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Bachelor Thesis

Automating Scan-to-BIM for Telecom Site Planning

A Comparative Analysis and Case Study

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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]

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Abstract

This bachelor's thesis investigates the automation of Scan-to-BIM processes for telecommunications site planning. The goal was to develop an automated framework for generating a BIM model of the building's exterior structure from a point cloud. The framework was methodically developed following the Design Science Research Methodology (DSRM). Based on this, a pipeline was implemented and validated in a case study. The software CloudCompare and Autodesk Revit were used. For automation, the programming language Python and the visual scripting interface Dynamo were used.

The results of the case study demonstrate that a largely automated conversion of point clouds into BIM models at LOD-200 level is fundamentally possible. However, additional manual adjustments were required for practical application. Furthermore, challenges regarding geometric accuracy and model completeness exist. Several solutions have been developed to address these limitations. If successfully implemented, the productive use of the framework in site planning appears realistic.

Keywords

Scan-to-BIM, Telecommunications Site Planning, Point Cloud Processing, PolyFit, ifcopenshell, Autodesk Revit, Dynamo, Python, Design Science Research Methodology (DSRM)

Preface

This thesis was written as part of my bachelor's degree in Geospatial Engineering. To connect theoretical content with practical experience, I sought contact with an industry partner. My special thanks go to Axians for the opportunity to collaborate. I would like to thank Jean-Charles Schaegis in particular for his support as a practical supervisor.

I would like to thank Helena Laasch from the Institute of Geodesy and Photogrammetry (IGP) for facilitating the contact with the Institute of Construction and Infrastructure Management (IBI). I am grateful to Prof. Catherine De Wolf for enabling the academic supervision of my work in her research group Circular Engineering for Architecture (CEA). The technical supervision was provided by Dr. Kasimir Forth and Océane Durand-Maniclas, to whom I extend my special thanks for their dedicated support and constructive feedback.

Finally, I would like to thank Prof. Liangliang Nan from TU Delft for his support in integrating the software he developed.

Jeffrey Leisi
Zurich, 2025

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

Contents

Chapter 1

Introduction

1.1 Background and Motivation

The construction industry is one of the most significant economic sectors, yet its productivity has remained static for several decades. In the period spanning two decades from 1995 to 2015, the observed productivity growth was a mere 1 %, a figure that falls considerably short of the global economic average of 2.8 % [1]. This phenomenon can be attributed, in part, to the limited automation present within the sector.

Despite the substantial digitalisation of construction planning through the utilisation of computer-aided design (CAD), the fundamental work steps have remained relatively unaltered [2]. Conventional planning was merely optimised. The geometry of a physical object is mapped inductively using individual, usually two-dimensional drawings (e.g. floor plan, section, elevation). The individual drawings are typically isolated files that are neither geometrically nor semantically linked to each other. Alterations require manual adjustments in the affected drawings. [2]

The introduction of Building Information Modelling (BIM) enabled a profound change in planning methodology [2]. BIM enables work processes to be restructured fundamentally. In model-based planning, semantic information – such as that relating to materials or costs – is integrated into an intelligent 3D model alongside the geometric form. Different specialist disciplines integrate their content into a common model, enabling more efficient collaboration throughout a building's entire life cycle. Two-dimensional drawings can be derived deductively from the model for use on the construction site, for example. Changes to the model are automatically updated in these drawings. [2]

The introduction of BIM in Switzerland was initially hesitant. Despite the existing productivity potential, only 20 % of Swiss construction companies were using Building Information Modelling in 2021 [3]. This was due to the fragmented structure of the construction industry and high price pressure, which caused smaller companies in particular to shy away from the initially high investment costs [4].

The Swiss telecommunications industry has recognised the potential of model-based planning. In future, BIM is to be used for the planning of new mobile base stations on existing buildings, known as rooftop cell site planning. In contrast to the traditional construction industry, which typically focuses on large, individual construction projects, site planning is characterised by a high project volume with smaller, largely standardised infrastructure interventions. Even minor improvements in the efficiency of individual tasks can result in significant cumulative effects across a large number of projects. As a result of these economies of scale, automated planning processes are becoming increasingly impactful.

One such process that has the potential to be automated is the digital recording of buildings using reality capture. This process entails the generation of precise digital images of the physical environment through the utilisation of methodologies such as laser scanning or photogrammetry. The captured digital models provide a reliable data basis for subsequent planning processes. Two principal approaches have been established for the development of digital models:

- **Scan-to-Mesh:** The Scan-to-mesh process involves the generation of a geometric surface model (mesh). This model frequently comprises thousands of small triangles that are not logically organised geometrically. The absence of semantic information, such as object classes or component properties, is a key feature of this approach, which is primarily employed for the purpose of visualisation. Whilst the initial generation of the data is relatively expeditious, subsequent editing or structuring is time-consuming. [5]

  Analogy (author's own): Scan-to-Mesh is comparable to scanning a text document as an image. Despite the content being visible, it is not possible to structure or edit it.

- **Scan-to-BIM:** Scan-to-BIM facilitates the generation of a BIM model for utilisation within the designated BIM software environment. The model is characterised by the logical organisation of its components and the incorporation of semantic information. The software is utilised for the purpose of meticulous planning and documentation of buildings. The generation process is more intricate than that of Scan-to-Mesh, as the models must possess a higher geometric accuracy and semantic structure. [2]

  Analogy (author's own): Scan-to-BIM is comparable to typing a text document into a word processing program. Despite the increased time investment, this approach facilitates subsequent editing.

1.2 Research Gap

For site planning, components must not only be visualised, but also specifically modifiable. This necessitates the implementation of a Scan-to-BIM workflow. In recent years, Scan-to-BIM has been extensively researched and further developed [6]. The extant literature appears to concentrate principally on the conventional construction sector and the documentation of historic buildings. Despite extensive research, no publications specifically addressing site planning were identified. One potential explanation for this phenomenon may be found in the perceived limited professional relevance of the subject beyond the confines of the specialised field. The application area is situated at a particular intersection of three distinct disciplines: telecommunications, geomatics, and construction (see Fig. 1.1).

However, a separate consideration is warranted due to the distinct requirements of site planning. The necessity for interior structures is negated, and the geometry of the façade can be represented in a highly simplified form. In comparison to the requirements of the conventional building sector, the framework conditions are therefore less complex, which engenders greater potential for automation – a potential that has primarily been realised in Scan-to-Mesh approaches.

