# Scan to BIM: virtual reconstruction of a historic building using BIM (H-BIM)

Master Thesis

International Master of Science in Construction and Real Estate Management
Joint Study Programme of Metropolia UAS and HTW Berlin

## Faculty 2

from


Mehrzad Vali Yousefi

(S0568004)


Date:

Berlin, 30.10.2020

1st Supervisor: Prof. Dr.-Ing. Markus Krämer
2nd Supervisor: M.S Zsuzsa Besenyöi

***Acknowledgement***

*Firstly, I would like to express my sincere gratitude to my first supervisor Prof. Dr.-ING Markus Krämer for his continues support, patience and motivation prompting me to complete the thesis. I am also grateful for his insights and revisions on my project.*

*I would like to thank my dear second supervisor, M.S Zsuzsa Beseyöi, whose inspirational guidance and advice helped me to improve my study. I would also like to appreciate all my professors of HTW Berlin University and also Metropolia University in Finland, for their valuable and informative teachings.*

*I like to express my very profound gratitude to the most impressive person in my life that this accomplishment would not have been possible without her, my dear aunt Mrs Minou Baghini.*

*Finally, I must say special thanks to my beloved and warmhearted family and friends for their endless encouragement and support.*

## Conceptual formulation

**International Master of Science in Construction and Real Estate Management**
**Joint Study Program of Metropolia Helsinki and HTW Berlin**
**Date 26.06.2019**
**Conceptual Formulation**
**Master Thesis for** Ms. Mehrzad Vali Yousefi
**Student number:** S0568004
**Topic:** Scan to BIM: virtual reconstruction of a historic building using BIM (H-BIM)

---

## Introduction

Historical works and buildings clearly show the identity, architecture, culture, and lifestyle of people for a period of time and will be available to the next generations as a treasure trove. Cultural heritages are divided in two parts; tangible heritages have a physical dimension and include a variety of historical works and buildings, and intangible heritages include the creators of historical, artistic, scientific and other works such as artists and elites. It should be noted that the protection of these works not only plays a vital role in the registration of the national identity of the community but also serves as an element of income for its economy.

Different types and forms of technologies have been part of the built heritage and the evolution of such technologies have brought about several modeling tools; among is Building Information Modeling (BIM), which is a digital representation of physical and functional characteristics of a building. Today, there is a huge need for highly skilled professionals to successfully implement BIM in heritage projects. The reconstruction of historical buildings relies on a series of activities such as measuring and surveying, drafting and modeling, and post-construction management. In contrast to traditional

methods of survey and measurement using manual tape and photographing, digital documentation such as laser scanning and photogrammetry has gained more attention amongst scholars and professionals.

## Aim and advance

The purpose of this research is to outline in detail the procedure of harvesting data in heritage preservation using laser scanning, photogrammetry and point cloud methods. Once the geometry of the building is extracted, BIM is used to translate the harvested data to engineering drawings and 3D representations.
The result can be used in a wide range of applications such as education, maintaining, reconstruction, job vacancy creating, virtual tour for tourism and preserving the historical background of a community and facility management. The facility management part is substantial in this case. Considering that all of the historic buildings need to be safe and caring them for the futures is necessary, so we should know more about those buildings. Hence, scan to BIM helps to know more about the constructions work to find the best solving solution for the problems in the emergency time.

## Research Questions

- What are the state-of-the-art methods for digital documentation of built heritage
- How can a part of a historic building or site be reconstructed and depicted
- What are the potential uses of these reconstructed virtual models in Historical buildings

## Methodology

To answer the research questions, we first review and identify documentation methods according to the size and condition of the heritage project. This is followed by a discussion of the essential steps involved in a virtual reconstruction of buildings such as building material, information about the architect, geometric analysis of the project, materials and textures attribution, urban contexts and assembly of virtual and remaining building

elements. The implementation of heritage buildings (H-BIM) methods on an old building or site is demonstrated in the form of the case study to describe better the steps taken to the virtual reconstruction of the historic building. It should be noted that this technique can also be used to redesign all buildings and their components in the road construction, mapping, urbanization, and construction and maintenance of buildings. In this thesis, we investigate various stages of using BIM in H-BIM and modelling and documenting the built heritage with photogrammetry and point cloud method.

Signature of the supervisor

## Abstract

World Heritage is classified into the three groups natural, cultural, and underwater heritage according to what is proclaimed by UNESCO. Cultural heritage includes tangible and intangible culture (UNESCO, 2020). It has been more than two decades that preservation, visualization, and documentation of architectural heritage, by means of developing digital technologies in architectural science, have been brought to the fore.

Nowadays, it has been attempted to save the historical sites by these approaches. Needless to say, inconsistency and disorganization in the data gathered to result in human errors in some parts of the process which would detrimentally impact on the accuracy and cost of the project as well as the time consumed on work. There are different tools and approaches which can facilitate the process. Architecture, engineering, and construction field have been developed to build improved structures through BIM technology; therefore, it assists them to preserve the cultural and historical heritage. Historical building information management (HBIM) is a new approach that is spreading into intricate modelling of historical heritage by the use of BIM in the context of its documentation, perception, reconstruction and maintenance of buildings.

This modern technology enables the analysis of information through BIM for data assimilation of the remained technical reports, ancient manuscripts, old archived maps, ground and aerial laser scans and photogrammetry in order to design a tangible model of the building to be utilized in different fields as in facility management (FM), virtualization and future technologies.

The aim of this research is threefold; firstly, it attempts to specify the definitions in the context of HBIM; secondly, it attempts to analyze the various concepts in the context of novel methods of maintenance and documentation of historical buildings. Finally, by drawing on the parallel studies in the similar contexts, and the technological apparatuses which discussed earlier, it is aiming to reach at a methodology with enhanced quality and certitude for model building with precise details.

This thesis is studying the museum building of Berlin Naturkundemuseum, which has been modelled and documented with Trimble TX8 laser scanner. In the end, the results of this study, along with other parallel studies, will be presented, and then the limitations, as well as the future perspective of the study, will be discussed. It is also important to mention that the final results of the case study will be saved in *.RVT, *. E57,

*.LAS and IFC formats in order to be used for further studies, maintenance, renovation and documentation of the building.

**Key words**: BIM, building information modeling, Facility management, laser scanning, point cloud data, Historical building information management (HBIM), As-built.

# Table of Contents

## Table of Figures

## List of Tabulations

## List of Abbreviations

| | |
|---|---|
| AR | Augment reality |
| BIM | Building information modeling |
| CMMS | Computerized maintenance management system |
| CMP | Conservation Management Plan |
| COBie | Construction Operations Building information exchange |
| Fig. | Figure |
| FM | Facility Management |
| GDL | Geometric Descriptive Language |
| GSA | General Service Administration |
| H-BIM | historical building information modeling |
| ICOMOS | International Council on Monuments and Sites |
| IAI | International Alliance for Interoperability |
| LADAR | Laser Detection And Ranging |
| LOD | Level of detail |
| LOG | Level Of Geometry |
| LOI | Level of Information |
| NKM | Naturkundemuseum |
| PCD | Point cloud data |
| PS | Phase Shift |
| PB | Phase Base |
| TLS | Terrestrial Laser Scanners |
| TOF | Time of Flight |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| VR | Virtual Reality |

# 1. Introduction

Historical works and buildings clearly show the identity, architecture, culture, and lifestyle of people for a period of time and will be available to the next generations as a treasure trove. Cultural heritages are divided in two parts; tangible heritages have a physical dimension and include a variety of historical works and buildings, and intangible heritages include the creators of historic al, artistic, scientific and other works such as artists and elites. It should be noted that the protection of these works not only plays a vital role in the registration of the national identity of the community but also serves as an element of income for its economy.

