Bachelor Thesis

Automating Scan-to-BIM
for Telecom Site Planning

A Comparative Analysis and Case Study

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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

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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].

1.1.1 Conventional Planning with CAD

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.

1.1.2 Model-Based Planning with BIM-Software

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].

1.1.3 Telecommunications Planning

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.

1.1.4 Scan-to-BIM

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 Mobile Communications

Mobile communications is a subfield of telecommunications that deals with the wireless transmission of voice and data over radio networks. The planning of these networks is referred to as **mobile network planning**. Within this field, different disciplines have developed:

- **Network Planning:** Network planning involves the implementation and optimization of the network architecture of a mobile network. It includes detailed planning of the cell structure, frequency distribution, capacity calculation, and interference minimization to ensure efficient, stable, and high-performance network coverage. An essential part of network planning is determining the geographical perimeter where a mobile radio system is required. The focus of network planning is on electronic and signal engineering aspects, making it highly standardized and internationally regulated. Due to this standardization and technical complexity, the available literature on mobile network planning is largely focused on network planning.

- **Site Planning:** Site planning refers to the identification and construction of a physical site within the perimeter defined by network planning. This includes selecting suitable sites, taking into account topographical, structural, legal, and environmental factors. In contrast to network planning, site planning is less standardized, as it depends heavily on local conditions. This variability means that the scientific literature on this topic is relatively limited. Instead, planning processes and definitions often arise from practice, such as regulatory guidelines or internal company processes.

This work focuses on the site planning of mobile radio systems. First, the relevant basics are established without going into too much technical detail. The case study then goes into more detail on the individual processes related to BIM.

2.1.1 International Status of Mobile Communications

The global mobile data traffic is increasing exponentially. Until around 2020, traffic volumes doubled approximately every two years. For the period up to 2030, annual growth rates of an average of 19 % are still projected. Currently, 34 % of mobile data traffic is handled via 5G networks. By 2030, this share is expected to rise to 80 %.
A key driver of this increase has been video streaming with ever-higher screen resolutions (4K, 8K), which now accounts for 74 % of mobile data traffic. The main

drivers of future growth are expected to be in the areas of autonomous driving, extended reality, Industry 4.0, and generative AI. Fixed Wireless Access (FWA) is expected to gain significant importance and account for a substantial 36 % of total data traffic by 2030. In this context, stationary devices (e.g., computers) are supplied via a CPE device with a fixed broadband connection provided through mobile networks (4G/5G). Particularly in economically less developed regions, FWA is expected to increasingly replace traditional fixed-line connections as a more cost-effective alternative. [7]

2.1.2   National Status of Mobile Communications

In Switzerland, the federal government takes the view that a powerful telecommunications infrastructure is of great importance for the economy and society. Therefore, rapid expansion of powerful 5G networks is important. According to the three providers, this requires 7,500 new antenna sites and investments of CHF 3.2 billion. [8]
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 [9]. The market penetration was 128.9 %. This means that there are more active SIM cards than residents. [10].
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. These have been 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 be present. Due to health concerns, so-called system limit values have been defined [11]. 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 will be present 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 [12]. Once a system has reached the maximum permissible transmission power, it can no longer be expanded. To increase network capacity, new sites must be built. [8].

2.1.3   Mobile Network Generations

Approximately every ten years, a new mobile network generation is introduced. Each generation has a higher data transfer rate, lower latency, and a higher number of devices connected simultaneously. Currently, the fifth generation (5G) is being expanded until the introduction of the sixth generation (6G Vision, around 2030). Also relevant in practice is the fourth generation (LTE), which was expanded from 2012. The third generation (UMTS) will be discontinued by Swisscom at the end of 2025 [13]. The second generation (GSM) was discontinued by the three providers between 2020 and 2023. 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. These have been 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 be present. Due to health concerns, so-called system limit values have been defined [11]. 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

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2.1.4   Network Architecture

The network architecture of a mobile network can be divided into various components or subareas:

- **Access Network:** The access network 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. [14]

- **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 **mobile radio cell**. This results in an idealized hexagonal basic pattern. [14]

2.1.5   System Classification

The classification of the system can vary depending on the perspective. From a technical point of view, a distinction according to cell size is useful for radio network planning. Here, a distinction is made between macrocells (rural areas), microcells (urban areas), picocells (indoor coverage), and femtocells (private areas). [8]
From a construction planning perspective, a classification according to site type has been established:

- **Greenfield site:** predominant in rural areas. Characteristic is a usually between 20 and 50 meters high, freestanding mast.

- **Rooftop site:** predominant in populated areas. Characteristic is the installation on an existing building.