1.3 Research Objectives

The aim of this thesis is to develop an automated Scan-to-BIM process for cell site planning. The process is designed to convert a point cloud, i.e. a set of spatial

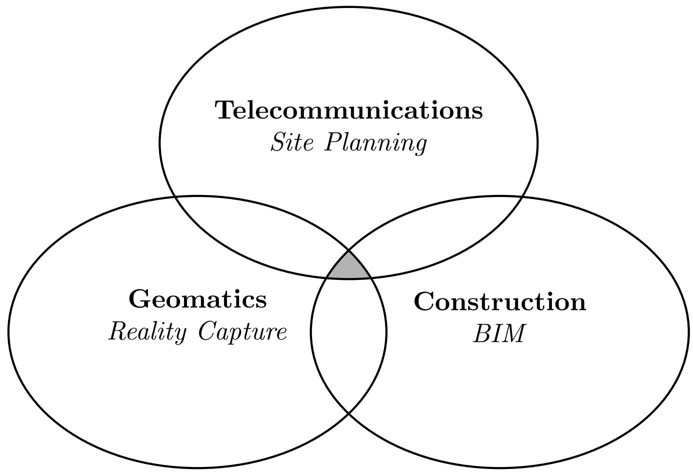

Figure 1.1: Intersection of Disciplines

measurement points, of a building exterior into a BIM model. Consequently, it should be feasible to derive a permit drawing that meets regulatory requirements, as well as a visualization, from the model. The following research questions can be derived from this:

- **Main Question:** How can Scan-to-BIM be automated for telecom rooftop site planning?
  - **Sub-Question 1:** Which steps of Scan-to-BIM can be automated for telecom rooftop site planning?
  - **Sub-Question 2:** Which tools enable Scan-to-BIM automation for telecom rooftop site planning?

Chapter 2

Literature Review

2.1 Cell Site Planning for Telecommunications

Mobile communication can be defined as a sub-area of telecommunications (see Fig. 2.1) that generally concerns the wireless transmission of voice and data. In this context, receivers or transmitters can move freely (e.g., WLAN, Bluetooth, satellite communication) [7]. Cellular communications can be considered a sub-area of this field, in which cellular networks are used [8]. A cellular network is composed of multiple radio cells. The planning of these networks is termed 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]

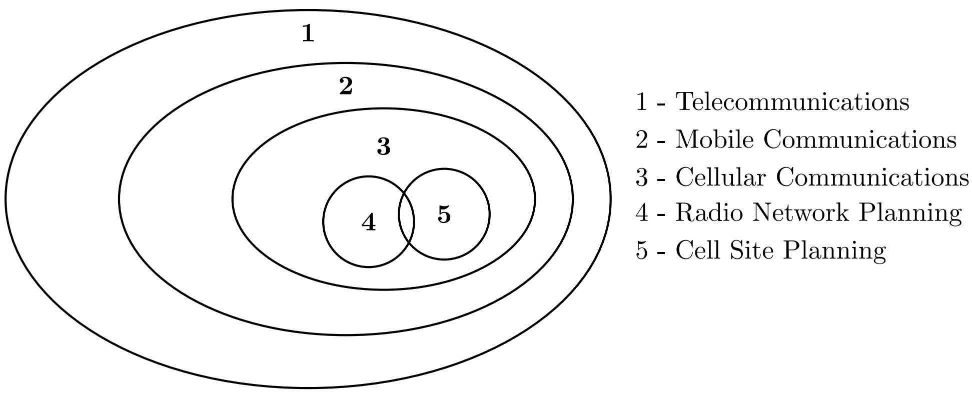

Figure 2.1: Telecommunications Hierarchy (author's own illustration based on [7], [8], [9], [10], [11])

This work focuses on cell site planning. 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 (e.g., ITU, ETSI, 3GPP). Structural topics, on the other hand, depend more on local conditions, which are regulated by practical guidelines and regional standards. For this purpose, a report [16] commissioned by the Federal Council was consulted.

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. [17]

To meet increasing demand, a new generation of mobile network technology is introduced roughly every ten years [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. Newer generations tend to use higher frequency bands, which allow for higher data transmission rates. However, these frequencies are more sensitive to obstacles and have a shorter range. Therefore, more sites are required to achieve the same coverage. [16]

2.1.2 National Status

The Federal Government of Switzerland has expressed the view that a robust telecommunications infrastructure is of significant importance for the nation's economy and society [16]. Consequently, it is vital to facilitate the rapid expansion of powerful 5G networks. According to the operators Swisscom, Sunrise, and Salt, 7,500 new antenna sites and investments of CHF 3.2 billion are required for this expansion [16].

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 [18]. 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) [18]. 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 [19]. Once an installation has attained the maximum permitted transmission power, further expansion is rendered impossible. In order to increase the network capacity, it is necessary to construct additional sites [16].

2.1.3 Site Classification

While in radio network planning the classification by cell size (macrocells, microcells, picocells, femtocells) is common [8], the following classification (see Fig. 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 tower.

- **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.

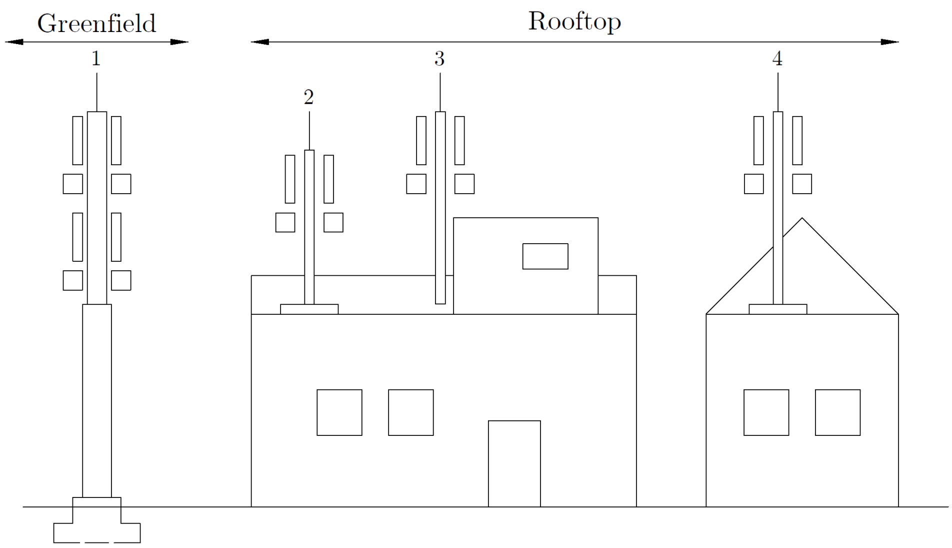

Figure 2.2: Site Classification (author's own illustration)

2.2 Building Information Modeling (BIM)

The term BIM is defined differently [20]. According to National BIM Services USA, BIM stands for the modeling process (Building Information Modeling), the digital representation (Building Information Model) and the overarching organisational process (Building Information Management). In Europe, the ISO 19650-1:2018(E) definition in section 3.3.14 is more widespread:

> **Definition:**
> use of a shared digital representation of a built asset to faciliate design, constructions and operation processes to form a reliable basis for decisions.

BIM is therefore a methodology for the digital planning, execution, and management of buildings throughout their entire life cycle [20]. For clarity, the digital representation is referred to as the BIM model, while the processing environment is referred to as BIM software. The key findings of the literature analysis are summarised below:

2.2.1 Characteristics of a BIM Model

A BIM model, similar to a three-dimensional CAD model, is initially composed of geometric data. In addition to geometric information, the BIM model incorporates further data referred to as semantic properties. A CAD model is typically constituted of an aggregation of geometric primitives, such as points, lines and surfaces. In contrast, a BIM model is composed of object-based components enriched with semantic information. These components include, in addition to their geometric representation, descriptive attributes such as material or cost.

BIM components are generally defined parametrically, meaning that both their geometry and semantic properties can be controlled through adjustable parameters such as length, height, thickness, or type. In addition, components can be linked both semantically (i.e., based on functional or categorical relationships) and topologically (i.e., based on spatial or structural connections) in order to represent functional dependencies as well as constructive relationships within the model.