Different types and forms of technologies have been part of the built heritage and the evolution of such technologies have brought about several modeling tools; among is Building Information Modeling (BIM), which is a digital representation of physical and functional characteristics of a building. Today, there is a huge need for highly skilled professionals to successfully implement BIM in heritage projects. The reconstruction of historical buildings relies on a series of activities such as measuring and surveying, drafting and modeling, and post construction management. In contrast to traditional methods of survey and measurement using manual tape and photographing, digital documentation such as laser scanning and photogrammetry has gained more attention amongst scholars and professionals. (Borrmann, et al., 2018)

## 1.1 Problem description

Historical buildings, regardless of their physical (object) dimensions, have other dimensions that keep historical, cultural, and artistic and all non-material values.

The first and inevitable attention to the body of the building in many restorations has caused less attention to be paid to these non-physical dimensions. This is especially important because the character, value, historical role, cultural expression, and other values of a building; these are the parts of building that give identity to it and keep it alive; So that the maintenance operation makes sense. There are methods and sets of human activities for the protection and maintenance of historical buildings that are generally influenced by factors such as geographical history, ethnicity, culture, and conservation technologies. Maintenance of these kinds of buildings has a wide range

of method that is under facility management tasks, for restorations needs to use the high level of detail LOD information of the building which restorer be able to use them to continue their work. Moreover, remodel the historical building regarding the facility management needs a very high accuracy in details and structure information. Hence, Historical building due to the rough accessibility situations and many obstacles that covered the places for achieving the building details are in specific cases and needs to use a proper approach instead of traditionally procedures.

If carried out traditionally, that is semi-automatically it would take a more significant amount of time and endeavor for the implementation. (Krämer & Besenyoi, 2018)

In the majority of the practices going on at present, what restricts the totality of the project is the fact that the required information for the advancement of as-built BIM is gathered after the final stages of the construction. Since, part of the building elements and components are in fact buried and hidden inside, data collection for these components is not possible. Accordingly, several researchers have suggested to collect this information on the process so as to achieve a more accurate modeling of as-built construction. However, there are numerous other factors to be thought of when discussing the notion of incompleteness in the domain of construction application. (Liu, et al., 2012)

## 1.2 Aim and advance

Preserving the historical buildings for the future generation is a really significant issue. Because they have the right to access important information about their past, history, culture, and civilization in every historical era.

In order to maintain and preserve historical buildings, it is required to collect precise data about the building structure. The collected data can be used to accomplish the aim of preserving the building over a long period of time. These data would be useful for some groups such as architects, engineers, facility managers, researchers, and university students. The importance of maintaining historical buildings develops new methods and technologies to serve the needs.

The traditional as-built approaches in collecting data on historical buildings have some human error in terms of measurements. So, it is required to have documentation in the field of historical buildings preservation entirely; therefore, project documentation

methods must be progressed as other parts of a project. There are plenty of methods and one of them is collecting point clouds through scan to BIM.

In this study, it is attempted to elaborate on laser scanning approach and point cloud data collection for the purpose of preserving heritage buildings. Moreover, to gain the aim of having a tangible perception of physical characteristics of ancient buildings, it is recommended to prepare a model of the building. Hence, BIM technology in historical buildings (HBIM) is used for building modelling. And the model can be used in different fields and practices.

HBIM technology has been employed in this study for project documentation. Its procedures to prepare a model were delineated. The useful applications of HBIM are examined and stated through a case study which is a historical building in this study.

## 1.3 Research questions

• What are the state-of-the-art methods for digital documentation of built heritage?

• How can a part of a historic building or site be reconstructed and depicted?

• What is the potential uses of virtual modeling in Historical buildings?

## 1.4 Structure of the research and methodology

The research methodology in this thesis is based on reviewing the existing case studies and practical case study on historical museum building in Berlin.

Firstly, several implementations of building models with different workflow from other researches have been studied. Then, through an investigation of different papers and books in the field of BIM, FM, HBIM, a workflow has been selected which assists the examination of the case study.

For achieving the information needed, the only way of gathering data in this field of study is by reviewing the literature and analyzing the approaches. Hence, it surveyed 49 articles include books, papers, journals, and official websites. Which, the topic of the resources is about building information modelling, facility management, historical information modelling, some devices and their software that obtained from the related company’s website.

In the bellow bar chart shows the numbers of paper found based on the years are presented which shows how up to dated they are.

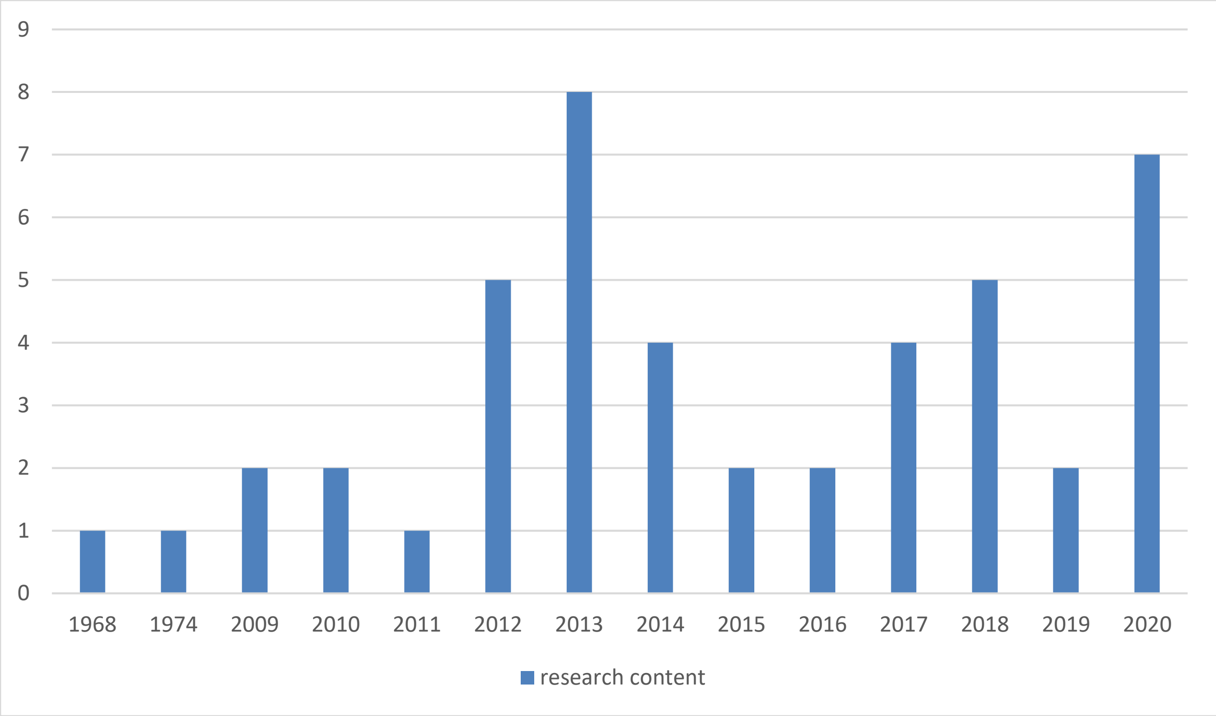



**Figure 1: Number of found base on paper years**

This chart shows that the relevant articles on the topic of the dissertation were mostly between 2010 and 2020.

This thesis has used various sources. The number of which has been tried to be equal, and reliable sources have been used.

In the following Figure 2, it showed a number of the sources and different type between them that this study obtained from them.

