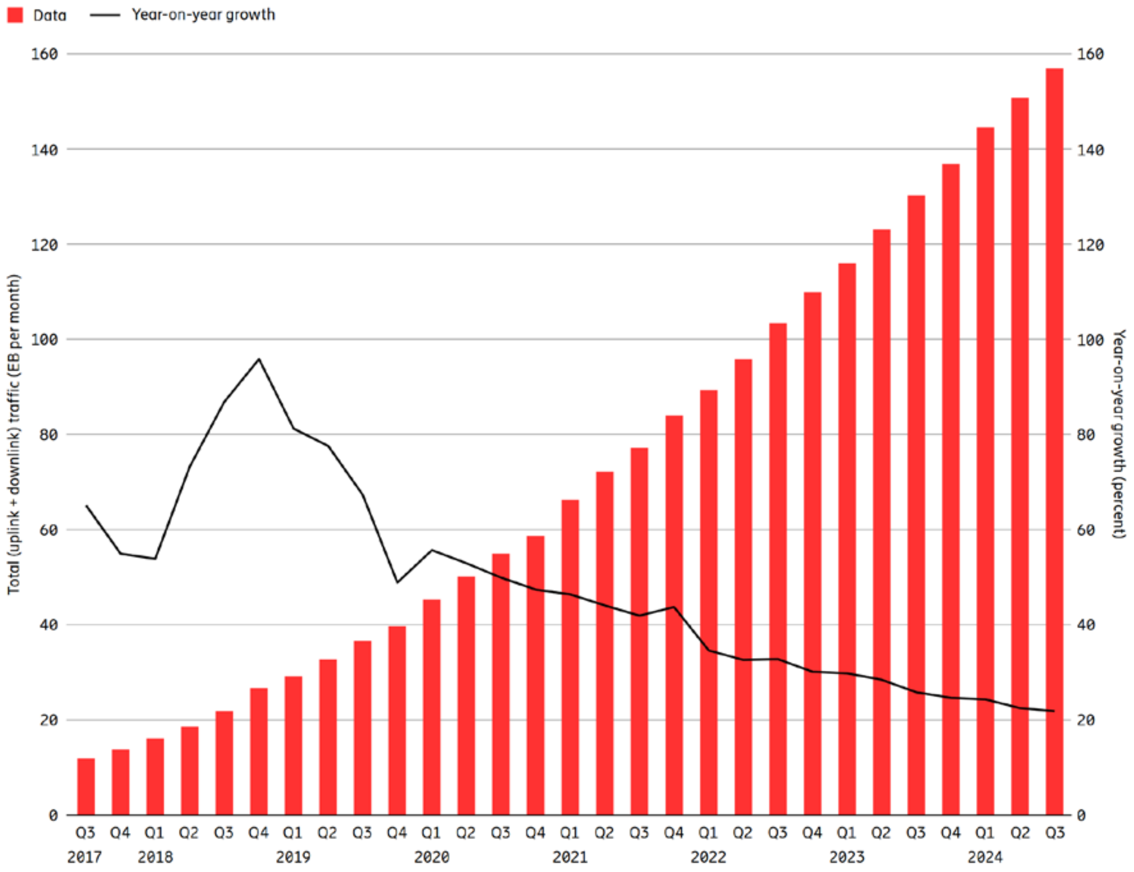
Institute for Construction and Infrastructure Management

Motivation

Mobile data traffic increases



Source: Ericsson Mobility Report (November 2024)