A completed BIM model allows for the automatic derivation of 2D plan representations (e.g., floor plans, sections, elevations) as well as bills of quantities and material take-offs. Any modifications made to the model are automatically reflected in all associated drawings and documentation. This represents a significant advantage over conventional planning methods, where changes must be implemented manually in each individual plan. [20]

2.2.2 BIM Terminology

A set of standardized terms and key indicators has been established to describe, assess, and compare BIM applications. These serve to systematically capture the information content and level of development of models, as well as the processes within a BIM project. A consistent terminology provides the foundation for clear communication among all project stakeholders and supports the uniform implementation of BIM standards.

This work places particular emphasis on the concepts of Level of Development (LOD) and Level of Information (LOIN), as well as the distinction between BIM use cases and BIM implementation types:

Level of Development (LOD)

No official ISO definition could be found for the term Level of Development (LOD). The non-profit organization BIMForum describes LOD in its *2024 Level of Development (LOD) Specification, Part I* as follows:

> **Description:**
> The Level of Development (LOD) Specification is a reference that enables practitioners in the AEC Industry to specify and articulate with a high degree of clarity the content and reliability of Building Information Models (BIMs) at various stages in the design and construction process.
>
> **Note**
> LOD is sometimes interpreted as Level of Detail rather than Level of Development. Level of Detail is essentially how much detail is included in

> the model element. Level of Development is the degree to which the element's geometry has been thought through – the degree to which project team members may rely on the information when using the model.

The Level of Development refers to the extent to which a model element is developed at a specific stage of a project. It consists of two components: the Level of Geometry (LOG), which defines the degree of geometric detail, and the Level of Information (LOI), which specifies the richness of associated non-graphical data [20]:

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

The Level of Development (LOD) is represented by numerical stages ranging from 100 to 500 (cf. Fig. 2.3). The level of detail increases with higher LOD stages. As the design progresses, the LOD typically advances accordingly.

Figure 2.3: Level of Development (LOD) [21]

Level of Information Need (LOIN)

The term Level of Information Need (LOIN) is defined in *ISO 19650-1:2018(E), Section 3.3.16* as:

> **Definition:**
> Framework which defines the extent and granularity of information.

LOIN thus describes the scope and level of detail of information required for a specific project phase. It serves as the basis for determining the appropriate LOD. The objective is to prevent a BIM model from being either insufficiently or excessively detailed. Excessive detailing would unnecessarily increase the modelling effort and impair efficiency in the planning process. [20]

BIM Use Cases

The term BIM use case is described by the non-profit organization buildingSMART International in its *BIMcert Handbook 2024, Section 3.9.1* as follows:

> **Description:**
> BIM use cases describe the purpose for which data and information are created and used in a digital building model. A use case describes the business case and the ideal scenario, including the objectives and success criteria for information exchange.

A BIM use case thus describes the purpose for which BIM is applied within a specific project or process.

BIM Implementation Forms

Four BIM implementation forms are described by BuildingSMART International in the BIMcert Manual 2024, Section 2.5.3 (cf. Fig. 2.4). These can be distinguished based on two dimensions [20]:

1. **Organisational scope:** Describes the organisational extent of BIM implementation within a project. The scope determines whether the model is used internally only or collaboratively across multiple project participants.

2. **Interoperability:** Describes the ability of different software solutions and project stakeholders to exchange, interpret, and further process BIM data independently of the system used.

A BIM implementation form describes how BIM is organisationally and technically applied within a project. The choice of an implementation form depends on the specific BIM use case, as it defines the requirements for collaboration and information exchange. In general, the use of Big Open BIM is recommended in order to enable interdisciplinary and software-independent cooperation [20].

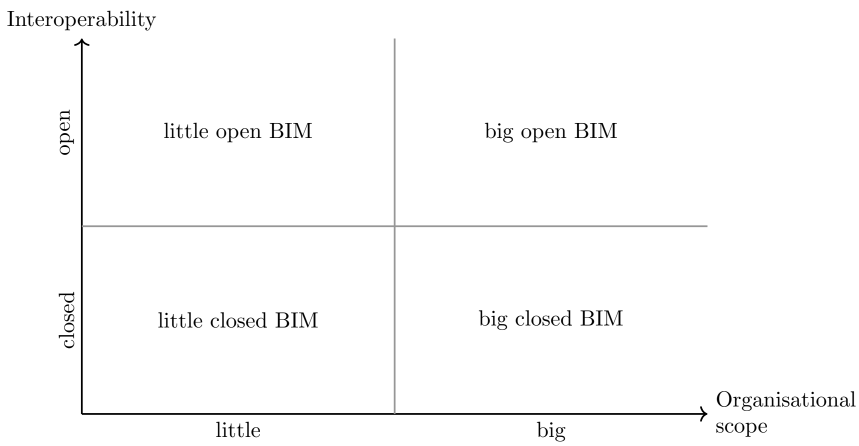

Figure 2.4: BIM implementation forms

2.3 Scan-to-BIM

Refurbishments are becoming increasingly important in the Swiss construction industry. Since 1980, annual construction expenditures for new building projects have remained nearly constant [22], while investments in building renewals have more than tripled over the same period.

In addition, documentation of privately owned existing buildings is frequently incomplete [23], [24]. This applies especially to older structures, which often possess only outdated or partial sets of construction drawings. While permit drawings can often be located in municipal archives, these typically reflect the original design state, are often outdated, and exhibit a low level of detail.

In Switzerland, 81.5 % of buildings were constructed before the year 2000 [25]. Where construction documents are available, they are typically only accessible in paper form. Even for more recent buildings, digital CAD or BIM files are often unavailable. Due to liability concerns, planners are generally reluctant to provide editable data. As a result, building owners are usually given printed plans only, a practice that is legally permissible in the absence of an explicit contractual agreement [26]. In such cases, Scan-to-BIM offers a viable solution for the retrospective digitization of buildings. The following section examines the workflow of the Scan-to-BIM process.

No academic textbooks could be identified that treat Scan-to-BIM as a primary subject. Therefore, the analysis draws on selected academic publications [27], [28], [29], [30], in which the described workflows consist of three to six steps (cf. Tab. 2.1).

Based on the reviewed literature, a consolidated workflow has been derived. It comprises the following five steps: Data Acquisition (1), Preprocessing (2), Geometric Reconstruction (3), Semantic Segmentation (4), and Modeling (5) (see Fig. 2.5). The individual steps are summarized and systematically discussed in the following section.

