Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Institut für
Bau- und Infrastruktur-
management

Bachelor Thesis

Automating Scan-to-BIM for Telecom Site Planning

A Comparative Analysis and Case Study

Autumn Term 2025

Supervised by:
Océane Durand-Maniclas (ETH Zürich)
Kasimir Forth (ETH Zürich)
Jean-Charles Schaegis (Axians Schweiz AG)

Author:
Jeffrey Leisi

Declaration of Originality

I hereby declare that the written work I have submitted entitled

Automating Scan-to-BIM for Telecom Site Planning

is original work which I alone have authored and which is written in my own words.[1]

Author(s)

Jeffrey	Leisi

Student supervisor(s)

Océane	Durand-Maniclas
Kasimir	Forth

With the signature I declare that I have been informed regarding normal academic citation rules and that I have read and understood the information on 'Citation etiquette' (`https://www.ethz.ch/content/dam/ethz/main/education/rechtliches-abschluesse/leistungskontrollen/plagiarism-citationetiquette.pdf`). The citation conventions usual to the discipline in question here have been respected.

The above written work may be tested electronically for plagiarism.

Place and date	Signature

[1]Co-authored work: The signatures of all authors are required. Each signature attests to the originality of the entire piece of written work in its final form.

Preface

This thesis was developed as part of my bachelor's degree in geospatial engineering. Since I enjoy translating scientific findings into practical applications, I sought an industry-related project for my research.
TODO: Finish this paragraph

Jeffrey Leisi
Zurich, 2025

Abstract

- **Introduction to the Topic**
- **Research Objective**
- **Methodology**
- **Results**
- **Conclusion and Impact**

Keywords

BIM, Scan-to-BIM, telecommunications, automation, point cloud processing

Contents

Symbols

Symbols

ϕ, θ, ψ	roll, pitch and yaw angle
b	gyroscope bias
Ω_m	3-axis gyroscope measurement

Indices

x	x axis
y	y axis

Acronyms and Abbreviations

ETH	Eidgenössische Technische Hochschule
D-BAUG	Departement Bau, Umwelt und Geomatik (depatement of ETH)
IBI	Institut für Bau- und Infrastrukturmanagement (institute of D-BAUG)
CEA	Circular Engineering for Architecture (research group at IBI)
BIM	Building Information Modeling

Chapter 1

Introduction

1.1 Background and Motivation

The construction industry is one of the largest economic sectors, yet its productivity has stagnated for decades. In the two decades from 1995 to 2015, its productivity grew by only 1%, far below the global economy's average of 2.8%. One of the reasons cited is the low level of automation [1].
Until the turn of the millennium, construction planning had been largely digitized, primarily through the use of Computer-Aided Design (CAD) for creating construction drawings. This represented an evolutionary innovation, optimizing conventional planning methods. Manual drafting on the drawing board was replaced by manual drafting on the computer, while the individual work steps remained largely the same. In conventional planning, a real object is inductively represented by individual two-dimensional drawings (e.g., floor plan, section, detail). These drawings are often stored as isolated files (e.g., DWG, DXF) and are neither geometrically nor semantically linked. Any changes to the real object must be manually updated in all drawings.

At the turn of the millennium, Building Information Modeling (BIM) began to gain traction. It represented a disruptive innovation that fundamentally changed previous workflows. In this context, BIM refers to both the technology (software) and the methodology (processes). In model-based planning, a three-dimensional model is created as a digital representation of the real object. The two-dimensional drawings are then deductively derived from the model. The model is stored as a unified file (e.g., IFC) and contains both geometry and semantics. Any changes made to the model are automatically reflected in all drawings.
Scandinavian countries and the United Kingdom have taken leading roles in the implementation of BIM. However, integrating the technology in Switzerland has proven challenging. By 2021, only 20% of Swiss construction companies had adopted BIM, compared to 70% in Germany and 80% in the UK. This places Switzerland slightly above the European average. [2]. Among the factors contributing to this slow adoption are the fragmented nature of the construction industry and high competitive pressure, which led smaller companies, in particular, to shy away from the initially high investment costs. [3].
The Swiss telecommunications industry has recognized the potential of model-based planning. BIM is increasingly being used for the management of approximately 20000 mobile network sites [4]. While the traditional construction sector typically focuses on large, individual building projects, the telecommunications industry operates with a high volume of smaller projects. This results in different requirements

for building models.
Whereas the conventional construction industry demands high-quality, detailed models of entire building structures, the telecommunications sector prioritizes efficiently generated models of exterior structures. While BIM is still primarily applied to new construction projects in the traditional building industry, mobile network installations are usually integrated into existing buildings. The efficient capture of existing buildings has opened up a research field that continues to be actively explored.
The reverse engineering process of converting a physical object into a BIM model (as-is BIM) using terrestrial laser scanning or photogrammetry is commonly referred to in the literature as Scan-to-BIM. While the data acquisition process is relatively fast, the post-processing of point clouds can become time-consuming when performed manually. To enhance efficiency, automated methods are required.