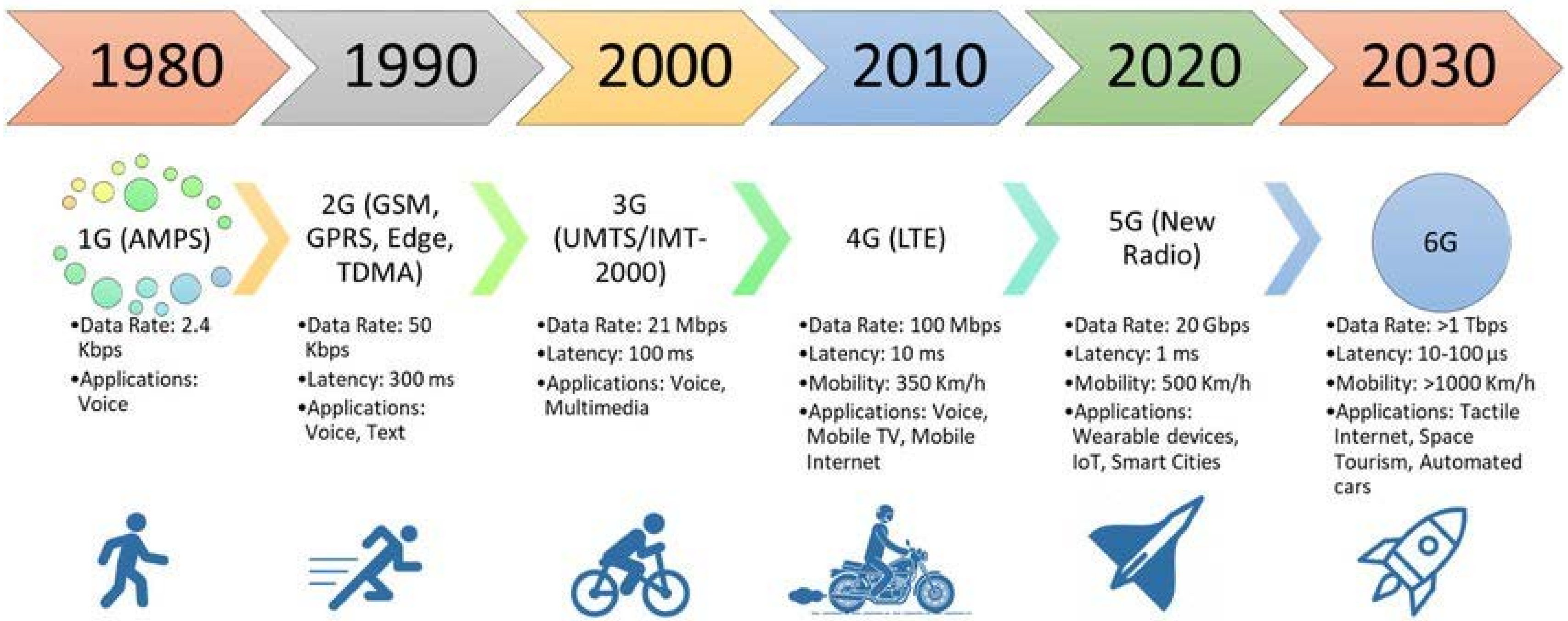
Motivation

Mobile data traffic increases

↓

New technologies
(*shift toward higher frequency bands)*

Currently relevant



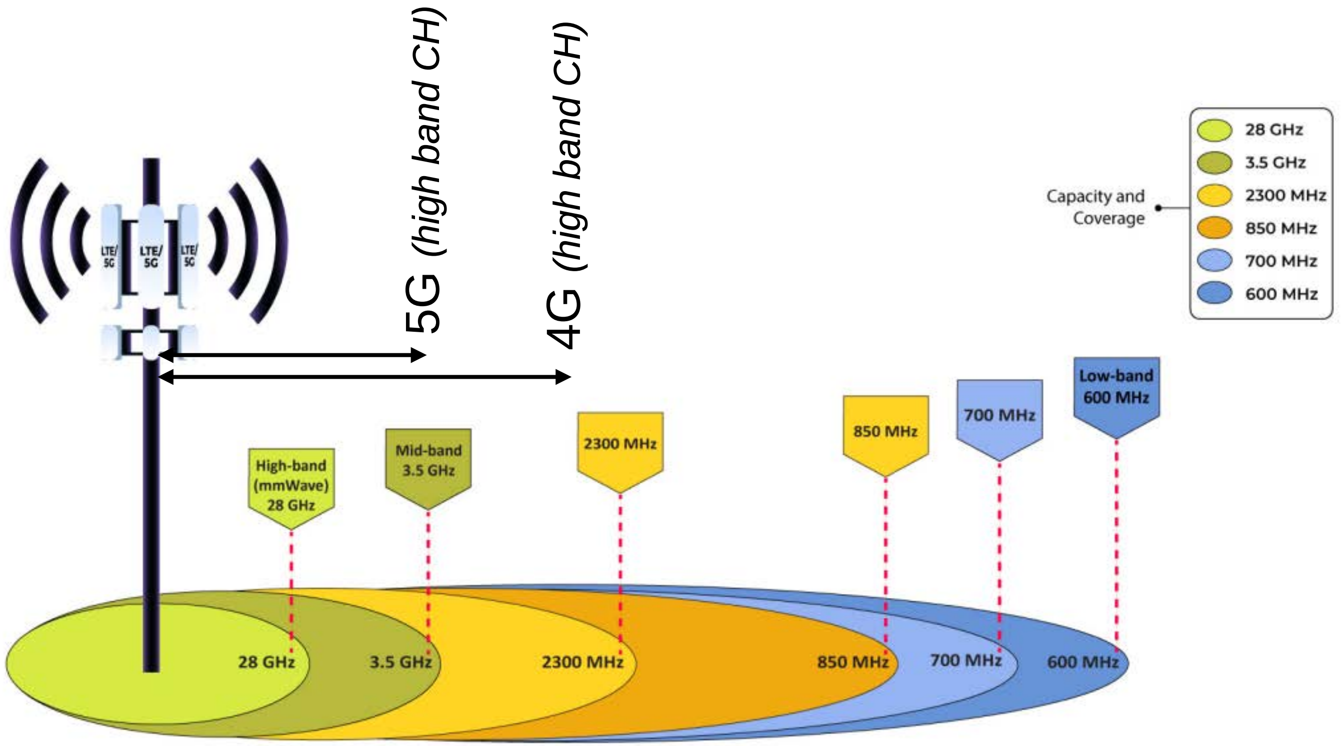
Source: https://www.linkedin.com/pulse/understanding-5g-glimpse-6g-evolution-connectivity-dr-manpreet-puri

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)