Publication	**Proposed steps**
[27]	1. Identification of information requirements
	2. Determination of required scan data quality
	3. Scan data acquisition
	4. As-is BIM reconstruction
[28]	1. Classification of considered elements
	2. Determination of required level of detail
	3. Scan data acquisition
	4. Point cloud registration and segmentation
	5. As-built BIM model generation
	6. Analysis
[29]	1. Data acquisition
	2. Data preprocessing
	3. Modeling
[30]	1. Data capture
	2. Semantic segmentation
	3. BIM model

Table 2.1: Proposed Scan-to-BIM Worksflows in Literature

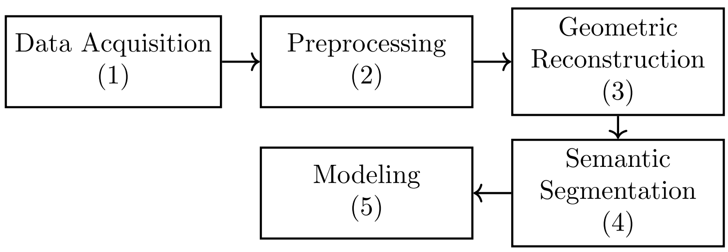

Figure 2.5: Proposed Scan-to-BIM workflow based on literature synthesis

2.3.1 Data Acquisition

Data acquisition is done using reality capture. A physical object is digitally captured and represented using sensors. Two main technologies are used for Scan-to-BIM:

- **Light Detection and Ranging (LiDAR):** LiDAR is an active, direct measurement method for determining distance. The emitter emits laser pulses, which are reflected by objects and received by a detector. The distance is calculated from the measured time of flight. The generation of a point cloud is effected directly as the native output format. [30]

- **Photogrammetry:** Photogrammetry is a passive, indirect measurement method based on the evaluation of overlapping photographs from different perspectives. It is possible to reconstruct point clouds or meshes from image geometry and perspective differences. [30]

LiDAR is generally considered to be more precise than photogrammetry, and it is particularly well-suited for capturing indoor environments and in conditions where lighting is suboptimal. Conversely, photogrammetry does not necessitate the procurement of costly, specialised hardware, thus rendering it a comparatively cost-effective alternative. Its utilisation in conjunction with drones to capture exterior facades is a common practice. [30]
The following formats are frequently utilised as digital representations:

- **Point Cloud:** A point cloud is defined as a set of points in three-dimensional space. Each point corresponds to a surface position (x, y, z) of the scanned object. In addition to the position, further attributes such as colour values (r, g, b) or a normal vector (n_x, n_y, n_z) can be assigned to the points. The normal vector delineates the orientation of the surface at the respective point position and functions as an input parameter for numerous algorithms. In contradistinction to voxel grids, which can be considered the three-dimensional counterpart to a 2D image, the points have no grid structure. The absence of structure renders them more complex to process computationally. Point clouds have been demonstrated to be a particularly suitable data structure for precise analyses. [31]

- **Mesh:** A mesh is defined as a planar three-dimensional representation of an object that consists of a set of corner points (vertices) and their connections (edges and faces). The surfaces are typically delineated as triangles, thus resulting in what is referred to as a triangular mesh. Meshes are particularly well-suited to realistic visualisations. [29]

The subsequent analysis focuses on point clouds. The central quality metrics are as follows:

- **Precision:** Describes the repeatability of measurements and thus the consistency of individual values. [32]

- **Trueness:** Indicates how much the mean of multiple measurements deviates from the actual (true) value. [32]

- **Accuracy:** Refers to the deviation of a single measurement from the true value and results from the combination of precision and trueness. [32]

- **Coverage:** Describes how completely the area or object of interest is represented by the point cloud. It serves as a measure of spatial completeness. [32]

- **Point density:** Indicates the number of points captured per unit area and reflects the level of detail represented in the point cloud. [32]

- **Resolution:** Defines the smallest spatial distance that a sensor system can distinguish. It determines how finely details can be resolved within the point cloud. [32]

2.3.2 Preprocessing

In preprocessing, the point cloud is prepared for further analyses. The following steps are often carried out:

Registration

Registration is the process of transforming multiple point clouds from their own scanner coordinate systems (SCS) into a unified local coordinate system (LCS), followed by the alignment of these point clouds with each other. The objective is to generate a coherent, complete point cloud in which all sub-areas are correctly positioned in relation to each other. [33]

Georeferencing

Georeferencing is the process of converting a point cloud from a local coordinate system (LCS) into a global coordinate system (GCS). The objective is to accurately position the point cloud in relation to real-world coordinates, facilitating its integration with other geodata and enabling further utilisation. Reference points, designated as ground control points (GCPs), are frequently employed for the purpose of georeferencing. These are salient points in the real world whose coordinates are known. The point cloud is then transferred to the GCS using a Helmert transformation (translation, rotation, scaling). The precision of georeferencing is contingent upon the quantity and configuration of the GCPs. [33]

Filtering

Point clouds frequently contain undesirable points that can compromise the integrity of the data. Such aberrations may be attributed to measurement noise, outliers, or the presence of unwanted objects. Filtering is employed to eliminate such undesirable points from the point cloud. The following filters are frequently utilised:

1. **Noise Filter:** Noise is defined as random, small-scale deviations of the measuring points from their actual position. The phenomenon may be attributed to sensor noise, unfavourable surface properties or external influences such as lighting conditions. In order to enhance the quality of the point cloud, the implementation of noise filters is a common practice, with the objective of reducing these deviations or removing the points affected. [31]
   Example: Moving Least Squares Filter (MLS)

2. **Outlier Filter:** Outliers are defined as individual measuring points whose position deviates significantly from the surrounding point distribution and which do not belong to the actual object geometry. Errors in measurement, reflections, or interference during data acquisition are frequently the underlying cause. In order to enhance the quality of the data, the implementation of outlier filters is a common practice, with the objective of identifying and eliminating such points. [31]
   Example: Statistical Outlier Removal Filter (SOR)

Downsampling

Downsampling is a process for the targeted reduction of the number of points within a point cloud. The geometrically essential structures should be retained. The objective is to minimise the data volume to enhance the subsequent point cloud processing efficiency. [31]

Example: Voxel Grid Downsampling, Farthest Point Sampling (FPS), Normal Space Sampling (NSS)

2.3.3 Geometric Reconstruction

Geometric reconstruction is the process of creating a 3D model from a point cloud. The process entails the identification of the geometric structures of the scanned object and their subsequent conversion into a suitable three-dimensional representation. Geometric reconstruction can be classified into two major categories:

1. **Rule-based Methods:** These methods are employed to extract geometric primitives from a point cloud using predefined features. These systems are characterised by the implementation of meticulously delineated algorithms, which govern their operational procedures. It has been demonstrated that these methods are most efficacious when employed with clean, structured point clouds. [34]
   Example: RANSAC, PolyFit

2. **Learning-based Methods:** These methods extract geometric primitives from point clouds based on self-learned features. These approaches require large, annotated training datasets. They offer greater flexibility and can be applied even to unstructured point clouds. However, such methods are computationally more intensive and require more time for processing. [34]
   Example: PointNet++, PointCNN

2.3.4 Semantic Segmentation

Semantic segmentation is the process of dividing a point cloud or mesh into meaning-related classes. The objective is to identify and interpret the geometric characteristics of the scanned object, subsequently assigning them a semantic interpretation (e.g., wall, slab, roof). Segmentation can be categorised as either rule-based or learning-based. [35]

2.3.5 Modeling

Modelling is the process of deriving a structured BIM model from a set of recorded data. The transfer of geometric and semantic information into parameterised components is a fundamental aspect of the process. [29]
Two approaches can be distinguished:

1. **Manual Modeling:** Components are created manually from the point cloud or mesh. This process is time-consuming but particularly advantageous in scenarios where automated methods face limitations, such as with complex geometries. [29]

2. **Automated Modeling:** Algorithms are used to automatically generate components from the point cloud or mesh. This approach is well suited to structured geometries, where clear rules can be defined. [29]

Chapter 3

Methodology

In this chapter, the methodological approach of this work is described. It explains how the Scan-to-BIM framework was developed and which steps were followed in the process.