1.2 Research Objectives and Questions

Both BIM and Scan-to-BIM have been extensively researched in recent years [5]. Surface modeling has also been a major research focus in the fields of computer vision and computer graphics, specifically in the general reconstruction of object surfaces from point clouds [6].
There are numerous existing algorithms that could be suitable for modeling point cloud data. Some of these algorithms are available as open-source code, while others have already been implemented as plugins for BIM software. Each algorithm has a different focus and is suited for specific applications, making it challenging to maintain an overview of the available options. So far, no dominant algorithm has been identified that consistently delivers the best results across all use cases.
As part of this study, the first phase will involve comparing various algorithms. In the second phase, the most promising approach will be implemented in a practical setting, and concrete recommendations for its application will be provided.
The following research questions are derived from this approach:

- **Research Question 1:** Which existing technologies are suitable for developing an automated Scan-to-BIM framework for telecom site planning?
- **Research Question 2:** How can the developed framework optimize existing Scan-to-BIM processes in telecom site planning?

1.3 Thesis Structure

To address the research questions, this thesis is divided into two parts, with each part focusing on one of the research questions:

- **Part 1:** The first part aims to answer the first research question through a comparative analysis. Chapter 2 provides an introduction to the three main topics of telecom, BIM, and Scan-to-BIM, laying the foundation for the subsequent analysis. Chapter 3 delves into the analysis itself, examining several Scan-to-BIM technologies introduced in Chapter 2 and evaluating their suitability. Based on this analysis, a concrete framework is developed.
- **Part 2:** The second part involves applying the developed framework to a practical case study. Chapter 4 identifies the initial problem, while Chapter 5 discusses the results of the implementation. Finally, Chapter 6 summarizes the findings and provides an outlook on future research.

Chapter 2

Literature Review

2.1 Cell Site Planning

Mobile communications is a subfield of telecommunications (see 2.1) that generally deals with the wireless transmission of voice and data and allows receivers or transmitters to move freely (WLAN, Bluetooth, satellite communication, ...). [7]. **Cellular communications** is a subfield of this, in which **cellular networks** are used [8]. A cellular network consists of several radio cells. The planning of these networks is called **cellular planning**. Within this field, different disciplines have developed:

- **Radio Network Planning (RNP):** Radio network planning has an electrical engineering focus and determines where radio cells should be located, how the signal is distributed, how many users can be connected simultaneously, and how interference can be avoided. [9], [10].
- **Cell Site Planning:** Cell site planning has a structural engineering focus and refers to the identification and structural implementation of a physical site within the perimeter defined by radio network planning [11].

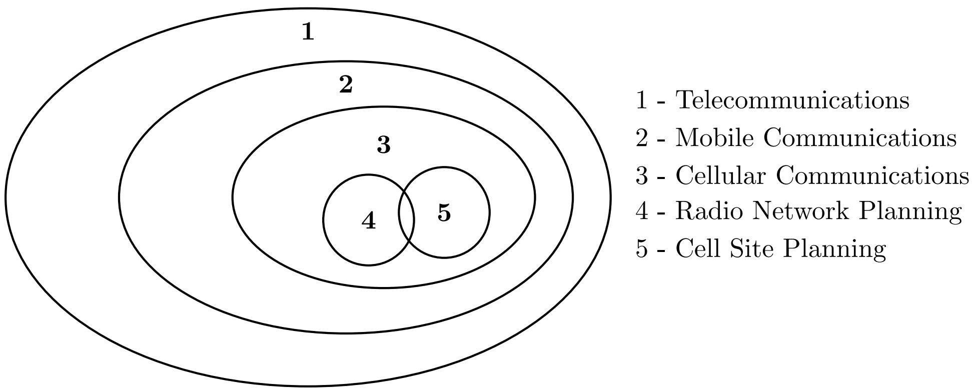

Figure 2.1: Telecommunications Hierarchy

This work focuses on cell site planning. For the literature analysis, two general works on mobile communications from Springer [8], [12] as well as three papers listed under cell site planning [13], [14], [15] were consulted. It was found that mainly electrical engineering topics are addressed. One possible explanation could be that electrical engineering areas such as radio technology and signal processing

have a high technical depth and are therefore extensively researched. As a result, these areas have been strongly standardized internationally (ITU, ETSI, 3GPP). Structural topics, on the other hand, depend more on local conditions, which are regulated by practical guidelines. For this purpose, a report commissioned by the Federal Council "Sustainable Mobile Network" was consulted [16].
The following section summarizes key findings of the literature analysis. In the field of cell site planning, the terminology of the Swiss mobile communications industry is used.