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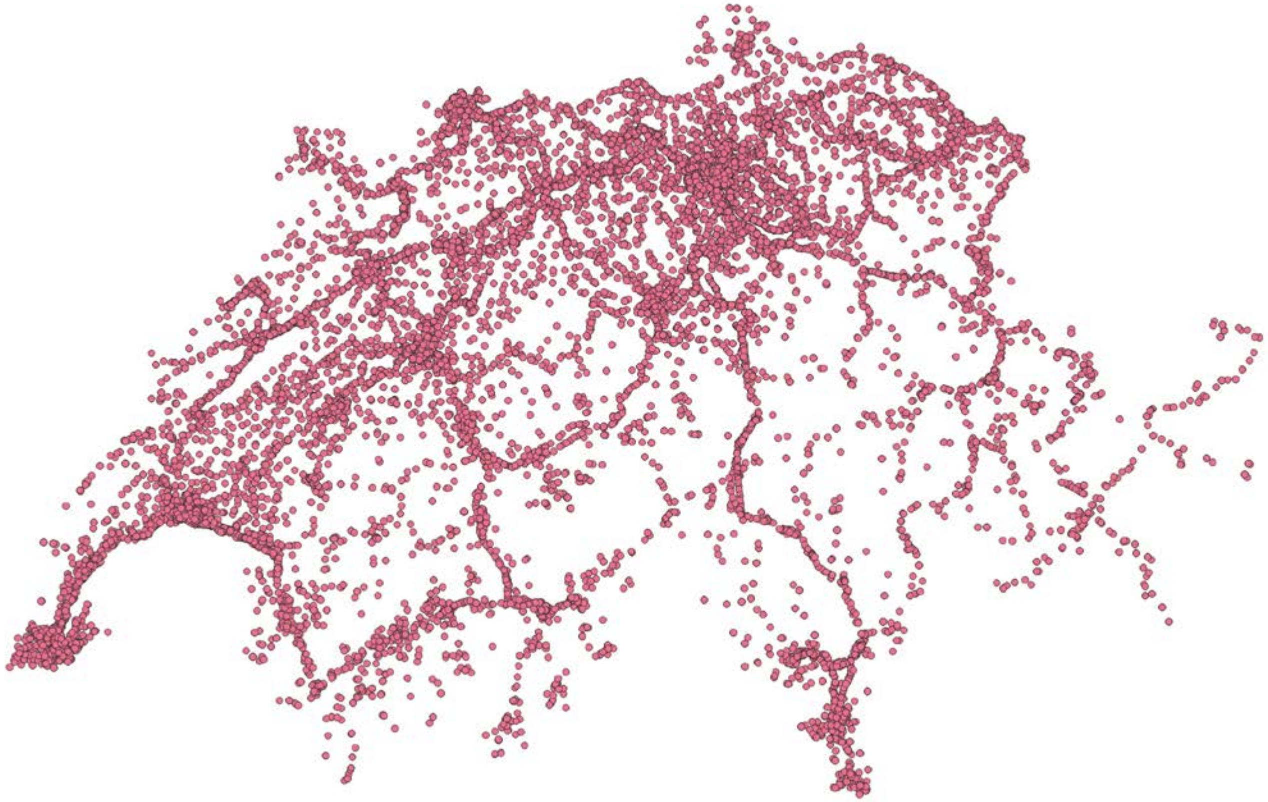
More antenna sites required
~(7,500 new 5G sites: CHF 3.2 bn)

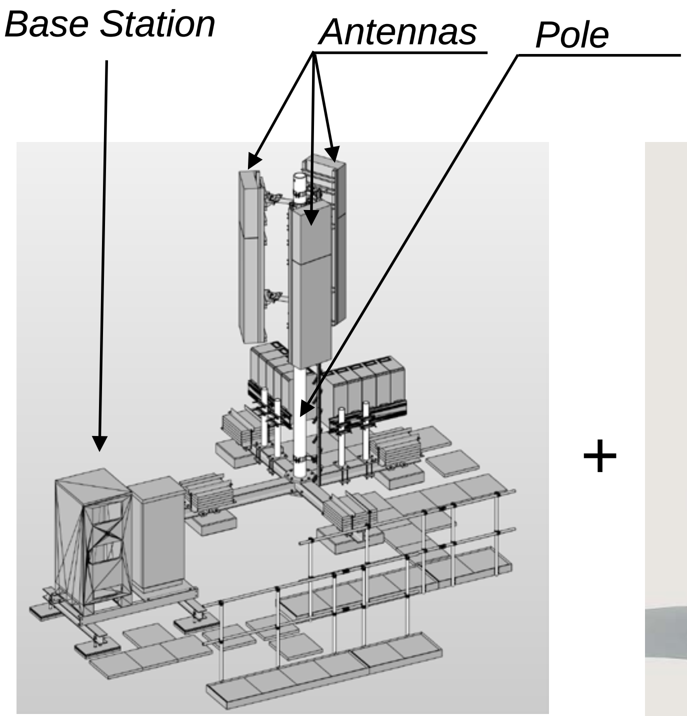
Conclusion: Large-scale deployment calls for <u>efficient</u> planning strategies.



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

Cellular Sites



- Steel structures
- Radio Access Network (RAN) Equipment

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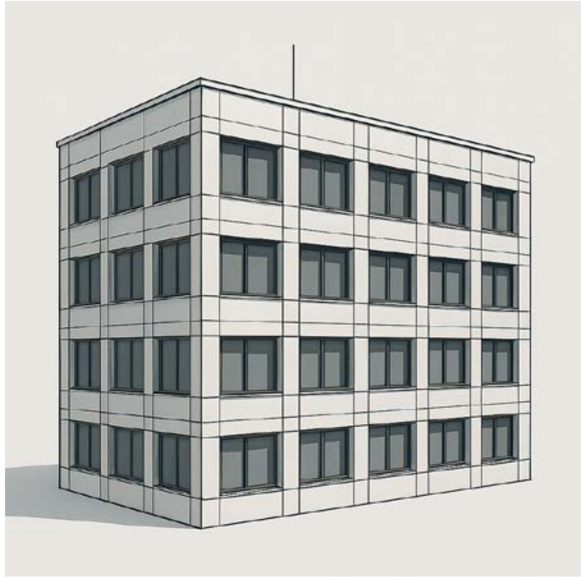