> Without a framework that is shared by authors, reviewers, and editors, DS research runs the danger of being mistaken for poor-quality empirical research or for practice case study - Peffers et al. [36].

To avoid this, the scientifically grounded Design Science Research Methodology (DSRM) by Peffers et al. [36] is used in this work. This methodology provides a structured framework for systematically developing innovative artifacts while generating scientific insights. The DSRM consists of six steps that can be iteratively traversed if necessary (see Figure 3.1).

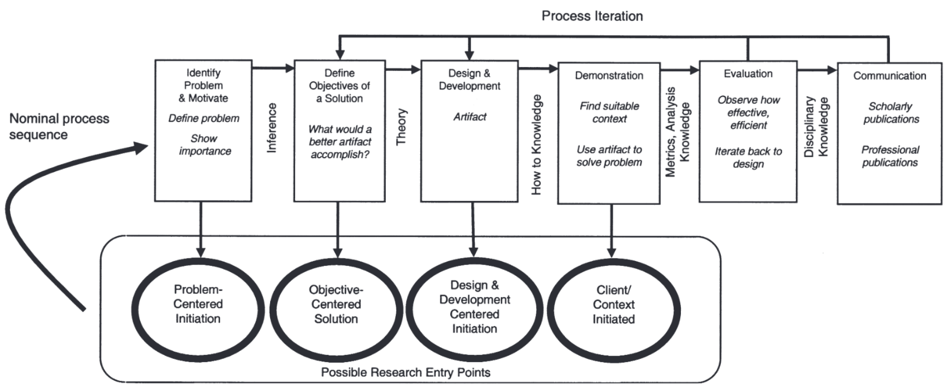

Figure 3.1: Design Science Research Methodology (DSRM) [36]

The implementation of the six steps is carried out within the classic structure of a scientific work. As an artifact, this chapter develops a Scan-to-BIM framework based on the literature analysis. This framework illustrates at a tactical level how an automated Scan-to-BIM workflow could look like. In the next chapter, a Scan-to-BIM pipeline is developed based on the framework. This shows at an operational level that an automated Scan-to-BIM workflow is possible. In the following chapters, the framework is then evaluated.
The following table 3.1 shows the mapping of the DSRM steps to the chapters of this work.

DSRM Step	Thesis Chapter
1. Problem Identification and Motivation	1.2: Research Gap
2. Definition of the Objectives for a Solution	1.3: Research Objectives
3. Design and Development	3.1: Design and Development
4. Demonstration	4: Case Study
5. Evaluation	5: Results
	6: Discussion
6. Communication	7: Conclusion

Table 3.1: Mapping of DSRM steps to thesis chapters

3.1 Design and Development

3.1.1 Data Acquisition

The starting point of the framework is a point cloud that contains information about the entire outer shell of the building to be modeled. If the building is part of a larger point cloud, it must first be isolated.

Due to the high acquisition speed and often better coverage, the use of a drone for data acquisition is recommended. Requirements for the quality metrics of the point cloud were not systematically investigated. However, given the preprocessing steps and the already high level of generalization in geometric reconstruction, it can be assumed that most point clouds captured with current drones will meet the requirements.

Since missing areas cannot be reconstructed, coverage is to be considered the central quality criterion of the point cloud. In addition, trueness is likely to be more relevant than precision, as outliers are removed during preprocessing and point positions are smoothed or averaged. A particularly high point density can be dispensed with, as the number of points in average-sized buildings must be reduced anyway to ensure the convergence of geometric reconstruction.

3.1.2 Preprocessing

For preprocessing the point clouds, the use of an outlier filter and downsampling is recommended.

The effectiveness of an outlier filter was not systematically investigated in this work, but its use generally seems reasonable, as gross errors can affect the trueness of the reconstruction.

Downsampling, on the other hand, is essential, as the runtime of geometric reconstruction increases superlinearly with the number of points. In average-sized buildings, this can lead to runtime overruns or instabilities during geometric reconstruction without reducing point density.

The two preprocessing steps will be described in detail below:

Statistical Outlier Removal (SOR)

Statistical Outlier Removal removes points that are significantly further away from their neighbors than the average. For each point $i = 1, \ldots, n$, a local neighborhood model is calculated with k nearest points, and the distances d_{ij} to the neighbors $j = 1, \ldots, k$ are determined.

The mean distance μ and the standard deviation σ of the point-neighbor distances are given by:

$$\mu = \frac{1}{nk}\sum_{i=1}^{n}\sum_{j=1}^{k} d_{ij}, \quad \sigma = \sqrt{\frac{1}{nk}\sum_{i=1}^{n}\sum_{j=1}^{k}(d_{ij}-\mu)^2}$$

A point is removed if its average neighbor distance lies outside a defined range. For example, a point i is removed as an outlier if:

$$\bar{d}_i > \mu + \alpha \cdot \sigma$$

where $\bar{d}_i$ is the average distance of point i to its k neighbors and α is a freely selectable threshold (typically e.g. $\alpha = 1.0$-2.0). [31]

Voxel Grid Downsampling

Voxel Grid Downsampling reduces the number of points in a point cloud by dividing the space into a regular 3D grid (voxel grid) with a fixed cell size r. Within each voxel cell, a representative point is determined (e.g., randomly, center, or centroid), which replaces the remaining points.

First, the minimum and maximum coordinates are determined:

$$x_{\min} = \min(x_1, \ldots, x_n), \quad x_{\max} = \max(x_1, \ldots, x_n)$$

Similarly for y and z.

Each point $p_i = (x_i, y_i, z_i)$ is then assigned to a voxel cell using the discrete index

$$i_x = \left\lfloor \frac{x_i - x_{\min}}{r} \right\rfloor, \quad i_y = \left\lfloor \frac{y_i - y_{\min}}{r} \right\rfloor, \quad i_z = \left\lfloor \frac{z_i - z_{\min}}{r} \right\rfloor$$

Exactly one point is retained per cell to approximate the point cloud. [31]

3.1.3 Geometric Reconstruction

For geometric reconstruction, the framework *PolyFit* by Nan et al. **nanPolyFitFramework2023** is proposed. It extracts connected planar surface regions from a point cloud and reconstructs them as a triangulated but globally planar mesh. The mesh is manifold (topologically correct) and watertight, meaning it has no holes and no overlapping surfaces. The framework focuses on reconstructing flat surfaces, making it suitable for most applications in construction, as most building components like walls, ceilings, and floors are flat. However, it is not suitable for curved geometries. It should also be noted that the components themselves are not modeled, but rather the envelopes defined by their surfaces.

The framework is implemented in C++ and publicly available on GitHub [37]. Initially, planes in the point cloud are identified using the RANSAC (Random Sample Consensus) algorithm. Similar planes are merged to obtain robust surfaces. Pairwise intersections of the planes create polygonal surfaces. Binary linear optimization selects a subset from a set of candidate surfaces $F = \{f_1, f_2, \ldots, f_N\}$ that best describes the point cloud while forming a compact, topologically correct model.