2.1.1 International Status

Worldwide, mobile data traffic is increasing exponentially [17]. Until around 2020, traffic doubled about every two years. Annual growth rates of an average of 19 % are still forecast for the period until 2030. Currently, 34 % of mobile data traffic is handled via 5G networks. By 2030, this share is expected to increase to 80 %.
The increase has been significantly driven by video streaming with ever higher screen resolutions (4K, 8K), which now accounts for 74 % of mobile data traffic [17]. The main drivers of future growth are seen particularly in the areas of autonomous driving, Extended Reality, Industry 4.0, and generative AI. Fixed Wireless Access (FWA) will become increasingly important and account for a significant share of the traffic by 2030 with 36 %. Stationary devices (e.g., computers) are supplied with a fixed broadband connection via a CPE device provided by mobile networks (4G/5G). Especially in economically less developed regions, FWA will increasingly displace traditional fixed network connections as a more cost-effective alternative.

2.1.2 National Status

In Switzerland, the federal government takes the view that a powerful telecommunications infrastructure is of high importance for the economy and society [16]. Therefore, a rapid expansion of powerful 5G networks is important. According to the operators Swisscom, Sunrise, and Salt, this requires 7,500 new antenna sites and investments of 3.2 billion Swiss francs [16].
Their market share by number of customers was 54.3 % for Swisscom, 23.6 % for Sunrise, and 17.1 % for Salt at the end of 2023 [18]. The market penetration was 128.9 %. This means that there are more active SIM cards than inhabitants [19].
To protect the population from scientifically proven damage due to non-ionizing radiation (NIS), the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has defined recommended limit values [20]. These were adopted by the federal government in the Ordinance on Protection against Non-Ionizing Radiation (NISV) as immission limit values and correspond to the EU recommendation. These must be complied with at all locations where people can stay. Due to health concerns, so-called system limit values were defined. This stricter limit value is 10 % of the immission limit value and must be complied with at locations with sensitive use (OMEN). These are areas where it is assumed that people stay regularly for longer periods. The electric field strength there is one-tenth of the permissible value in Germany and France. The power of an electromagnetic wave is proportional to the square of the electric field strength. A field strength reduced by a factor of 10 thus leads to a transmission power reduced by a factor of 100 [21].

2.1.3 Cellular Network Generations

Approximately every ten years, a new cellular network generation is introduced [16]. Each of these has a higher data transmission rate, lower latency, and a higher number of devices connected simultaneously. Until the introduction of the sixth generation (6G Vision) around 2030, the fifth generation (5G) is currently being expanded. Also practically relevant is the fourth generation (LTE), which was expanded from 2012. The third generation (UMTS) will be discontinued by Swisscom by the end of 2025 [22]. The second generation (GSM) was discontinued by the three providers between 2021 and 2023 [23].

2.1.4 Network Architecture

The network architecture of a cellular network can be divided into various components [8], [12]:

- **Access network:** The access network receives signals from the end device (e.g., smartphone) and forwards them to the core network. It includes the end devices, the transmitting systems, and the radio connection between them.
- **Core network:** The core network processes, controls, and mediates the connections and enables connections to external networks such as the Internet or the fixed network. Each operator has its own core network.
- **Backhaul connection:** The two networks are connected via the backhaul connection, which is preferably implemented as a line-based connection via fiber optic due to its high capacity. However, in remote areas, it can also be implemented as a microwave connection.

The **base station** is the central processing unit for controlling data transmission and is the heart of each system. Each base station also has at least one **antenna** through which bidirectional communication with the end device takes place via electromagnetic waves. Typically, three sector antennas are used per system, each radiating in a sector of 120 degrees. These are arranged in different planes for different technologies. Each antenna sector defines a **radio cell**. This results in an idealized hexagonal basic pattern. [12]

2.1.5 Site Classification

While in radio network planning the classification by cell size (macrocells, microcells, picocells, femtocells) is common [8], the following classification (see 2.2) has established itself in Swiss site planning:

- **Greenfield site:** This type of site is mainly found in rural areas. Characteristic of this is a usually between 20 and 50 meters high, freestanding mast.
- **Rooftop site:** This type of site is mainly found in populated areas. Characteristic of this is the placement on the roof of an existing building. Depending on the chosen mast construction, further distinctions can be made:
  - **Stand-mounted pole [2]:** Mast not firmly connected to the building, which is placed on a steel substructure and placed on the roof.
  - **Wall-mounted pole [3]:** Mast firmly connected to the building, which is mounted on the facade.
  - **Attic-mounted pole [4]:** Mast firmly connected to the building, which is mounted inside the building and protrudes through an opening in the roof to the outside.