Building

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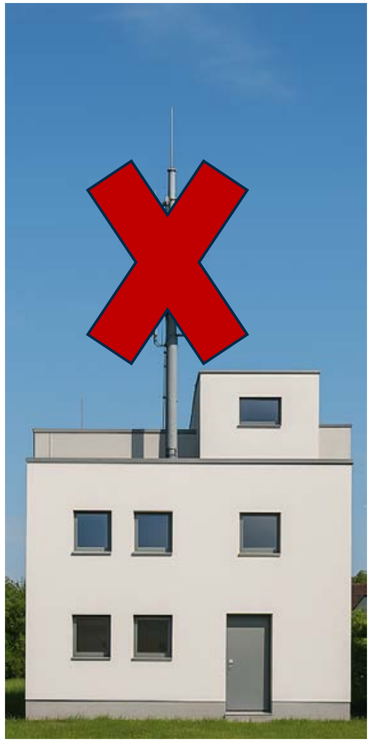
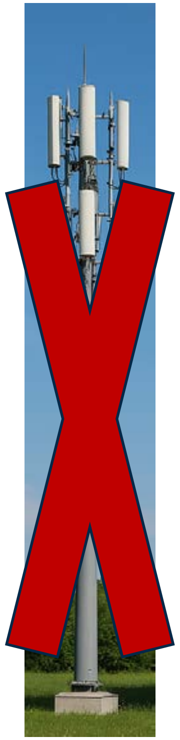


Rooftop Site
mainly urban areas

Thesis focus



Greenfield Site
mainly rural areas

Problem Statement: Conventional Site Planning

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

Building Permit

Site Survey: Site inspection with the provider, building owner, and a team of specialists

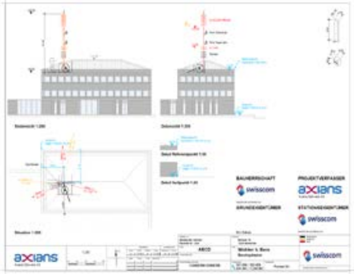
- Drone-based environmental capture for non-ionizing radiation (NIR) calculation
  → Building point clout as a by-product
- Geodetic survey with GNSS and total station
- Attempt to organize existing building drawings

Problem Statement: Conventional Site Planning

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

Building Permit

→



Schematic Design: Preparation for building permit application

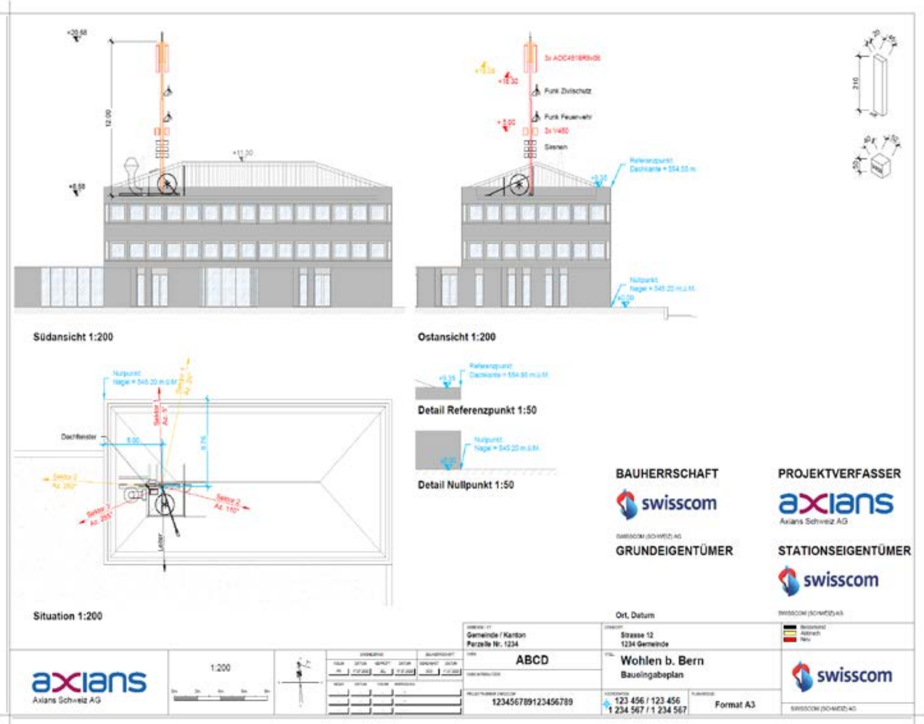
Computer-Aided Design (CAD): Software for 2D/3D drawings

Average Case:

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

Worst Case

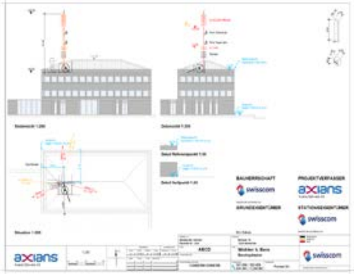
1. Draw building from scratch with geodetic survey data



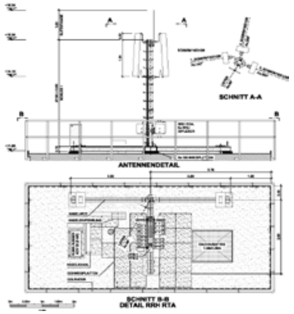
2D CAD Drawing
- *Building Reconstruction*
- *Simplified Technical Representation*