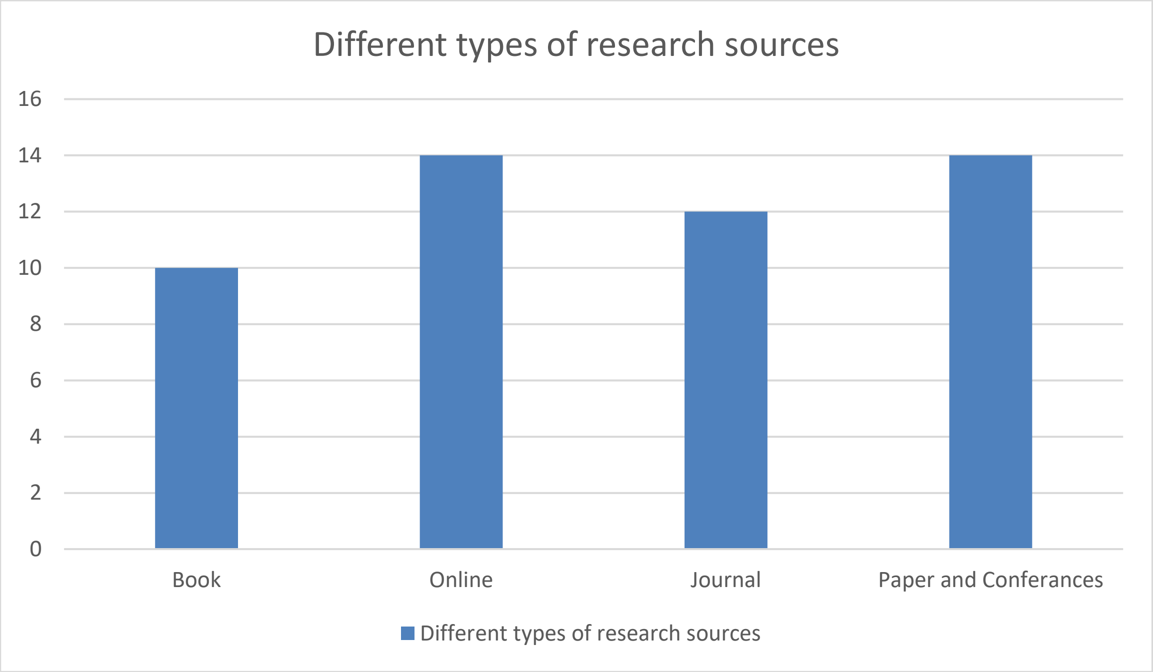



**Figure 2: Different types of research sources**

This thesis includes five chapters.

In first chapter, the problem statement, aim and advance, research question and structure of research and methodology has been described.

The important concept of this study such as BIM, HBIM, As-built, laser scanning and point cloud has been provided in the second chapter.

This chapter helps to have better understanding of HBIM technology by investigation and comparison of other researches.

By comparison and investigation of HBIM application in other researches; its usefulness for project documentation in historical buildings can clearly be portrayed; and also, this chapter paves the way to have a thorough examination of HBIM technology in the next chapter within a more specific perspective. This chapter contains the answer to the first research question as well.

In the third chapter, in this chapter the data can be analyzed comprehensively through four phases. These phases include data capturing, data processing, data post processing and building modelling. The answer of the second research question can be found in the third chapter.

In the fourth chapter, a case study will be discussed based on the information obtained from the previous chapters. Due to all of the data achieved and case study workflow is obtained. In this thesis, a case study of the Berlin Museum is illustrated through laser scanning and partial modelling in BIM software.

The results of this work are given at the end of chapter four.

Finally, in the fifth chapter, the results of this study are gained. The work limitations are investigated, and future suggestions explained the new perspective of work.

Consequently, the third questions will be answered after examining the Berlin museum für Nakurkunde case study with laser scanning approach and point cloud data in chapter four.

# 2. Literature review

## 2.1 Background

This chapter is comprised of four subchapters discussing overall portrayal, specification, and exploration of prior studies. Facility management is firstly attended to, and then it moves on to the discussion on the vantages and disadvantages of BIM and HBIM as the modern facilitating methodologies in the domains of Architecture, Construction, Engineering and Facility Management. Lastly, the procedures of Laser Scanning and Point Cloud data collection are presented.

### 2.1.1 Facility management

Today, most of the studies and reviews are based on scientific and applied projects on BIM structure and construction. Although the advantages of using BIM is evident, applied use in FM is still rare and time-consuming. One of the reasons is the lack of a completed project using BIM technology, especially in Germany, that could be considered a digital model of building for FM and Operation. Therefore, the question in present construction projects using BIM technique is that how a final model could build using as-built technique be included for FM purposes. (Krämer & Besenyoi, 2018)

**Definition of facility management from the point of view of theorists.**

There are several definitions of FM which is provided by different researches, this study evaluates some of these definitions as following:

According to Nicholas Burt (2012), “Facilities management is an age-old practice which has existed out of necessity since buildings were first constructed to support human activities. The FM industry is generally acknowledged as having stemmed from services provided by janitors and caretakers during the 1970s.” (Burt, 2012)

On the other definition, Jane M. Wiggins (2010) said on the Facility management guide desk “The most widely accepted definitions of FM are: International Facility Management Association (IFMA): The practice of coordinating people and the work of an organization into the physical workplace.

An integrated management process that considers people, process and place in an organizational context.

Association of Facilities Managers (AFM): the management of premises and buildings together with the facilities, services and people contained therein; this has implications in respect of initial design, maintenance, the day-to-day administration and control of manpower, energy and related resources' (1986)." (M. Wggins, 2014)

And finally, the general definition in the Facility management handbook, which can be said this definition is comprehensive and complete, which is in line with the purpose of this thesis. as Roper and Payant (2010) said "the most recent definitions of facility management is, Facility Management (FM) is a profession that encompasses multiple disciplines to ensure functionality, comfort, safety and efficiency of the built environment by integrating people, place, process and technology." (O.Roper & P.Payant, 2014)

**History of FM**

A brief history of FM, taken from the book (Jane M. Wiggins, 2010) are:

**"1960s:** This could be the first period in history in which facility management was first coined by Ross Perott from EDS in the United States.**1970s:** In this decade, energy crisis forced companies and organizations to analyse the real cost basis rigorously and interact with customers that truly understood the significance of planning and the value of space. **1979s:** FMI was established by Herman Miller and a group of users that were aware of property issues. It was only in this stage that the importance of FM was recognized officially in the process of strategic organizational planning and discussed at senior management level.**1980s:** In this decade, NFMA national association was formed in order to use and develop all of the potentials of FM. 1980 is key date for FM development. **2000 to present:** FM has been brought up professionally in many companies and has introduced issues including job continuation, security threats, risk management, and social responsibility of companies to provide efficiency in workplace."