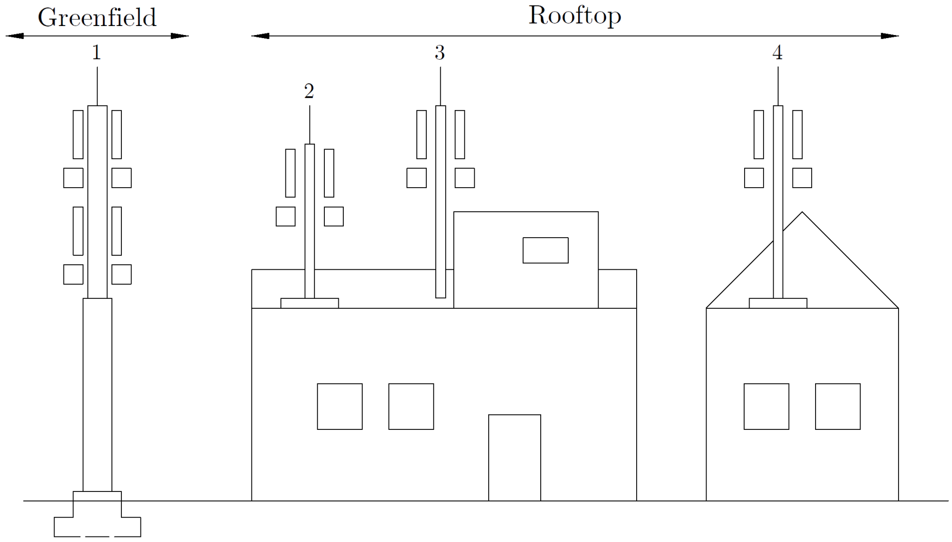

Figure 2.2: Site Classification

2.2 Building Information Modeling (BIM)

Building Information Modeling (BIM) is primarily a methodology for digitally planning, executing, and managing buildings over their entire life cycle. In practice, BIM is therefore often used as a synonym for model-based planning, although BIM can go beyond mere 3D modeling (e.g., 4D). To clearly distinguish it from the tool that enables this methodology, it will be referred to as **BIM software** in the following. After the introduction already addressed the development of BIM, the following chapter will explain the conceptual basics. The focus is on central concepts that will be relevant for the later understanding of the application in the case study.

2.2.1 Characteristics of a BIM Model

A **BIM model** initially consists, like the three-dimensional **CAD model**, of geometric data in three-dimensional space. In addition to the geometric data, however, the BIM model contains additional information, referred to as **attributes**. While the CAD model represents an aggregation of purely geometric primitives (points, lines, surfaces), the BIM model consists of parametrized objects. These are intelligent **components** that can contain attributes such as material and costs in addition to their geometry. This information must be represented graphically or textually in the CAD model. In addition, components can be semantically linked to model relationships. This will be illustrated by the following example. [24]

Example Civil Engineering
A ceiling slab of a single-family house is to be lowered by 10 cm.
BIM*: The component* `ceiling slab` *is lowered in the BIM model. The change is automatically reflected in the formwork and reinforcement plans. The reinforcement list is updated automatically. The financial implications can be determined directly via a cost calculation.*
CAD [1]*: The ceiling slab is lowered in the CAD model. The change is manually transferred to the formwork and reinforcement plans. The reinforcement list must*

[1]Modern CAD systems now also have semi-automated functions.

be updated manually. The financial implications must be calculated separately.

2.2.2 BIM Terminology

Standardized metrics are available for evaluating and classifying BIM processes and BIM models. These enable an objective evaluation and facilitate communication between project participants. The most important metrics are:

BIM Maturity Level

The **BIM maturity level** is a quality measure that describes how systematically and comprehensively BIM is implemented in a company or project. The focus is on data networking, standardization, and collaboration between the participants. According to VDI 2552, the following four maturity levels are distinguished: [24], [25]

Level	BIM Usage	Description
0	None	Traditional 2D CAD drafting is used with no object-based modeling or intelligent data sharing. Collaboration is minimal, and document exchange is paper-based or in simple file formats.
1	None	Combination of 2D and 3D CAD tools. While 3D models may be used internally, there is no standardized collaboration between different disciplines. Data exchange remains file-based without integrated workflows.
2	Collaborative	Different disciplines work on their own BIM models, which are then shared and combined at specific project stages. Collaboration is structured, but data exchange is still semi-automated, requiring manual coordination. Lifecycle phases are considered separately.
3	Integrated	All disciplines collaborate in a fully connected and shared BIM environment. A single, integrated model covers the entire building lifecycle, from design to operation. Automated data exchange and real-time collaboration enable seamless workflows.