Problem Statement: Conventional Site Planning

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

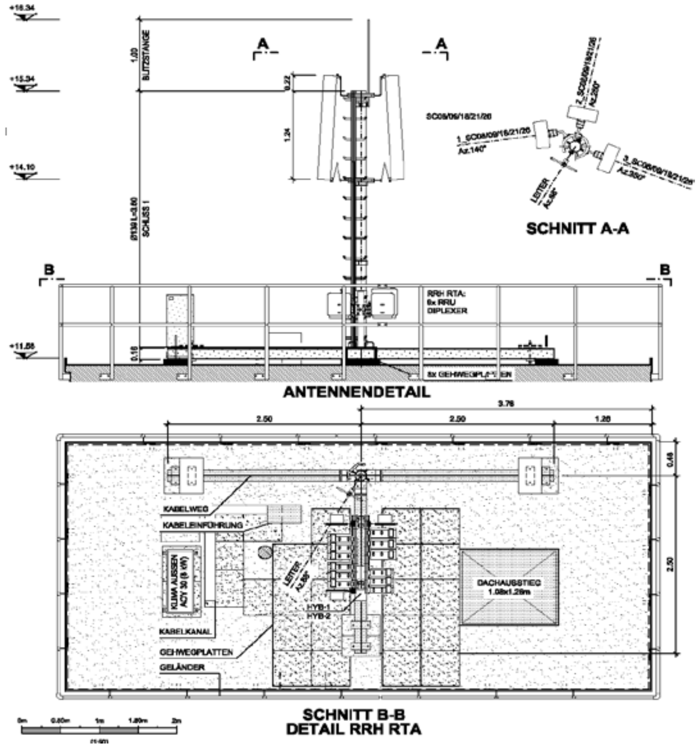


Building Permit



Technical Design: Preparation for execution

- Planning of steel structure and RAN equipment.
- Bills of materials must be manually derived from the drawings
- High component density
- Many standardized, modular components



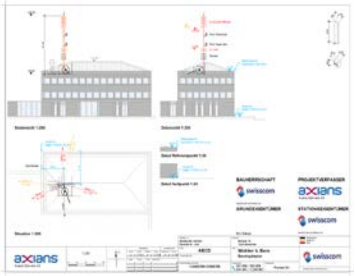
2D CAD Drawing

- *Detailed technical representation*
- *Bill of Materials*

Problem Statement: Conventional Site Planning

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

→



Building Permit

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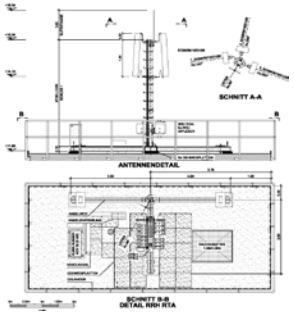

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Execution: Construction and maintenance of planning documents.

- Sites are operated over many years.
- Technical modifications must be manually updated in the drawings (often in multiple views)

Conclusion

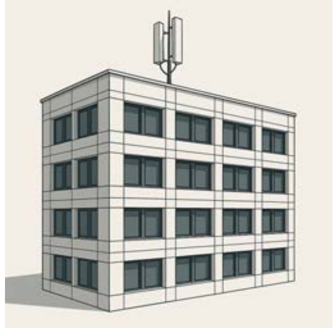
- High dependence on third parties (building drawings)
- Labor-intensive

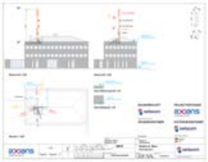
Proposed Solution

- Model-based site planning

Proposed Solution: Model-Based Site Planning

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



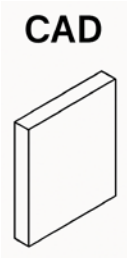


Building Permit

Building Information Modeling (BIM): Planning Method that works with a smart 3D model.

Process:

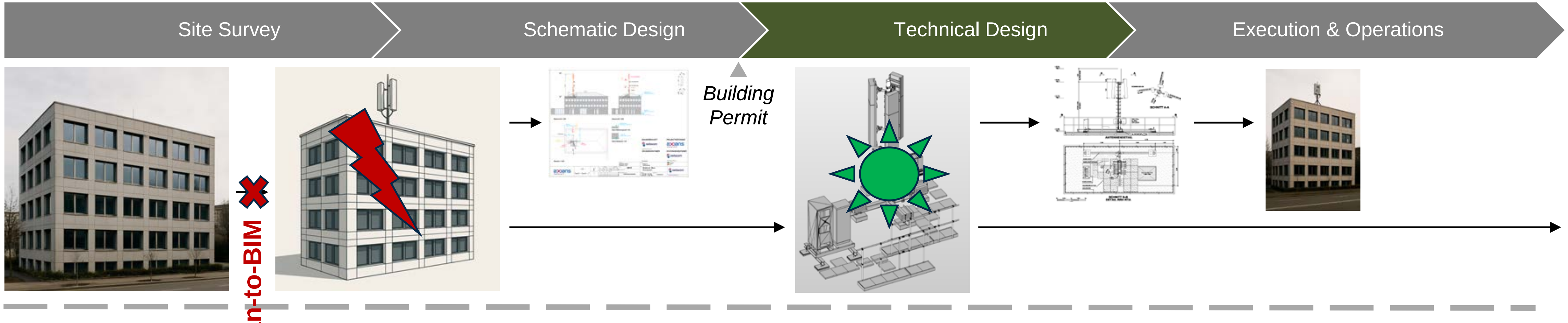
1. Generate a model from point cloud data
2. Automatically generate plans from the model



geometry

geometry + information

Proposed Solution: Model-Based Site Planning



Process:

- Technical design is already done using BIM
- The process would be simplified if a building model were available

Scan-to-BIM: Converts building point cloud into BIM model

Conclusion

- **BIM has proven effective in the execution phase**
- **No efficient solution for Scan-to-BIM has been found yet**
- **The logical next step is the development of a Scan-to-BIM method**