Objective Function:

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

Explanation:

- $\mathbf{x} = (x_1, \ldots, x_N)$ is a vector of binary decision variables:

$$x_i = \begin{cases} 1, & \text{if surface } f_i \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$$

- E_f: *Data Fit* - prefers surfaces that fit well to the point cloud.
- E_m: *Model Complexity* - penalizes sharp edges and small details.
- E_c: *Point Coverage* - prefers surfaces that cover as many points as possible.
- λ_f, λ_m, λ_c: weighting factors to control the influence of these terms.

Constraints:

$$\sum_{j \in \mathcal{N}(e_i)} x_j \in \{0, 2\} \quad \forall e_i \in E$$

- Each edge e_i must either not be used at all or be used by exactly two surfaces to ensure a *manifold* and *watertight* model.

$$x_i \in \{0, 1\} \quad \forall i = 1, \ldots, N$$

- Binary decision: surface is either included or discarded.

3.1.4 Semantic Segmentation

In order to transfer the mesh from the geometric reconstruction into a BIM model, the surfaces must first be semantically segmented. This means that the surfaces need to be assigned to the corresponding building components. A custom rule-based segmentation method is applied, based on the properties of the surfaces. The segmentation is performed in two steps:

1. **Feature Extraction:** First, the mesh model is oriented so that the largest surface lies in the x-y plane. Then, for each surface of the mesh, the associated normal vector is calculated, which describes the spatial orientation of the surface.

2. **Classification:** The surfaces are then classified based on the orientation of their normal vectors into the following classes:

$$\text{SurfaceType}(n_i) = \begin{cases} \text{Wall}, & \text{if } |\hat{z}_i| \approx 0 \\ \text{Slab}, & \text{if } \sqrt{\hat{x}_i^2 + \hat{y}_i^2} \approx 0 \\ \text{Roof}, & \text{otherwise} \end{cases}$$

   where n_i is the normal vector of surface i and $\hat{x}_i$, $\hat{y}_i$, $\hat{z}_i$ are the normalized components of the vector. Horizontal surfaces are classified as slabs, vertical surfaces as walls, and inclined surfaces as roofs.

3.1.5 Modeling

In the final step, the semantically segmented mesh is converted into a BIM model. The following approach is recommended:

1. **Automated Modeling:** For each surface of the mesh, a corresponding building component is automatically created in the BIM model. The geometry and relevant properties are extracted from the mesh and transferred to the BIM model. The assignment to a building component type (e.g., wall) is based on the previously defined classes from the segmentation.

   For software-independent implementation, it is recommended to use the IFC interface. This allows for standardized transfer of geometry and building component properties and ensures interoperability between different BIM systems.

   If the downstream BIM software does not fully support IFC, the API of the respective software can be used to programmatically create the components. In cases where IFC support is limited, conversion to a native format of the target software is recommended. This process can be automated using visual scripting environments for parametric design, which are integrated into many BIM platforms.

   Each building component type (e.g., wall) can be assigned a specific building component type (e.g., concrete 25 cm). Native modeling allows for better integration into the respective software environment and facilitates subsequent editing, analysis, and reuse of the generated components.

   At the end of this step, a complete BIM model in LOD 200 should be available.

2. **Manual Modeling:** Depending on the application case, a higher level of detail may be required. In this case, it is recommended to use the automatically generated model as a starting point and then make manual adjustments. This includes adding windows, doors, or other architectural elements that could not be automatically reconstructed from the point cloud. The assignment or adjustment of building component types and properties can also take place in this step to meet project-specific requirements.

   From this extended model, plans and visualizations can then be derived for use in further planning and execution of the construction project.

Chapter 4

Case Study

To demonstrate and evaluate the effectiveness of the developed framework under real-world conditions, a case study was conducted. A pipeline was developed based on the previously established framework.

The case study was carried out in collaboration with Axians, an internationally operating ICT company. The goal was to extract a residential building from a given point cloud, model it as automated as possible, and subsequently derive the plans required for a building application.

4.1 Data Acquisition

The data acquisition was carried out by Axians. Therefore, the design of the acquisition was not part of the case study. The aerial images were captured using a DJI Mavic 3 Enterprise drone. The photogrammetrically generated point cloud covered an area of approximately 700 x 500 m and contained around 33.1 million points.

Specification	**Value**
Camera Model	DJI M3E (integrated)
Sensor Size	4/3" CMOS
Effective Resolution	20 MP (5280 x 3956 pixels)
RTK Support	Yes (integrated RTK module)

Table 4.1: Key camera specifications of the DJI Mavic 3 Enterprise (M3E) [38]

4.2 Preprocessing

First, the target building was isolated using the open-source tool *CloudCompare*. The segmentation was performed manually by drawing a box around the building in the top view with approximately 1 m distance. This reduced the point count to about 780,000 points.

Next, the point cloud was cleaned using a Statistical Outlier Removal (SOR) filter implemented in Python. Points were removed if their average distance to the 20 nearest neighbors was greater than the global mean of these distances plus two standard deviations. This removed approximately 35,000 points, resulting in a reduction of about 4.5%. The remaining point cloud contained around 745,000 points.

Subsequently, the point cloud was further reduced using voxel grid downsampling. It was observed that the mesh generated by geometric reconstruction depends on the number of points and thus indirectly on the chosen voxel size. The voxel size can therefore be considered an additional parameter for controlling the geometric reconstruction, alongside the three PolyFit-internal lambda weights. Since it proved to be the most influential factor in the case study, only the voxel size was considered as a hyperparameter.

4.3 Geometric Reconstruction

The geometric reconstruction was performed using the PolyFit framework in Python. The source code, written in C++, is available on GitHub [37]. To utilize the functions in Python, a corresponding Python binding was created using CMake. Additionally, the Python library *Easy3D*, also developed at TU Delft, was required for the first step of the PolyFit workflow - surface extraction using RANSAC [39].

Since the bindings need to be manually compiled for the target platform (operating system and Python version), the setup process is relatively complex. Therefore, the developed script cannot be easily adopted by other users, which currently limits the productive use of the pipeline.

No invariant parameters were found for the geometric reconstruction that reliably produce good mesh models for different buildings. Therefore, a brute-force approach was chosen, where the voxel size was iterated to generate a variety of mesh models. The model with the subjective best quality was then selected. This model was created from a point cloud with approximately 87,000 points, which corresponds to about one-tenth of the original point cloud. For point counts above approximately 150,000 points, the optimization problem became too complex and led to program termination. The open-source solver SCIP was used for the calculations. The commercial Gurobi solver is available free of charge for scientific projects and is expected to offer better performance [37], potentially allowing for a higher point count. However, since the model quality already reached its maximum at around 87,000 points, the Gurobi solver was not tested.

4.4 Semantic Segmentation

The semantic segmentation was performed using the framework described in Chapter **??**, which was implemented in Python. The surfaces were identified, segmented, and each exported as .obj files. The associated classification was encoded in the filename to avoid the use of additional auxiliary files.