Table 2.1: BIM Stages and Their Characteristics

Level of Development (LOD)

The **level of development (LOD)** of a model indicates how much project information is already contained in the model. This consists of the degree of elaboration of the geometry (LOG) and the depth of the alphanumeric information (LOI):

$$\mathrm{LOD} = \mathrm{LOG} + \mathrm{LOI} \tag{2.1}$$

The LOD thus indicates the level of completion of a model at a specific project phase. This is marked with numbers between 100 and 500 (see 2.3). The level of detail increases with increasing number. As the planning progresses, the LOD usually increases. Since a high LOD is associated with a higher workload, it is important to determine how many details are useful at what time. This is indicated by the Level of Information Need (LOIN). [24]

Figure 2.3: Level of Development (LOD) [26]

BIM Dimensions

The **BIM dimension** describes the depth of information of the attributes. It is indicated by a value between 3D and 7D. The level of detail increases with increasing number. [27]

Dimension	Additional Attributes	Use Cases
3D	None	Geometric modeling
4D	Time	Construction scheduling, project phases
5D	Cost	Quantity takeoff, pricing, budgeting
6D	Efficiency & Sustainability	Energy performance, lifecycle assessment
7D	Facility management	Operations, maintenance, asset tracking

Table 2.2: BIM Dimensions and Information Depth

BIM Types

BIM application forms are distinguished in terms of two dimensions: [24]

1. **Depth of Integration:** Quantity measure that describes the extent to which a BIM model is integrated into the value chain. A low depth of integration exists when BIM is only used in a single phase. A high depth of integration means that BIM is used throughout the entire life cycle.
2. **Software Independence:** Quality measure of interoperability, i.e., the ability to use BIM models and data outside of specific software families or providers.

The following four BIM types result from the expression of the two dimensions:

2.2.3 BIM Management

BIM management involves the strategic and operational control of BIM. The aim is to standardize workflows and improve collaboration. In this subchapter, three tools will be presented (see 2.5), which will be used in the case study.

Exchange Information Requirements (EIR)

The **Exchange Information Requirements (EIR)** correspond to a specification tailored to BIM. They describe why which information is needed when. They define the client's requirements for BIM processes, data, and collaboration throughout the entire project life cycle. This includes specifications for model structure, level of detail, data exchange formats, responsibilities, and collaboration methods. [24]

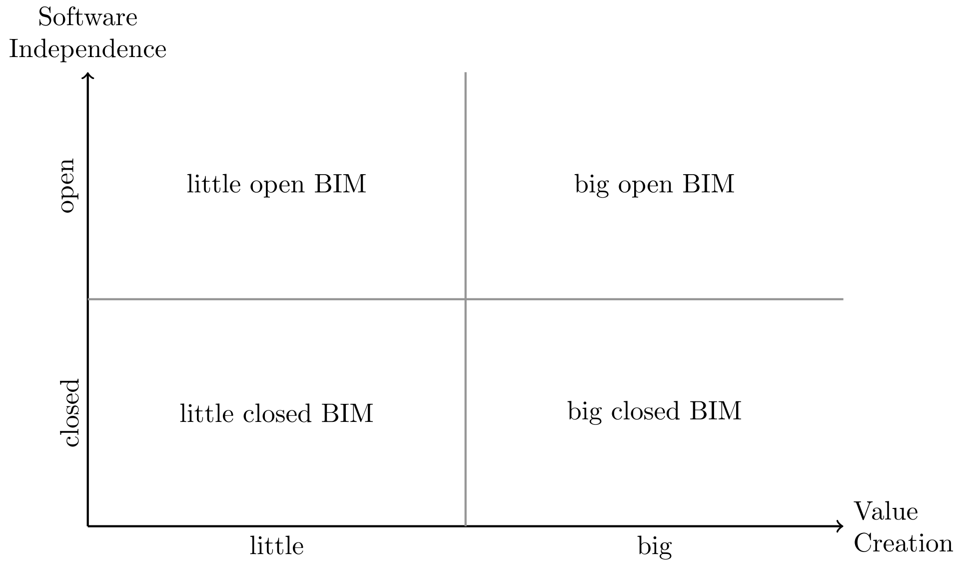

Figure 2.4: BIM Types

BIM Execution Plan (BEP)

The **BIM Execution Plan (BEP)** corresponds to a specification tailored to BIM. It describes how the requirements from the **Employer's Information Requirements (EIR)** are implemented by the contractor in the project. [24]

BIM Modeling Guidelines

The **BIM modeling guidelines** define how a BIM model should be structured and organized. For this purpose, standards, methods, and requirements for creation and management are defined. They ensure uniform data structures, better collaboration, and high model quality. Typically, the modeling guidelines are defined or referenced in the BEP. [24]