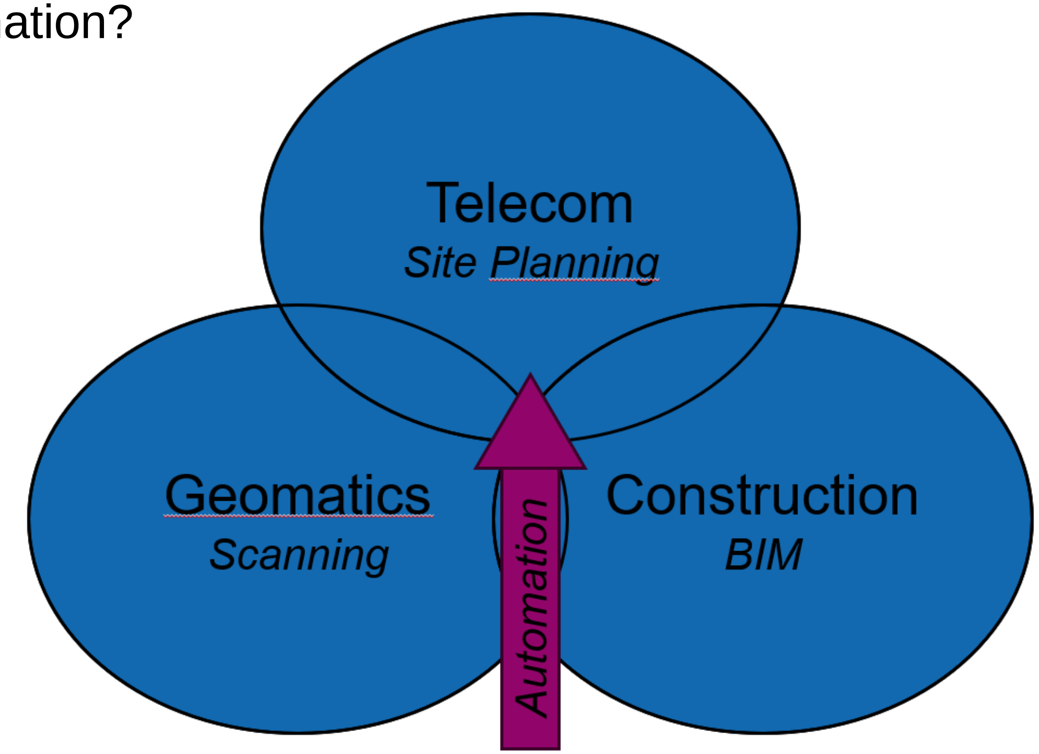
Research Questions

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) *by Peffers et al. (2007)*

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

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

Problems

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

Objectives

- Tool that converts point clouds into a BIM model

Artefacts

1. Scan-to-BIM Framework
2. Python-Script

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
axians

Jeffrey Lei
Bachelor Thes
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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

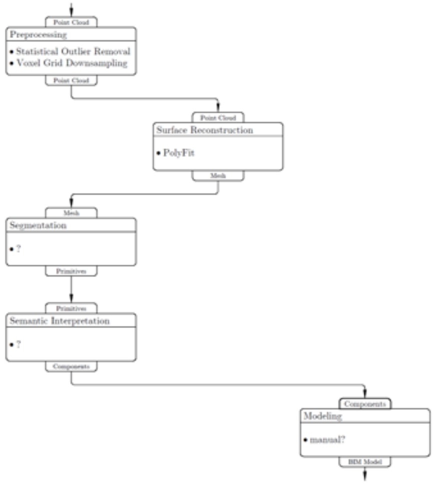
Requirde Level of Development (LoD)	Generally lowest required according to the Building Authority of Zurich (100-200).
Required Level of Geometry (LoG)	Pole area: approximate geometry (20 mm) Remaining area: conceptual (50 mm)
Model referencing	Georeferenced

Design Science Research Methodology (DSRM) *by Peffers et al. (2007)*

Problem Identification | Objectives | **Design and Development** | Demonstration | Evaluation | Communication