  - Stand mast [2]

  - Facade-mounted mast [3]
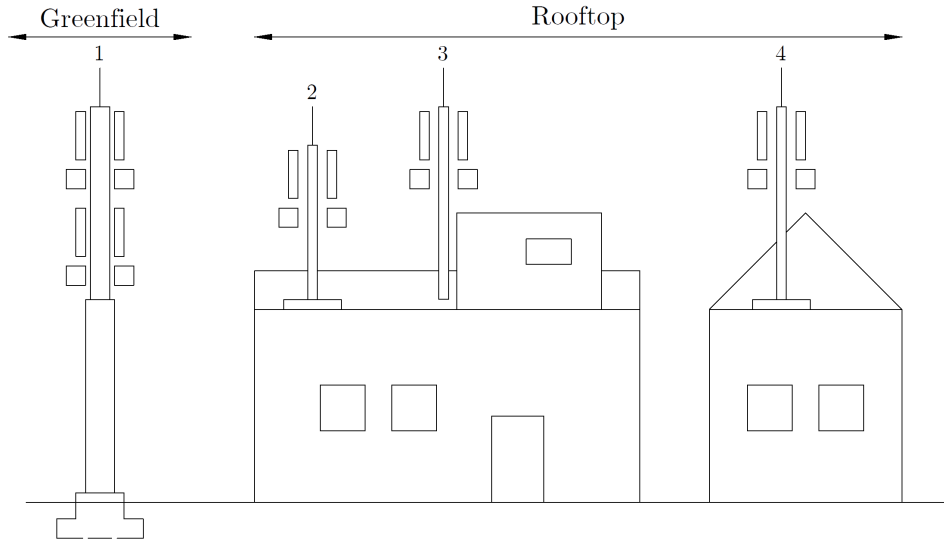
  - Roof-penetrating mast [4]

Figure 2.1: 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. [15]

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*

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[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: [15], [16]

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):

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

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 2.2). 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). [15]

Figure 2.2: Level of Development (LOD) [17]

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. [18]

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: [15]

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 2.4), 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. [15]
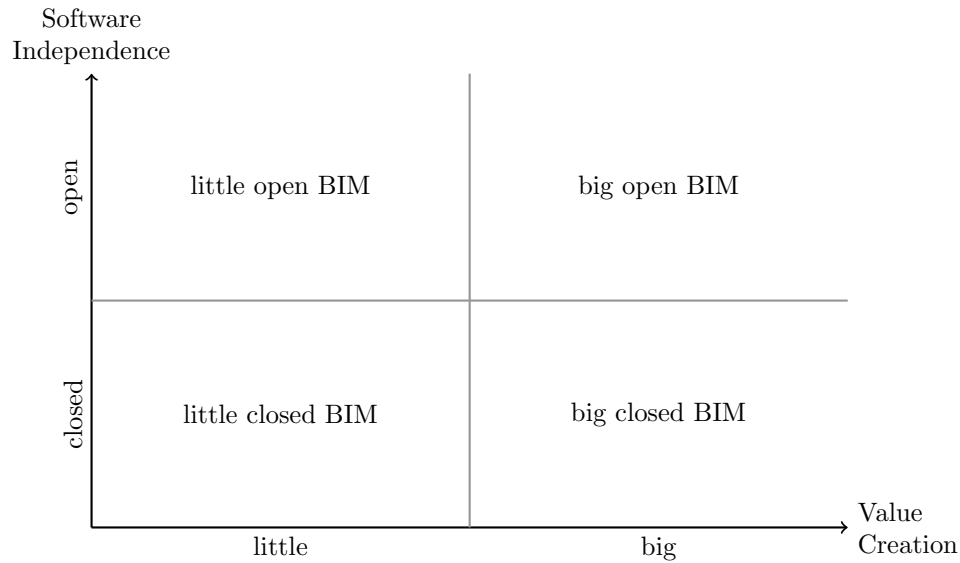
Software
Independence

	little	big
open	little open BIM	big open BIM
closed	little closed BIM	big closed BIM

Value
Creation

Figure 2.3: 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. [15]

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. [15]
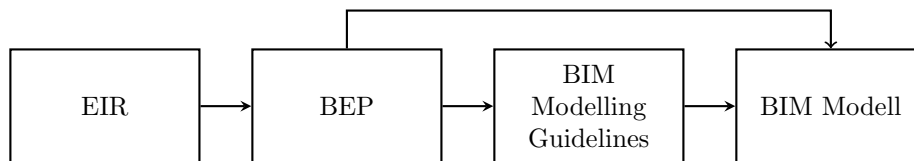

Figure 2.4: Simplified BIM Management Process Flow

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 [19]. 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**, [20]. 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 [21].
If planning documents exist, they are usually only available in paper form. How-
ever, 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 [22]. 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 documenta-
tion. 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,
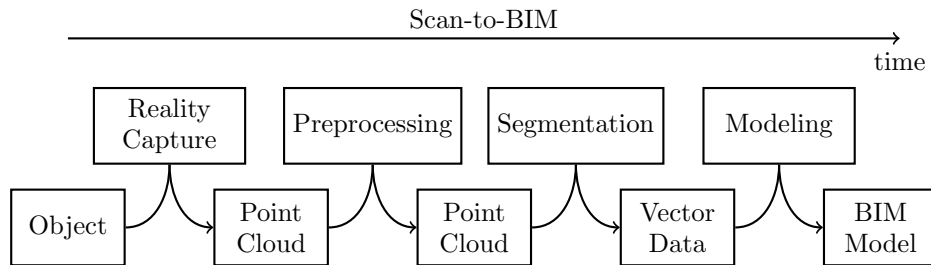four central sub-processes (see 2.5) will be presented.

Figure 2.5: 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: [23]

- **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.

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