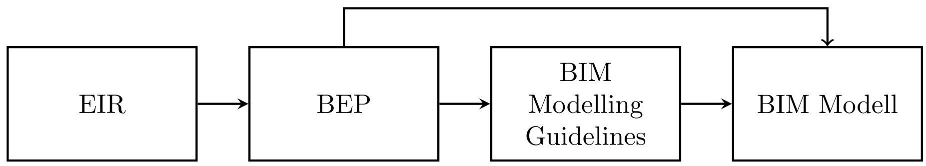

Figure 2.5: Simplified BIM Management Process Flow

2.3 Scan-to-BIM

Renovation projects are becoming increasingly important in the Swiss construction industry. The construction expenditure for new buildings has remained almost the same since 1980. In the same period, investments in renovations, extensions, and demolitions have more than tripled [28]. This means that the total Swiss investments for renovations, extensions, and demolitions already amount to 66 % of those for new buildings.
At the same time, the documentation of private existing buildings is often incomplete **dewolfCircularBuiltEnvironmentg**, [29]. Older buildings, in particular,

often have only incomplete or outdated planning documents. Although building permit plans can often be found in municipal archives, these document the original construction status, are often outdated, and in low detail.
In Switzerland, 81.5 % of buildings were built before the turn of the millennium [30]. If planning documents exist, they are usually only available in paper form. However, even in newer buildings, editable CAD or BIM files are usually not available. According to Swiss law, the copyright to plans remains with the respective planner. Although the often contractually included SIA 102 grants the client the right to copies of the work products, paper plans or PDF files are sufficient to fulfill this obligation without explicit contractual regulation [31]. Since planners are reluctant to provide editable data due to liability risks and clients are usually satisfied with paper or PDF plans, further regulation is often dispensed with.
As a result, even in newer buildings, there are no digitally processable planning documents available, which significantly complicates digital inventory documentation. For model-based planning, methods are therefore required that can reliably transfer the physical construction status into a BIM model. One possibility is to manually reconstruct the model from existing construction plans. However, this approach is time-consuming and error-prone, especially if the plans are incomplete or outdated. A more efficient solution is **Scan-to-BIM**. It is a process in which a physical building is precisely captured using reality capture technologies such as 3D laser scanning or photogrammetry and transferred into a BIM model. This enables an exact digital representation of the actual state and provides a reliable basis for further planning.
The Scan-to-BIM frameworks described in the literature can be divided into various sub-processes. The number and designation of these sub-processes vary depending on the chosen level of detail but follow a similar basic structure. In the following, four central sub-processes (see 2.6) will be presented.

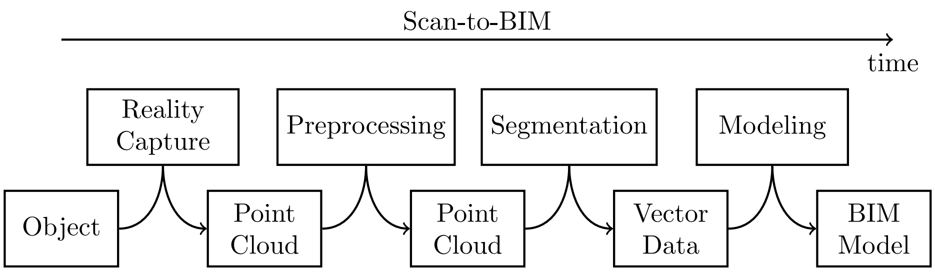

Figure 2.6: Scan-to-BIM Framework

2.3.1 Reality Capture

Reality Capture is a process in which a physical object is digitally captured using sensors. The following technologies are distinguished: [32]

- **LiDAR:** TODO: Description
  - Terrestrial LiDAR Scanners: TODO: Description
  - Portable LiDAR Scanners: TODO: Description
  - Drone-based LiDAR Scanners: TODO: Description
- **Photogrammetry:** TODO: Description

The following two important formats can be distinguished as the output product of Reality Capture:

- **Point Cloud:** TODO: Description
- **Mesh:** TODO: Description

The following metrics are distinguished as quality metrics of the point cloud:

- **Accuracy:** TODO: Description
- **Precision:** TODO: Description
- **Point Density:** TODO: Description
- **Resolution:** TODO: Description

2.3.2 Preprocessing

The **Preprocessing** step is used to prepare the raw data of the point cloud. The following tasks are performed:

- **Registration:** TODO: Description Traditional/Deep-Learning
- **Filtering:** TODO: Description
- **Georeferencing:** TODO: Description
- **Downsampling:** TODO: Description

2.3.3 Segmentation

Segmentation is a process in which the point cloud is divided into individual objects or components. The following methods are distinguished:

- **Manual Segmentation:** TODO: Description
- **Semi-automatic Segmentation:** TODO: Description
- **Automatic Segmentation:** TODO: Description

2.3.4 Modeling

The **Modeling** step is used to transfer the vector data from the point cloud into a BIM model. The following methods are distinguished:

- **Manual Modeling:** TODO: Description
- **Semi-automatic Modeling:** TODO: Description
- **Automatic Modeling:** TODO: Description

Chapter 3

Methodology

Chapter 4

Case Study

4.1 Introduction

TODO: Provide a brief introduction to the chapter.