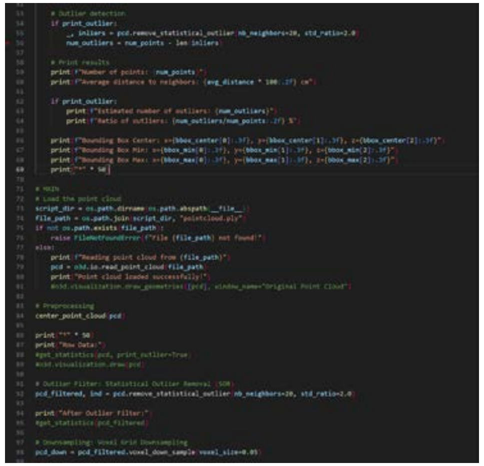
Artefact 1: Scan-to-BIM Framework

Development of a Scan-to-BIM framework based on the current state of research



Artefact 2: Python Script

Concrete implementation of the developed framework

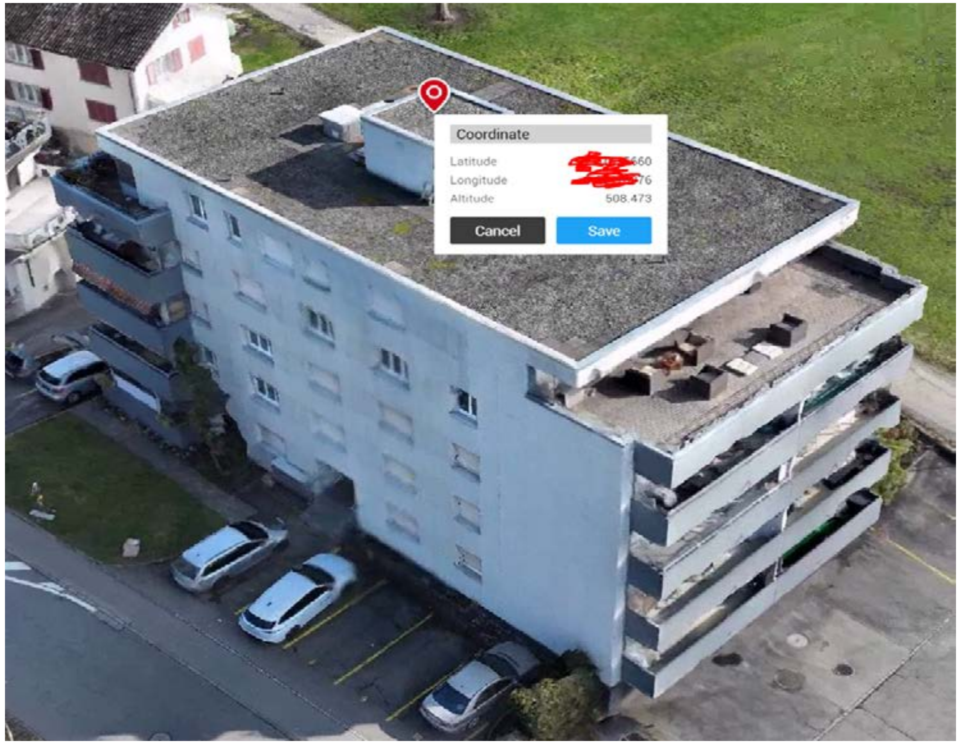


Design Science Research Methodology (DSRM) *by Peffers et al. (2007)*

Problem Identification | Objectives | Design and Development | **Demonstration** | Evaluation | Communication

Applying the developed artifact in a real-world **case study.**

The point cloud is provided



Design Science Research Methodology (DSRM) *by Peffers et al. (2007)*

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

Evaluation of the demonstration

Evaluation methodology yet to be defined

Scan-to-BIM Framework

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

Building *Point Cloud*

Reality Capture: Captures the real world and represents it as a point cloud

- **Photogrammetry:** Captures the real world using overlapping images
- **LiDAR:** Scans the environment using laser pulses

Scan-to-BIM Framework

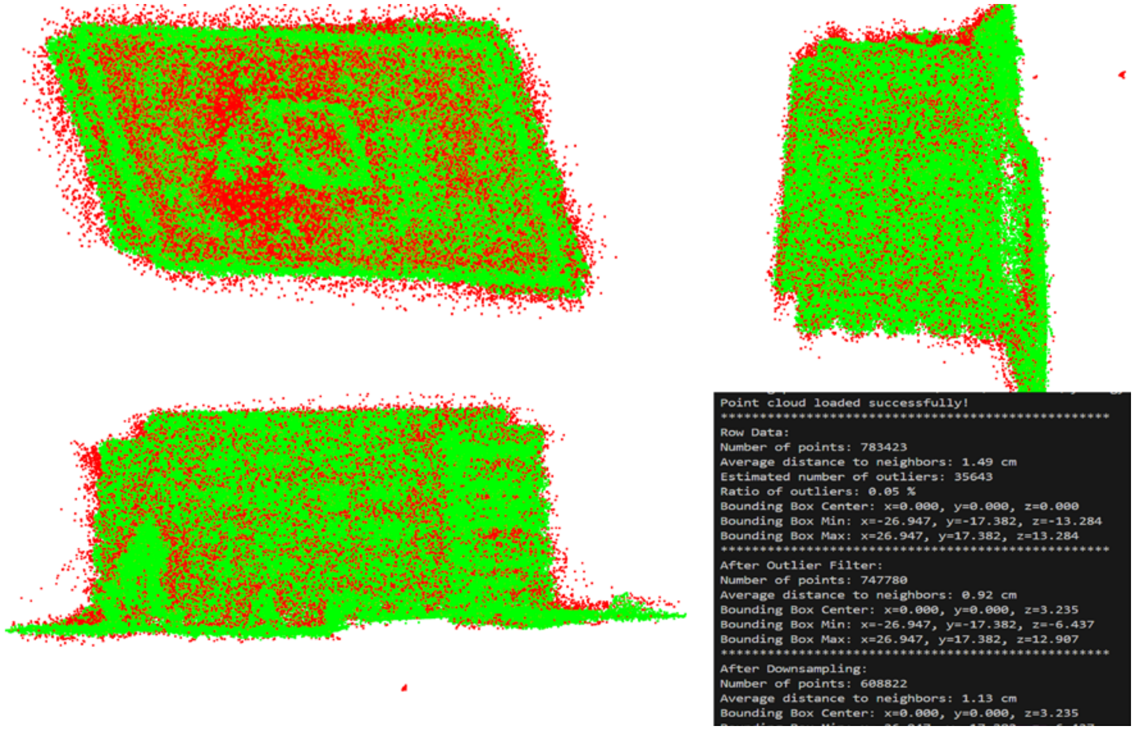
Data Acquisition → **Preprocessing** → Geometric Reconstruction → Semantic Segmentation → Modeling

Point Cloud *Point Cloud*

Preprocessing: Prepare data for further processing

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

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



Scan-to-BIM Framework

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

Point Cloud *Geometry*

Geometric Reconstruction: Determine geometry of building elements

Achieved with **PolyFit Software** by Nan & Wonka (2017)