And the same author Jane M. Wiggins (2010) points out that, "after the formation of facility management, to create the necessary standards, due to the professional growth of FM, organizations were formed. Some of which can be said about the maintenance of buildings such as:

**EuroFM:** It is a network with more than 75 organizations in 15 European countries that all focus on FM. They are professional representatives of educational institutions and research organizations and exchange information through holding seminars and training meetings. **GlobalFM:** This is a global federation with global FM member organizations. Their perspective is to have a global society with organizations that lead, develop, and facilitate facility management." (M. Wggins, 2014)

**Facility management for Historical building**

According to Talamo and Bonanomi (2015) "in the fields of knowledge management along with information tools that aimed at preservation of a building, demands for using FM services will be in different sets one of which is space and infrastructure based on Table 1. Taking this set into account could help understand the importance of FM in old and historical buildings. In this respect, the more we delve into the need of BIM in FM, the better we will understand that, today, the need of BIM for FM is more than before in old and historical buildings." (Talamo and Bonanomi, 2015)

**Table 1: Categories of demand for FM services.**
**Source: (Talamo and Bonanomi, 2015)**

| Space and infrastructure | |
|---|---|
| Accommodation (space) | – Strategic space planning and management<br>– Programming and briefing<br>– Design and construction<br>– Lease and occupancy management<br>– Building operations and maintenance<br>– Renovation and/or refurbishment |
| Workplace (working environment) | – Workplace design and ergonomics<br>– Selection of furniture, machinery and equipment<br>– Move management<br>– Equip internal and external environment<br>– Signage, decorations, partitions and furniture replacement |
| Technical infrastructure (utilities) | – Energy/utilities management<br>– Environmental sustainability management<br>– Technical infrastructure operations and maintenance<br>– Building management systems operations and maintenance<br>– Lighting maintenance<br>– Management of waste (hazardous) disposal |
| Cleaning (hygiene and cleanliness) | – Hygiene services<br>– Workplace cleaning, machinery cleaning<br>– Building fabric and glass cleaning<br>– Cleaning equipment provision and maintenance<br>– Outdoor space cleaning and winter services |
| Outdoor (land, site, lot, parking) | – Hiring of special measuring equipment<br>– Fitting out with machinery and equipment<br>– Retail unit space management |

There needs to be long term strategies that can be managed to run by short-term planning to preserve Historical heritage. A facility manager can use a short-term plan for a long-term strategy to conserve a building and set the stage for accurate estimation and prioritization of maintenance costs. Old materials usually constructed heritage buildings, so buildings elements are exposed to different conditions at different times, and it is not something favorable and following cultural heritage. In the context of conserving the historical heritage, there are proven approaches. But it is preferred to utilize a rapid and less costly method. (FMmanager, 2015)

**Definition Conservation Management Plan of CMP**

Base on Heritage consul "A CMP is the principal guiding document for the conservation and management of a heritage place. The main objective of the CMP is to ensure that decisions are made with regard to the cultural heritage significance of a heritage place. To that end, a CMP identifies the heritage significance of the place and provides clear policies for the sustainable future of the place." (council, 2013)

CMP is the central guiding document for managing and conserving a heritage building. This is an approach that enables the managers and building owners to make precise decisions about heritage buildings. It identifies the value and importance of a building and the conservation policies to protect the place from any harm and danger. Consequently, after the identification and the employment of the agreed strategy, the systems would be practiced. This guide concentrates on historic districts. Some areas may also have natural and congenital heritage values. All conditions can be addressed inside an individual CMP.(Jude and Church, 1968)

According to the Heritage consul "The process in preparing a CMP is described in the Burra[1] Charter Process. Essentially, this process can be broadly broken down into three parts:

1. Understanding the significance of a place
2. Developing policies to guide maintenance and change
3. Developing an action plan." (council, 2013)

---

1. Burra Charter is for the places of cultural significance, and the associated of practice note is the best usage norm for maintaining cultural heritage areas in Australia. (ICOMOS, 2013) (Burra Charter).

As a result of its significance, CMP can be the starting point for facility management in historical buildings. CMP includes historical investigations, physical examination, and comparative analysis of the structure. So, the outcome allows the facility managers to make an accurate decision in order to employ the proper approaches to renovate the building. (FMmanager, 2015)

The (Figure 3) illustrates five steps in the production of a CMP.

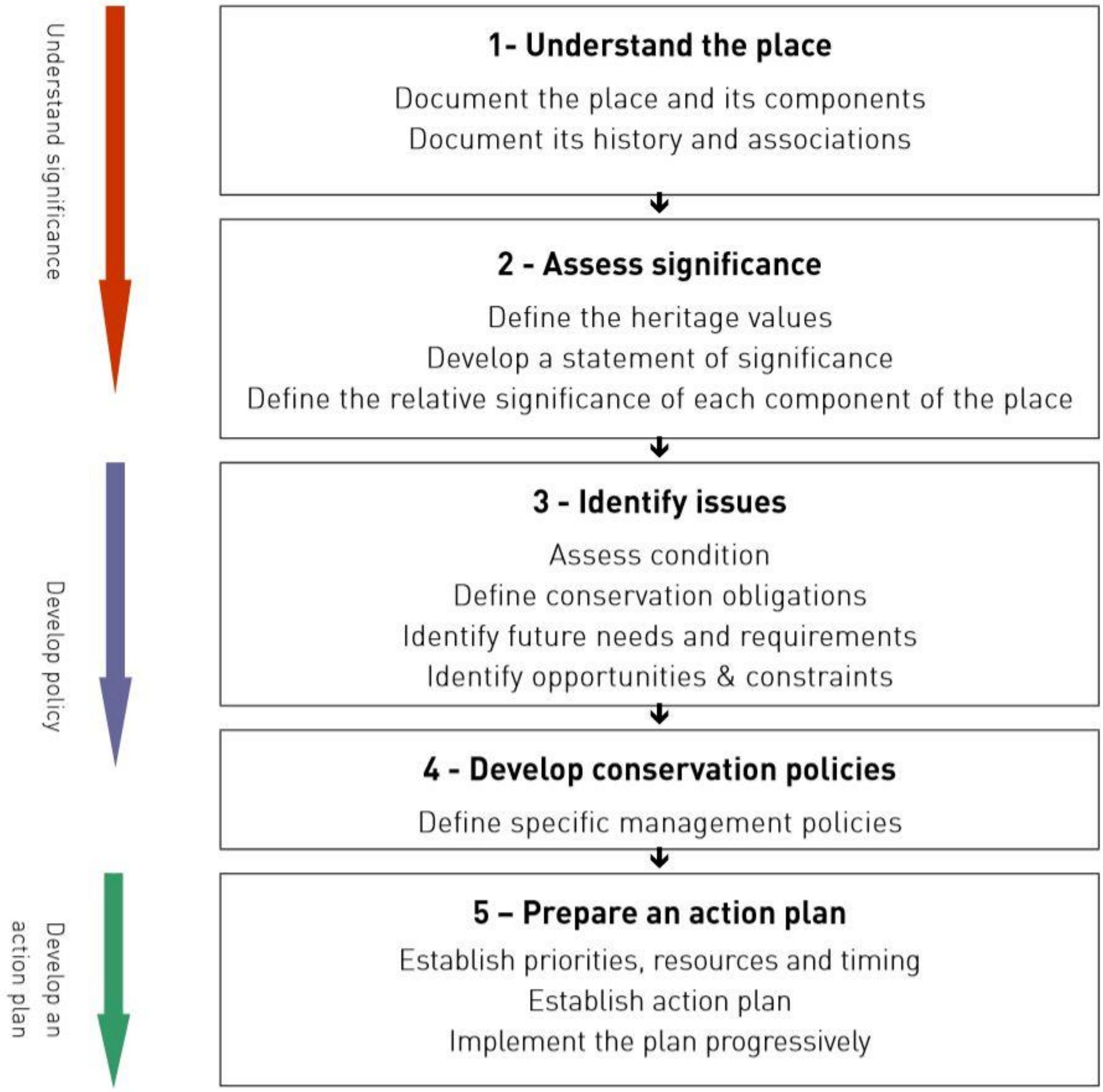



**Figure 3: Five steps for preparing the CMP (Church & Carlton, 1968)**

Consequently, after investigating the FM articles, it is clear to understanding that, nowadays, drawing on the work of Roper and Payant (2014) on The Facility Management Handbook, “FM narrows down into a variety of measures listed below:

1. Organizational Managements
2. Anticipatory Facility Planning
3. Interior Design, administration and Management
4. Sketching Architectural and Engineering Plans
5. Planning, Administrating and economically justifying Workplace
6. Property purchase and transfer
7. Sustainability
8. Managing the construction project
9. Implementations, preservations, and renovation
10. Technical Management
11. Life-Protection and Safety
12. Overall management services." (O.Roper & P.Payant, 2014)