4.2 Initial Situation

4.3 Chosen Approach

Chapter 5

Results

5.1 Introduction

TODO: Provide a brief introduction to the chapter.

Chapter 6

Discussion

6.1 Introduction

TODO: Provide a brief introduction to the chapter.

Chapter 7

Conclusion

7.1 Introduction

TODO: Provide a brief introduction to the chapter.

Bibliography

[1] F. Barbosa et al., "Reinventing Construction: A Route to Higher Productivity. McKinsey & Company," McKinsey Global Institute, Tech. Rep., 2017, p. 15. Accessed: Mar. 7, 2025.

[2] J. Heinrich, *Die Schweiz im BIM-Europavergleich - PlanRadar CH*, https://www.planradar.com/ch/bim-europavergleich/, Aug. 2022. Accessed: Mar. 8, 2025.

[3] A. Ivanic, "Erfolgreiche Einführung von Building Information Modeling in der Schweizer Baubranche," Ph.D. dissertation, Jun. 2020.

[4] Federal Office of Communications (OFCOM), *Locations of mobile phone base stations*, https://data.geo.admin.ch/browser/index.html#/collections/ch.bakom.standorte-mobilfunkanlagen?.language=en. Accessed: Mar. 9, 2025.

[5] G. Rocha and L. Mateus, "A Survey of Scan-to-BIM Practices in the AEC Industry—A Quantitative Analysis," *ISPRS International Journal of Geo-Information*, vol. 10, no. 8, Aug. 2021, ISSN: 2220-9964. DOI: 10.3390/ijgi10080564. Accessed: Mar. 8, 2025.

[6] L. Nan and P. Wonka, "PolyFit: Polygonal Surface Reconstruction from Point Clouds," 2017.

[7] Bundesamt für Strahlenschutz, *What is mobile communication?* https://www.bfs.de/EN/topics/emf/mobile-communication/basics/basics_node.html. Accessed: Mar. 18, 2025.

[8] W. Jiang and B. Han, *Cellular Communication Networks and Standards: The Evolution from 1G to 6G* (Textbooks in Telecommunication Engineering). Cham: Springer Nature Switzerland, 2024, ISBN: 978-3-031-57819-9 978-3-031-57820-5. DOI: 10.1007/978-3-031-57820-5. Accessed: Mar. 18, 2025.

[9] Academy for LoRaWAN®, *Academy for LoRaWAN®: What Is Radio Planning? — — Academy for LoRaWAN*, https://learn.semtech.com/mod/page/view.php?id=100. Accessed: Mar. 18, 2025.

[10] T. Trainer, *RNP Radio Network Planning*, https://www.telecomtrainer.com/rnp-radio-network-planning/, Jun. 2023. Accessed: Mar. 18, 2025.

[11] M. A. Habib, *(PDF) A Study of Cell Site Planning of GSM System*, https://www.researchgate.net/publication/271587738_A_Study_of_Cell_Site_Planning_of_GSM_System, Oct. 2024. DOI: 10.13140/2.1.2437.6645. Accessed: Mar. 18, 2025.

[12] K. Behnke, J. Karla, and W. Mülder, *Grundkurs Mobilfunk und Mobile Business: Anwendungen, Technologien, Geschäftsfelder*. Wiesbaden: Springer Fachmedien Wiesbaden, 2022, ISBN: 978-3-658-00140-7 978-3-658-00141-4. DOI: 10.1007/978-3-658-00141-4. Accessed: Mar. 13, 2025.

[13] A. Engels, *Dimensioning, cell site planning, and self-organization of 4G radio networks* (Berichte aus der Kommunikationstechnik). Aachen: Hochschulbibliothek der Rheinisch-Westfälischen Technischen Hochschule Aachen, 2013, ISBN: 978-3-8440-2315-2.

[14] M. M. Ahamed and S. Faruque, "5G Network Coverage Planning and Analysis of the Deployment Challenges," *Sensors*, vol. 21, no. 19, p. 6608, Jan. 2021, ISSN: 1424-8220. DOI: 10.3390/s21196608. Accessed: Mar. 18, 2025.

[15] X. Huang, U. Behr, and W. Wiesbeck, "Automatic cell planning for a low-cost and spectrum efficient wireless network," in *Globecom '00 - IEEE. Global Telecommunications Conference. Conference Record (Cat. No.00CH37137)*, vol. 1, Nov. 2000, 276–282 vol.1. DOI: 10.1109/GLOCOM.2000.892016. Accessed: Mar. 18, 2025.

[16] Bundesrat, "Nachhaltiges Mobilfunknetz," Tech. Rep., Apr. 2022.