1. **Candidate Face Generation:** Generates many planar faces
   RANSAC, …

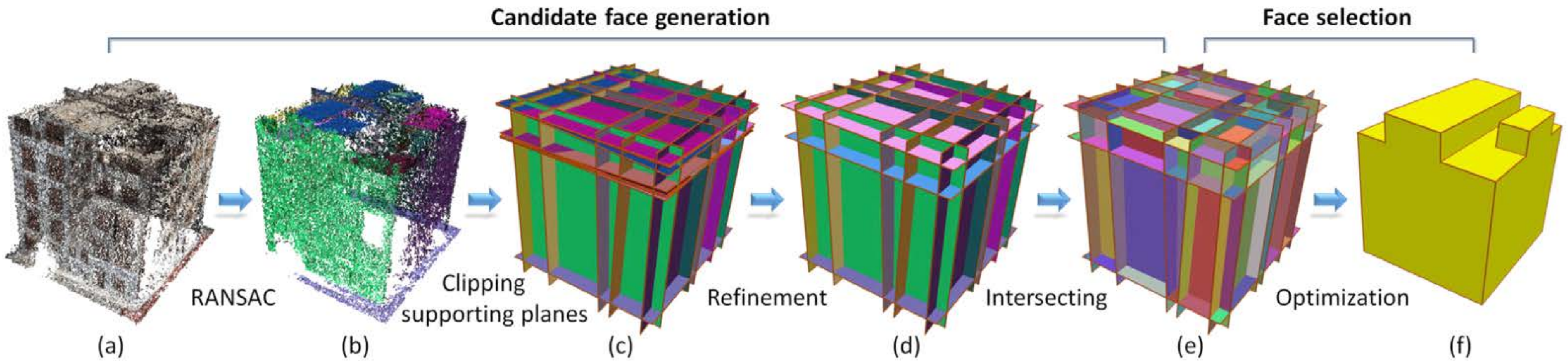
2. **Face Selection:** Selects optimal faces
   Optimization Problem (Integer Linear Programming)

$$\min_{\mathbf{x}} \quad \lambda_f \cdot E_f + \lambda_m \cdot E_m + \lambda_c \cdot E_c$$
$$\text{s.t.} \quad \begin{cases} \sum_{j \in \mathcal{N}(e_i)} x_j = 2 \quad \text{or} \quad 0, & 1 \leq i \leq |E| \\ x_i \in \{0, 1\}, & 1 \leq i \leq N \end{cases}$$

E_f: Point-to-face fitting error

E_m: Penalizes unnecessary complexity

E_c: Encourages clean topology and connectivity



Scan-to-BIM Framework

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

Geometry *Semantic*

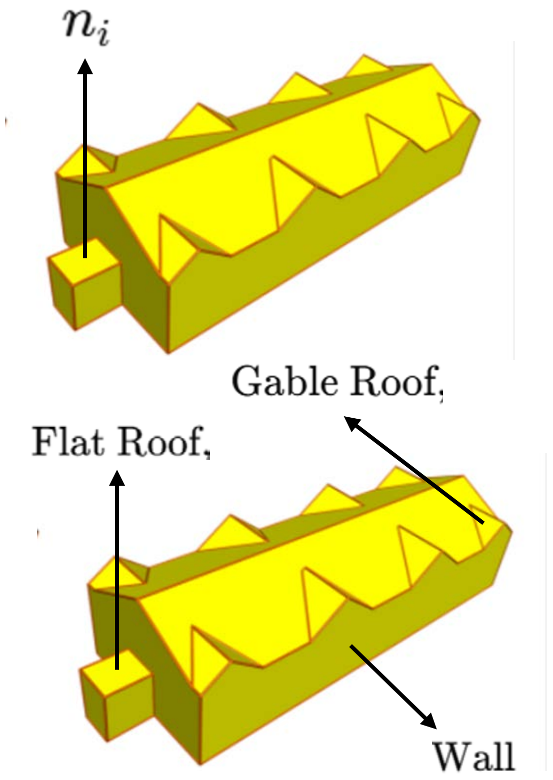
Semantic Segmentation: Determine semantics of building elements

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

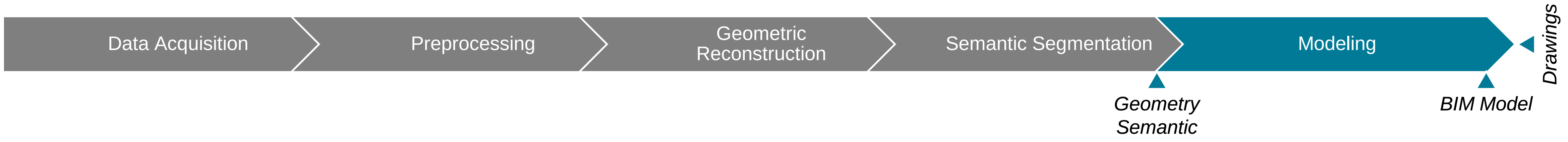
$$n_i = \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}, \quad \text{for } i \in \mathcal{I} \subset \mathbb{N}, \text{ the index set of all faces in the model}$$

2. **Classification:** Labeling data points
   Rule Based Classification

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



Scan-to-BIM Framework



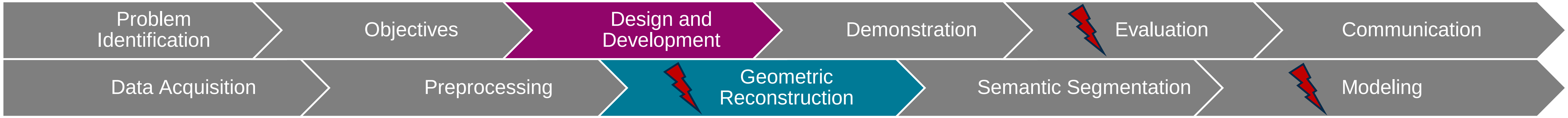
Modeling: Integration of geometry and sematic in BIM-Software

1. **Automated Model Generation:** Automatic generation of building elements
   ?

2. **Model Refinement:** Import and manual refinement in BIM software
   LOD enhancement (windows, doors), ?

3. **Derivation of 2D drawings**

Where am I standing?



Challenges:

1. Implementation of PolyFit (C++) in Python is not yet working
2. Difficult to estimate the complexity of the modeling due to lack of BIM experience
3. Evaluation methodology is still undecided
4. Writing report (and other courses) takes more time than expected - leaving little time for coding 😔

Thank you

Happy to hear your suggestion! ☺