4.5 Modeling

The first part of the automated modeling, the creation of the IFC model, was done in Python. The library *ifcopenshell* was used, which provides an interface for the IFC data structure [40]. The .obj files of the segmented surfaces were read in and integrated into the IFC model. The IFC model was then exported as an .ifc file, creating a base model that can be further processed in various BIM software solutions.

The second part of the automated modeling, the parameterization of the IFC components, was done in the BIM software *Revit* by *Autodesk*. The IFC model was imported and manually parameterized using Revit functions. This workflow was then automated with *Dynamo*, a visual programming environment that has been integrated into *Revit* since 2020 [41].

At this point, the created model was expected to have a Level of Detail (LoD) of 200. Since it was unclear whether the model already met the requirements for building application plans, the Building Permit Office of the City of Zurich was contacted for a general assessment.

> When approving mobile radio installations, different design requirements must be observed depending on location and zone. Therefore, a pure volume model is not sufficient. All structuring elements must also be represented in the elevations. [42]

The response from the building authority indicated that the model in its current form did not meet the requirements for building application plans. It was therefore decided to raise the model to LoD 300.

The refinement of the model was then carried out manually in *Revit*. Windows and balcony railings were integrated into the model. The inserted components were only for illustrative purposes and were not positioned precisely. To keep the effort minimal, pre-installed Revit families were used for the windows. The balcony railings were modeled as simple walls. Additionally, improvements were limited to the two views presented in the building application plans. The roof area was also improved by modeling the missing roof structure, which is relevant for both building application plans and technical facility planning. For representing antenna masts, a Revit family already provided by Axians was used.

Finally, the building application plans were generated from the model using a predefined plan layout. No adjustments were made, as the plans were only for illustrative purposes. A visualization of the model was also created. An environmental model was generated in *Infraworks*, which could be imported into *Revit* via *Navisworks*.

Chapter 5

Results

This chapter presents the results of the case study. It shows what has been created through the application of the framework. The primary result is the BIM model derived from a point cloud. Secondary results include the permit drawing and an animation derived from the BIM model.

5.1 BIM-Model

The IFC model of the five-story residential building, with approximate dimensions of 28 × 17 × 16 m (length × width × height), consists of a total of 14 components. Among these are nine walls (`IfcWall`), four slabs (`IfcSlab`), and one roof (`IfcRoof`).

The components are modeled as two-dimensional surfaces in three-dimensional space. The ground slab lies in the XY-plane at height 0. Millimeters were used as the length unit. The components are not parametrically modeled; their geometry cannot be directly modified in the model.

The generated geometry is *manifold* and *watertight*, meaning it is topologically consistent and closed. The model corresponds to a Level of Detail (LOD) of 200.

For the manually improved BIM model, 8 balcony railings, 24 windows, 1 door, 1 roof structure, and 2 antenna masts including RAN equipment were added. One of the predefined window families could be integrated into the IFC walls, so parameterization was omitted. Since the roof slab is not perfectly horizontal, the pavement slabs were adjusted to the slab's course in discrete height steps. The surrounding model represents the approximate terrain and strongly generalized buildings in the vicinity.

5.2 Permit Drawing

The permit drawing was derived from the BIM model and corresponds to the current industry practice in Switzerland. An A3 layout was chosen, consisting of a plan view and two elevations at a scale of 1:200. Additionally, two rendered visualizations were included.

The building dimensions were dimensioned. The mast center was measured from the building edge. Sector designation for the main beam directions was omitted. The plan header comes from an Autodesk template, and the plan header data was not modified.

5.3 Animation

The animation shows a camera tour around the modeled building. Due to technical limitations, the surrounding model could not be rendered. The textures used are simple but allow for a basic spatial representation of the overall scene.

Chapter 6

Discussion

6.1 Evaluation

A comprehensive evaluation of the case study was excluded from the beginning due to time constraints. A ground-truth validation of the model did not take place. Therefore, the evaluation was limited to the following three aspects:

6.1.1 PolyFit Runtime Analysis

To analyze the behavior of the PolyFit algorithm, a runtime analysis was conducted during the development phase. This was performed on an Intel Core i7-9700K 3.60 GHz processor with 32 GB RAM. The runtime was measured for various point cloud sizes.

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6.1.2 Model Quality

To assess the model quality, a purely qualitative analysis was conducted. Both the geometric and semantic quality were evaluated.

Geometric Quality

The geometric quality was assessed based on the visual consistency of the components. The characteristic shape of the building was well represented in the model. No conclusive statement could be made regarding geometric accuracy. The Building Permit Office did not specify concrete accuracy requirements. In practice, a guideline accuracy tolerance of 10 cm is aimed for. It is doubted whether this tolerance was met. A high variation of the generated models was observed, and reproducibility was low. Even with consistent parameters, different models were sometimes generated. It is suspected that the low precision may be due to the non-deterministic RANSAC algorithm or an ambiguity in the optimization problem. Ultimately, the low precision leads to low geometric accuracy.

In addition to geometric accuracy, the completeness of the model is also important. It was observed that some components considered relevant were not included in the model, such as the shaft head.

Another challenge was geometric imperfections. It is assumed that the slabs are slightly less parallel to each other than in the actual building. Additionally, the walls show an unsystematic inclination. While these imperfections may be negligible for permit purposes, they can limit the usability of parameterized components. This seems plausible since, for example, an inclined wall cannot be represented solely by a base line and a corresponding height. Without usability, the component cannot be geometrically adjusted, which can significantly restrict its practical use.

Semantic Quality

The semantic quality of the model was assessed based on the correct classification of the components. Correct classification of components is particularly important for automated parameterization. The 14 components were correctly classified, with the exception of one inaccurately reconstructed wall. The wall was modeled at an angle, resulting in a normal vector with a z-component, which led to its classification as a roof (`IfcRoof`). Thus, the semantic quality is strongly dependent on the geometric quality.