[17] "Ericsson Mobility Report November 2024,"

[18] B. f. K. BAKOM, *Marktanteile Mobilfunknetz*, https://www.bakom.admin.ch/bakom/de/home/telekommunikation/zahlen-und-fakten/sammlung-statistischer-daten/marktstruktur-und-stellen/marktanteile-mobilfunknetz.html. Accessed: Mar. 12, 2025.

[19] B. f. K. BAKOM, *Anzahl Mobilfunkkundinnen und -kunden*, https://www.bakom.admin.ch/bakom/de/home/telekommunikation/zahlen-und-fakten/sammlung-statistischer-daten/mobilfunk/anzahl-mobilfunkkundinnen-und-kunden.html. Accessed: Mar. 12, 2025.

[20] J. Baumann, "Mit der Verordnung über den Schutz vor nichtionisierender Strahlung (NISV) soll die Bevölkerung vor Elektrosmog geschützt werden. Was regelt die NISV, was nicht? Wie werden die Grenzwerte festgelegt und wer ist zuständig für den Vollzug? Zudem: Wie wird die Strahlung berechnet und gemessen?," 2005.

[21] CHANCE5G, *Anlagegrenzwerte im Mobilfunk: Strenges Vorsorgeprinzip in der Schweiz*, https://chance5g.ch/de/storys/anlagegrenzwerte-im-mobilfunk-strenges-vorsorgeprinzip-der-schweiz/. Accessed: Mar. 12, 2025.

[22] Swisscom, *Abschaltung 3G - Erneuerung Mobilfunknetz Swisscom*, https://www.swisscom.ch/de/about/netz/5g/abloesung-3g.html. Accessed: Mar. 12, 2025.

[23] h. online, *Schweiz: Endgültiges Aus für GSM-Mobilfunk Anfang 2023*, https://www.heise.de/news/Schweiz-Endgueltiges-Aus-fuer-GSM-Mobilfunk-Anfang-2023-7201820.html, Aug. 2022. Accessed: Mar. 18, 2025.

[24] H. Astour and H. Strotmann, *Lehrbuch Grundlagen Der BIM-Arbeitsmethode*. Springer Fachmedien Wiesbaden, 2022, ISBN: 978-3-658-37238-5.

[25] C. C. Eichler, C. Schranz, T. Krischmann, and H. Urban, "BIMcert Handbuch: Grundlagenwissen openBIM," Mironde-Verlag, Niederfrohna, Tech. Rep., 2023.

[26] ncircletech, *BIM Level of Development — nCircle Tech*, https://ncircletech.com/blogs/bim-level-of-developments. Accessed: Mar. 15, 2025.

[27] M. May, M. Krämer, and S. Maik, *BIM Im Immobilienbetrieb*. Springer Fachmedien Wiesbaden, 2022.

[28] Bundesamt für Statstik, *Bauausgaben nach Art der Arbeiten*, https://www.bfs.admin.ch/asset/de/32153298. Accessed: Mar. 15, 2025.

[29] R. Kaden et al., "Leitfaden Geodäsie und BIM,"

[30] Bundesamt für Statstik, *Bauperiode*, https://www.bfs.admin.ch/content/bfs/de/home/statistiken/bau-wohnungswesen/gebaeude/periode.html. Accessed: Mar. 16, 2025.

[31] B. Schw, "Bauen + rechten : Und die Pläne? In welcher Form sind Pläne an den Bauherrn herauszugeben?,"

[32] R. Rashdi, J. Martínez-Sánchez, P. Arias, and Z. Qiu, "Scanning Technologies to Building Information Modelling: A Review," *Infrastructures*, vol. 7, no. 4, p. 49, Apr. 2022, ISSN: 2412-3811. DOI: `10.3390/infrastructures7040049`. Accessed: Mar. 16, 2025.

[33] G. Borruso et al., "Procedural Point Cloud Modelling in Scan-to-BIM and Scan-vs-BIM Applications: A Review," *ISPRS International Journal of Geo-Information 2023, Vol. 12, Page 260*, vol. 12, no. 7, p. 260, Jun. 2023, ISSN: 2220-9964. DOI: `10.3390/IJGI12070260`.

[34] C. De Wolf, S. Çetin, and N. Bocken, *A Circular Built Environment in the Digital Age* (Circular Economy and Sustainability (CES)).

[35] Samsung, *What is a Cellular network or Mobile network?* https://www.samsung.com/in/support/mobile-devices/what-is-a-cellular-network-or-mobile-network/. Accessed: Mar. 18, 2025.

[36] Q. Wang, J. Guo, and M.-K. Kim, "An Application Oriented Scan-to-BIM Framework," *Remote Sensing*, vol. 11, no. 3, p. 365, Feb. 2019, ISSN: 2072-4292. DOI: `10.3390/rs11030365`.