### 2.1.2 Building information modeling

The BIM is not a novel concept. It dates to 1970s; academic research about the conceptualization and utilization of virtual building models were proclaimed in the early seventies. (Eastman, et al., 1974)

Base on Bormann (2018) explained in his article that, "a software company named Autodesk has been credited for universally publicizing the term by publishing it in a White paper in 2003. Over the last few years, different marketers have been published a wide variety of software product with potent BIM services. Therefore, the concept of BIM, which initially appeared in theoretical research papers, has now confirmed into industry employment." (Borrmann, et al., 2018)

Building Information Modelling used as a functional approach for designing constructions. It provides a 3D digital presentation of concrete, operative and semantic elements of an environment, construction, or existing structure. BIM programs are established on constituents which are on saved parametric components. Mostly, these parametric components can hold the geometric design or topological characteristics, and they are reusable objects.(López *et al.*, 2018)

Since BIM technique is mentioned in different articles with different expressions and definitions, building information modeling is defined from different perspectives. Hence,

they all convey the same meaning. Although BIM science is being updated and upgraded, its concept and purpose have been the same from the beginning, and whatever is added to the BIM, can be proof of the correct definitions of it. The following are some examples of BIM definitions that can express the existing concepts of this science. Base on (Krämer and Besenyoi, 2018), “In BIM method a digital representation of the real building (a digital twin) is used throughout the whole building lifecycle from planning over construction to the operation of the building in order to establish an optimized collaboration and information exchange between all participants and disciplines in building industry.” (Kia, 2013) also defines water in the article, “The Building Information Model is primarily a three-dimensional digital representation of a building and its intrinsic characteristics. It is made of intelligent building components which includes data attributes and parametric rules for each object. For instance, a door of certain material and dimension is parametrically related and hosted by element.” On the other hand, (Teicholz, 2013) defines water in this way, “BIM is a complex technology based on a collaborative approach to project production and facilities management. Organizations intent on deploying and leveraging BIM fully will need to evaluate and adopt new business processes in addition to the technology. Sharing, integrating, tracking, and maintaining a coherent building information model will affect all processes and participants that interact with that data.” This is the definition of water from (Volk, *et al.*, 2014) point of view, “A tool to manage building information over the whole life cycle, it is adequate to support data of maintenance and the construction process and Widespread differentiations of BIM are 3D (spatial model with quantity takeoff), 4D (plus construction scheduling) and 5D (plus cost calculation) 6D (Facility management)”

Finally, the final summary of these definitions can be found in the expression of Bormann and Koch opinion, which has more broadly stated all the goals of this science. This definition can also help the goals of this thesis, they said “By applying the BIM method, a much more profound use of computer technology in the design, engineering, construction and operation of built facilities is realized. Instead of recording information in drawings, BIM stores, maintains, and exchanges information using comprehensive digital representations: the building information models. This approach dramatically improves the coordination of the design activities, the integration of simulations, the

setup and control of the construction process, as well as the handover of building information to the operator. By reducing the manual reentering of data to a minimum and enabling the consequent re use of digital information, laborious and error prone work is avoided, which in turn results in an increase in productivity and quality in construction projects." (Borrmann, et al., 2018)

Based on Teicholz (2013) in "BIM for facility management book, 2013" that "BIM is a potent data application and more crucially has the capability of employment of essential changes in program delivery, assuring to back up more consolidated, productive process. Moreover, BIM is constitutionally potential for decreasing the costs and elevating productivity as follows:

- Early administration: BIM permits decisions and modifications to be conducted with a diminished implication on time and expenses as a result of former assessment on building performance.
- Enhanced Authenticity: The authenticity of the model cultivates efficient transmission of the various parties engaged in building projects and fortifies comprehension. Due to this, errors and modifications are shortened across the procedures in the construction and design. These streamlined and organic portrayals are implemented by the parametric machineries of BIM.
- Accelerated quantizing: Automated origination of quantities and publishing on data, the model can manufacture estimates and workflows with greater efficiency and swiftness than regular procedures.
- Vigorous Analysis: As well as a noticeable promotion in the complex analytics which composes detection of clashes, scheduling and reordering and energy analysis, that renown in 4D modeling, BIM elucidates decision making, unravelling issues, and minimizing hold-up in project procedures.
- Advanced Logistics: BIM is potential of virtually constructing the structure beforehand; therefore, the contractor and the supply companies involved in the project can discern any latent mismatches in the building systems which would otherwise come to an undesirable shift order were to be found out on the real time project.
- Enhanced Project Supply: At the project, turnover will be provided with a lucid, methodical, and thorough body of data all due to BIM." (Teicholz, 2013)

**Industry Foundation Classes (IFC)**

In order to interchange digitized building models vendor-neutrally, the Industry Foundation Classes (IFC) delivered an extensive, regularized format. Thereby, it is the core foundation of the Big Open BIM organization. Over the past few years, the IFC became the authority on the definitive format of Open BIM realization. (Borrmann, et al., 2018)

Various other BIM software applications are already supporting it, such as thermal performance analysis tools, software for facility management and structural computation tools. Open data format indicates the continuity of the data directory through the future for the others to use. Factoring the long life of buildings in, it would be easier to appreciate the significance of this technology. Building SMART that is formerly known as the International Alliance for Interoperability (IAI) was founded with the collaboration of construction firms and software industries; now, comprising of more than 800 organizations which initiated the inauguration of the Industry Foundation Classes-IFC as standardizing software for construction applications. (Borrmann, et al., 2018)

**BIM Software and Phases**

There is several BIM software, according to various dimensions, these different dimensions are each used in a part of project preparation, in the following figure we can see them briefly.