6.1.3 Transferability to other buildings

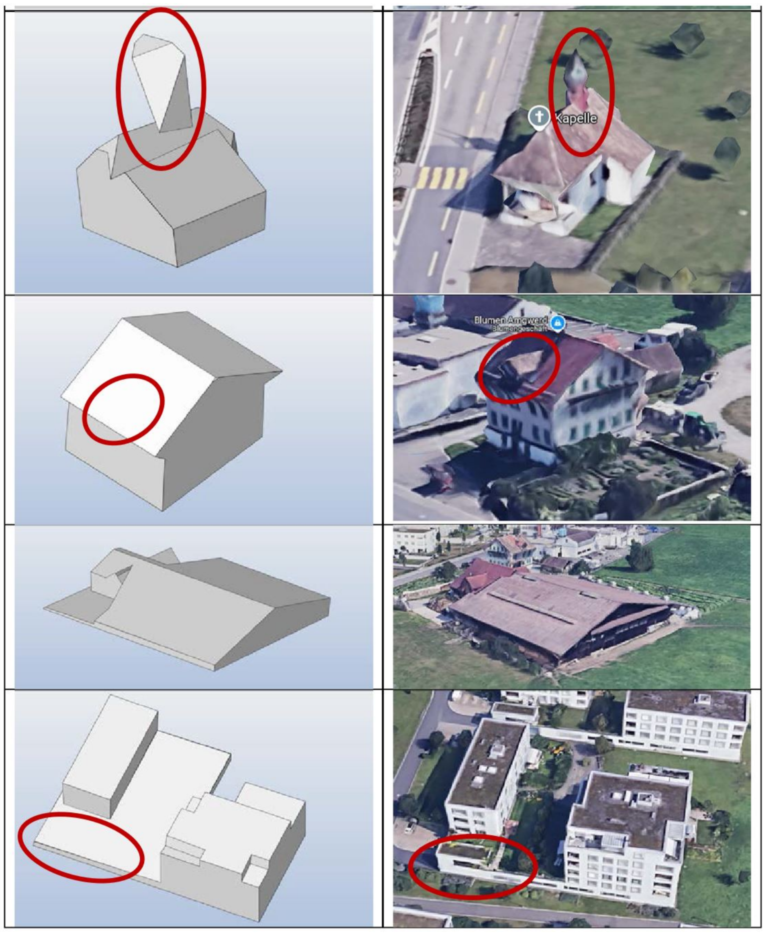

Figure 6.1: Transferability to other building types

To test the transferability of the developed framework to different building types, four buildings were reconstructed as examples, and the results were qualitatively evaluated. The buildings modeled include a chapel (1), a single-family house with a gable roof (2), an agricultural hall building (3), and a modern residential complex (4). The results are shown in Figure 6.1.

1. The weakest result was achieved with building 1. The reconstruction of the round tower top led to geometric artifacts. The characteristic shape of the building could only be inadequately represented in the model.

2. Buildings 2 to 4 were generally reconstructed well, although in models 2 and 4, significant components were lost due to generalization.

Overall, it was shown that the framework is fundamentally applicable to different building types. The results suggest that large-area buildings with simple geometries can be reconstructed more reliably.

6.2 Limitations

The developed framework still has some limitations that may restrict its applicability in practice. The limitations can be categorized based on their origin.

Limitations in Geometric Reconstruction

The biggest limitation is currently related to geometric reconstruction. At the same time, it is the most complex part of the framework, contributed by scientific research, and is unlikely to be optimized further. Limitations associated with this are:

- The framework can only be applied to isolated, individual buildings.
- The framework cannot be reliably applied to curved or complex geometries. What constitutes a complex geometry could not be conclusively defined and must be assessed on a case-by-case basis.
- The framework likely does not meet the accuracy requirements of 10 cm demanded in practice.
- The framework has low reproducibility. The variation of generated models is high. Subjective decisions must be made, further limiting reproducibility.
- The framework leads to geometrically imperfect models. These imperfections can complicate modeling and restrict parameterization.

Limitations in Automation

The automation of the framework is currently incomplete. Manual adjustments must be made to obtain a usable BIM model. These limitations are:

- The framework could not be fully automated. Manual adjustments are necessary to obtain a usable BIM model.
- The framework can currently only generate automated IFC models. The generation of parameterized models is not possible at this time.

Limitations in Usability and Integration

The framework was developed for the case study and not for productive use, leading to further limitations:

- The framework cannot currently be deployed efficiently. Dependencies lead to increased setup effort. Installation requires basic knowledge of Python tooling.

- The framework is not intuitively usable. It consists of several Python scripts, where hyperparameters must still be adjusted in case of poor performance. A technical documentation is missing.
- The framework requires knowledge of manual BIM modeling. Without corresponding knowledge, only an IFC model can be generated with the framework.
- The framework can currently only be applied to .ply point cloud formats. Other point cloud formats are not supported.

6.3 Future Work

The limitations of the framework significantly restrict its applicability in practice. To optimize the framework for productive use, the following points should be addressed:

Future Work in Geometric Reconstruction

The contribution of limitations from geometric reconstruction is overall considered the highest and should therefore be prioritized. At the same time, it is the most complex part of the framework, stemming from research. The likelihood of optimizing the actual algorithm is deemed unrealistic. It is therefore recommended to try alternative tools for geometric reconstruction. Thanks to the modular structure of the framework, tools can be replaced without affecting other parts. Methods based on assumptions like the "Manhattan Assumption" can be promising here. This assumption leads to the geometry of the building being limited to right-angled components, which is likely applicable to many buildings and should result in clean models. For future implementations, the following is recommended:

- **High Priority:** Replace PolyFit with an alternative tool. [43] looks promising based on initial analysis, but accessibility of the source code needs to be verified.
- **High Priority:** Alternatively, it is recommended to contact the developer of PolyFit, Professor Dr. Liangliang Nan from TU Delft. He has been helpful during implementation and could provide valuable insights into potential alternatives.

Future Work in Automation

The automation of the framework is currently incomplete. It is recommended to further advance the automation. The automatic parameterization of the IFC model with Dynamo is considered feasible with little effort. A complete automation beyond that would likely only be achievable with the use of learning-based methods, which would probably require a fundamental redesign of the framework. For future implementations, the following is recommended:

- **Medium Priority:** Automation of the parameterization of the IFC model with Dynamo.
- **Low Priority:** Exploration of learning-based approaches with neural networks, which could be part of a master's thesis.

Future Work in Usability and Integration

If the challenges of geometric reconstruction can be addressed, productive use can be considered. The usability and integration of the framework are currently insufficient and need to be improved. One possible approach is to integrate it into a web service that accepts the point cloud and generates an IFC model from it. This would allow global access to the framework without installation. A graphical user interface (GUI) could visualize the models and assist in finding optimal hyperparameters. For future implementations, the following is recommended:

- **Medium Priority:** Integration of the framework into a web service that accepts the point cloud and generates the IFC model.

Chapter 7

Conclusion

In this thesis, a process was developed that enables the generation of a BIM model from a point cloud. Based on the Design Science Research Methodology (DSRM), a corresponding framework was designed, implemented as a pipeline, and demonstrated in a case study in collaboration with Axians. The case study exemplified that the framework is fundamentally capable of producing a BIM model. This not only answered whether automation is possible but also how it can be concretely realized.

A five-step process was proposed, consisting of *Data Acquisition (1)*, *Preprocessing (2)*, *Geometric Segmentation (3)*, *Semantic Segmentation (4)*, and *Modeling (5)*. With the exception of data acquisition and parts of modeling, the steps were successfully automated. Tools such as *CloudCompare*, *Python*, *Revit*, and *Dynamo* were employed.

Throughout the work, several challenges were identified that currently limit practical applicability. These can be categorized into three areas: *Geometric Reconstruction (1)*, *Automation (2)*, and *Usability and Integration (3)*. Targeted solutions were formulated for each category. If geometric reconstruction continues to improve, the productive use of the framework in site planning for telecommunications equipment appears realistic. This would contribute to increased efficiency in the construction industry.

Data Availability Statement

The source code of this thesis will be published on GitHub at the end of July 2025. A technical documentation will not be provided. The point cloud used as the basis for the case study was provided by Axians and will therefore not be publicly accessible. Questions can be sent via email to leisij@student.ethz.ch.

Conflicts of Interest

The collaboration with Axians was part of a supervised practical project. There was no financial compensation or contractual influence on the content or results of this work.

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Appendix

Appendix A – Drawings

This appendix contains the technical drawings used in the evaluation.

Appendix B – Framework

This file contains the framework model as referenced in Chapter 4.

Appendix C – Pipeline

This appendix includes the detailed data pipeline used in the case study.