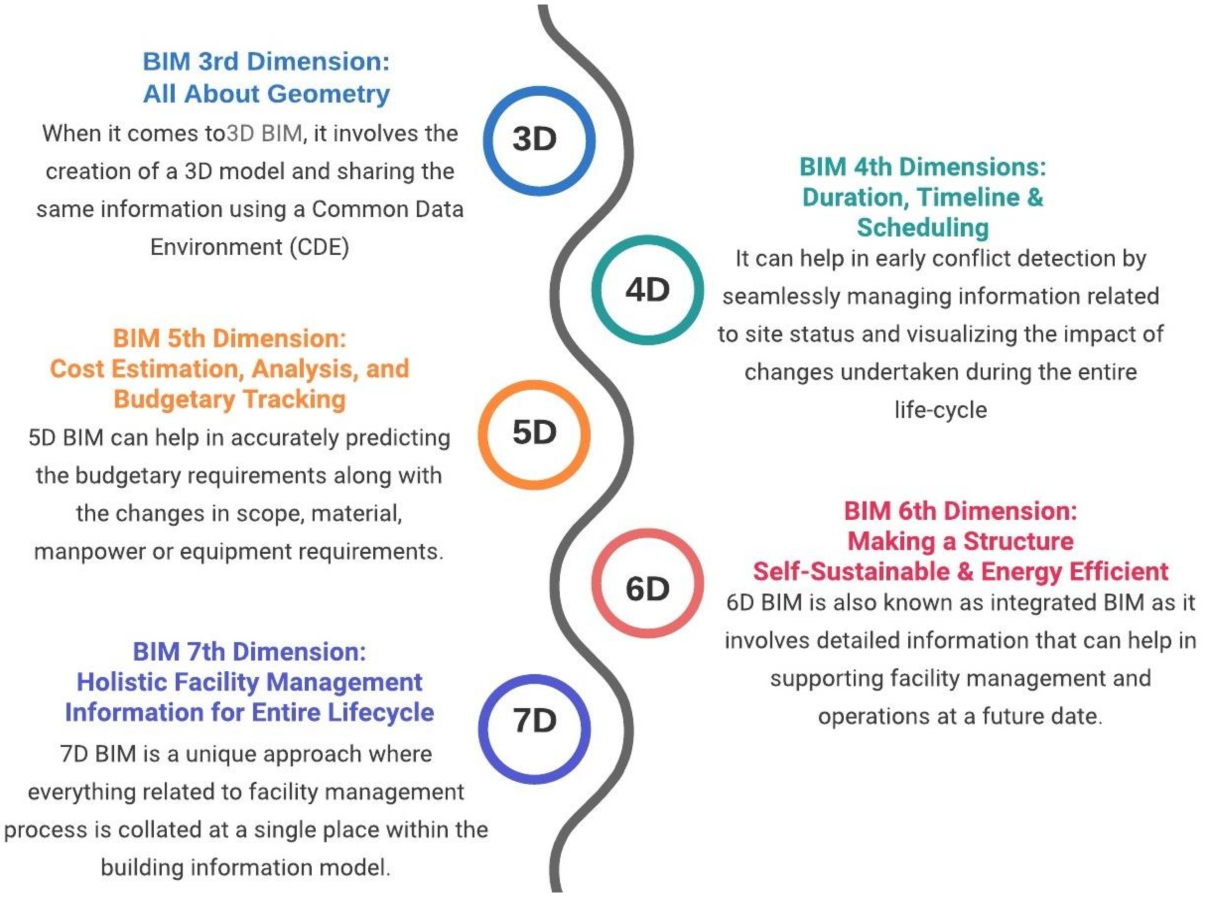



**Figure 4: BIM Dimensions in one view. (BIM, 2020)**

In the following it will be investigating two dimensions that are most relative to thesis purpose.

**(3D) modelling as a building information modelling (BIM)**

Three-dimensional modeling of BIM is a standard type of BIM modeling. Three-dimensional modelling, also known as a new generation technology, is physical modelling with some practices such as animating and rendering. During this type of modelling, numerous pictorials as well as non-pictorial information in the project are presented, and as the project continues, this information becomes more detailed and accurate. This animating will proceed until delivering final data to the project's employer.

Regarding to (BIM, 2020) 3D BIM merits are listed below:

- Improved 3D concept of the whole project,
- Modernized information and distribution of design expectations,
- Sheer cooperation within several parties regardless of their competence domain
- Not having to start over or shift practice due to the initial performance planning

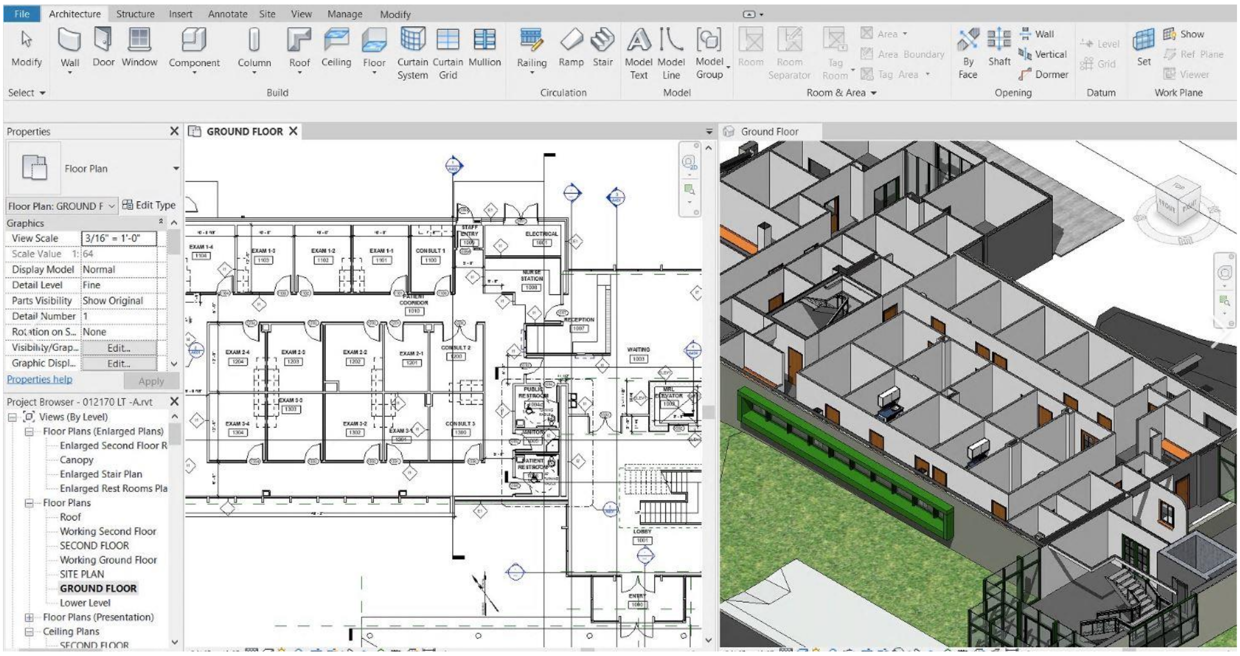



**Figure 5: 3D modeling in BIM software. (Autodesk, 2020)**

### (4D) Modelling: Scheduling

Four-dimensional BIM is a different type of modelling, which is known as scheduling. Modeling the procedure in this way leads to a better and more efficient project planning. Through 4D modeling, the user can visually observe steps of the project and its scheduling and thoroughly perceive it. The use of this type of modelling helps project scheduling managers to schedule the project accurately using these data. This type of modelling is highly essential and vital for all projects. By using 4D BIM from the start point of the project, we can accurately plan time and even resources.

Regarding to (BIM, 2020) merits of 4D BIM are listed below:

- Updated site planning and scheduling optimization.
- Seamless coordination with designers, contractors, and on-site partners.
- Better preparation in phases of following steps through each construction step.

- Improved data sharing associated with timeline expectations assisting in side-stepping costly obstacles
- Increased safety and productivity due to documentation of a complete plan with unique timelines

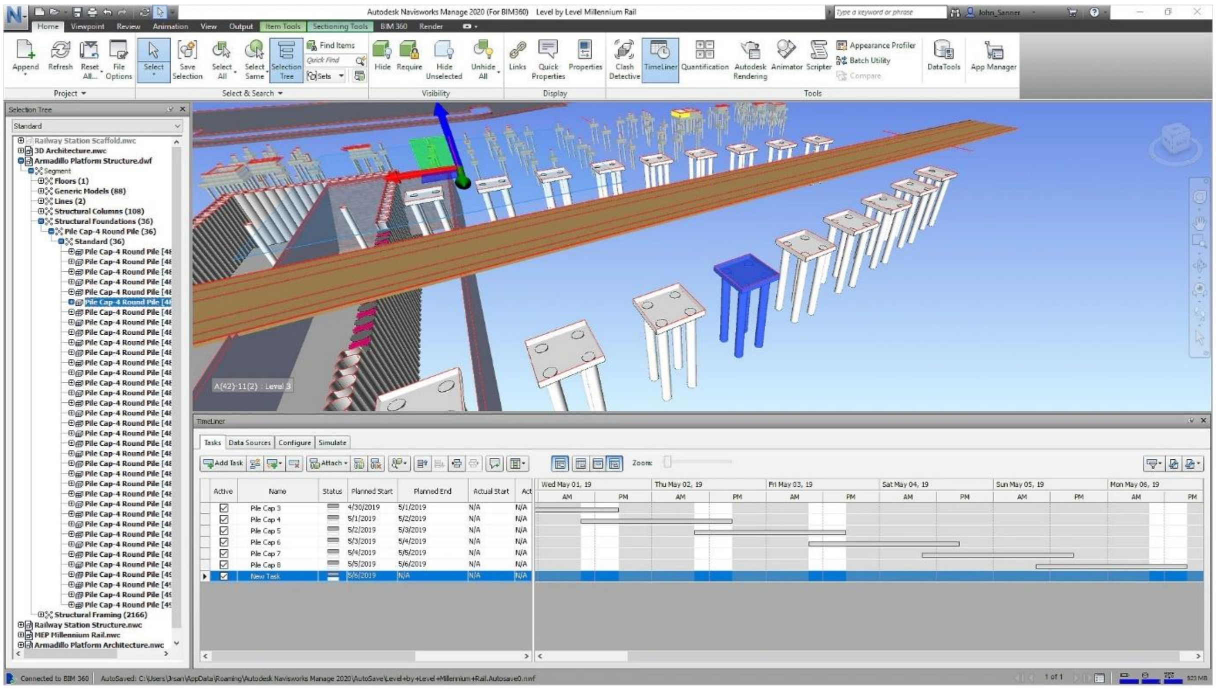


**Figure 6: 4Dmodelling in BIM software. (Autodesk, 2020)**

### BIM for Owner

At the end of the construction phase, the whole building models is done in 3D modelling for using the owners as tangible models. The owners are often those who do not have enough knowledge of building science, and 3D modelling can help their perspective. These 3d models can increase building accuracy and save time and costs during the project lifetime. In ordinary, all of the building information can be included in a wide range of source and data that many different expertise and engineers work on them. (Teicholz, 2013)

In one construction project, it has two significant problematics, first, the information overload pertaining to numerous originations in particular parts of the construction and then the way for a relation between them. This unclassified information will be challenging to continue working and using project data in the future. It can be said that not using BIM can lead to increased construction costs and wasted time. Construction phase, employers can use BIM in setting up the building. A step that can increase the

quality of work by integrating designing. BIM also could be used in all parcel of the project, including facility management, **maintenance** planning and control, time and cost schedule for repair or renewing, simulating emergencies and evacuation plans of large crowds and generally relevant project controlling. (Teicholz, 2013)

BIM can have some benefits for the owner, independently of the designers and engineers, owners have some advantage also, in the following base on (Desai, 2014), they are listed. (Figure7)

- Improving Building design
- Streamline information
- Integrate workflow
- Estimate cost accurately
- Enhance branding
- Maintain effectively
- Sustain building performance
- Effectively use available energy
- Improve lifecycle management

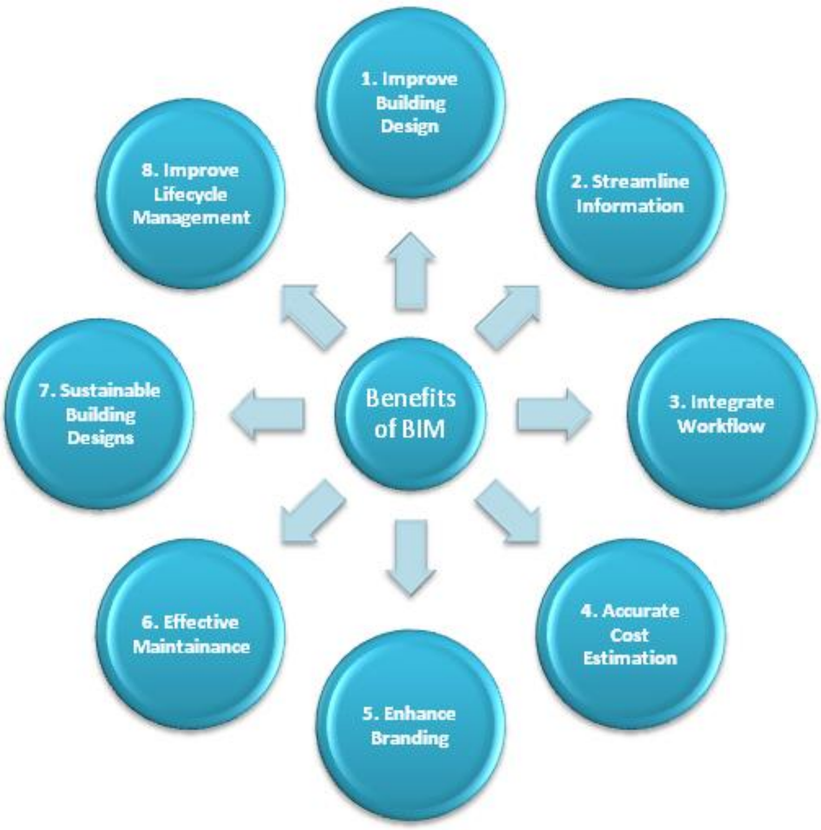



**Figure 7: Benefits of BIM. (Desai, 2014)**

(Figure 8) is visualizing the integration of BIM with FM systems which supports the information required in a building for life. General Service Administration (GSA) plans to pave the way of how BIM is used to endorse the BIM FM integration in the life cycle of the building starting with the planning to all the works done through the process. The most significant constituent in facility management is a central facility repository. This central facility repository aims at the integration as well as storage of 3D objects parametric information; designs for the mechanical, electrical, and plumbing systems; 2D data along with laser scanning data; and lastly the relevant sensor data and controls. The vision is that BIM could manage and be sustained for all building projects just by means of the central facility repository. Additionally, operation and maintenance (O&M) workers can observe the BIMs. What makes it possible to maintain security, supervision, tracking the updates and version control is the software tools that placed on top of the central facility repository. (Teicholz, 2013)

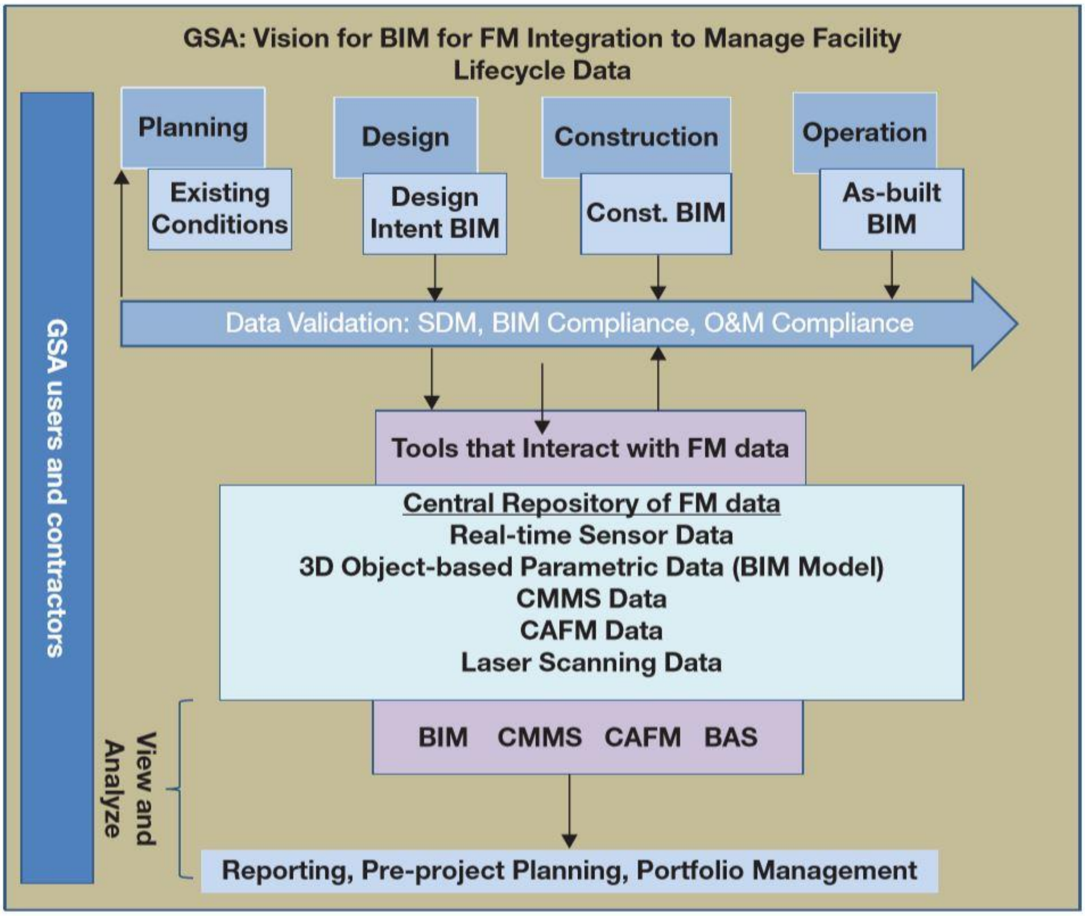



**Figure 8: integrating BIM with FM systems. (Teicholz, 2013)**

Additionally, based on Hardin and McCool (2015), some other advantages of BIM for owners and listed as follows:

- “Rise in staff competence to get to information (time)
- Maintenance of facilities to warranty standards (risk profile and expense)
- Proper documentation of charging issues (fire stopping, accessibility)
- An inadequate amount of wasteful issuing (costs)
- Experience to back up important digital and facility data that could be missed (risk profile)
- The information inserted or connected to the model to withdraw undesirable waste
- Less chance for facility downtime as a consequence of inappropriate maintenance
- More effective repair acknowledgement
- Update customer.” (Hardin & McCool, 2015)

**BIM for Facility Management (FM)**

BIM in FM is a relatively novel field and accordingly the actual studies in the domain are still rather scarce regarding planning, developing, and construction procedures. What makes the condition rather more perplexing is the fact that current cases are largely centralized on modern buildings, albeit they consist only %12 of each year`s construction cases. There is also scarcity in genuine instances of BIM application in FM. (Brumana *et al.*, 2018)

**Computer-aided facility management (CAFM)**

Computerized maintenance management system (CMMS) mandates the use of digital files, i.e. all the data and details must be digitized for the owner to be able to use the system. It is carried out customarily by the FM employees when time is not pressed. The evolution of the qualification and improved use of the system is undergone through the Construction Operations Building information exchange (COBie); it also monitors the veracity and integrity of these data. Computer-aided facility management (CAFM) as well requires the same mechanisms as does the COBie. The project costs are largely affected by factors such as the allocated time, updating and authentication of these data. (Teicholz, 2013)

The ratio of BIM constructed buildings over existing building will not be changing over a short period, not even all subsequent construction projects use BIM. That is due to the number of buildings to be applied in FM business are still existing buildings. Yet another complication in the way of universalizing the BIM in FM is the formidable task of building a library for the relevant As-Built digital models out of the standing construction. Therefore, the utmost priority in the FM business is to innovate a way to capture the digital building models most conveniently. Another factor further complicating the way is the long period of time sometimes exceeding 50 years that the FM organization is being obliged to keep the model. What is more, is the task of refreshing this As-Built model(s) in order to be always upgraded which is difficult. Upgrading the building model is often accompanied by secondary updates in various FM databases, which are practically hardly easy to stay updated. Space-related databases as well as CAFM systems when updated contribute to the modifications of space and reductions in costs and also enhances their effectiveness. (Jane M. Wiggins, 2010)

Full range of FM software platforms are available to be used by the managers of the facility including CMMS, CAFM, BAS, etc. (Teicholz, 2013)

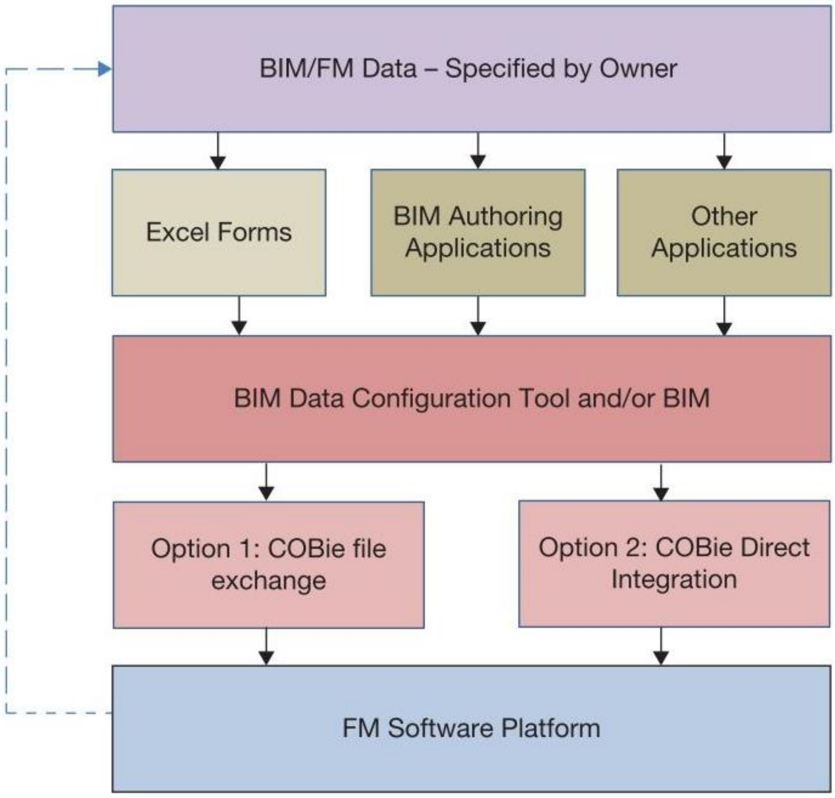



**Figure 9: Substitute data paths for the purpose of integration of BIM with FM. (Teicholz, 2013)**

**Advantages of BIM FM integration**

Principal data concerning types, zones, spaces, systems, equipment, finishes and so on can be consolidated in BIM FM integration and collected from BIM which makes it redundant to be reentered into a downstream FM system. (López *et al.*, 2018)

The benefits of BIM FM integration are listed below:

- By granting a building owner`s manual, it unifies information base.
- Singularly supports analyses for initiatives in preservation of energy.
- Data flooding in the case of designing interiors and equipping buildings.
- Corroborates urgent reaction, and security management and scenario analysis. (Murphy, *et al.*, 2009)

**Advantages of during the Building Life Cycle**

- The integrated system contributes to precise and comprehensive information that leads to significant cost benefits comprising the followings:
- Instead of mandating FM workforce to devote time starring at equipment documents, papers, and drawings for information, it improves staff efficiency by either in office or on the job in the field through introduction of refined information.
- Shrinking utility costs (water and energy) because of more significant enhancement in data maintenance that underpins broader precautionary maintenance planning and processes.
- If kept regularly and adequately maintained mechanical equipment for the building will function in a higher standard. (López *et al.*, 2018)

**Barriers of implementing BIM in FM**

Base on Becerik-Gerber (2012) “some technological and organizational challenges regarding the BIM in FM in to the two groups as a following:

1) Technology and process-related difficulties:

- unclear duties and tasks for providing required information of the model database as well as preservation of the model itself,
- Differences in FM and BIM programming tools and data exchanging difficulties,
- To model and model utilization is required Less productive collaboration between project stakeholders,

- Essential yet a great obstacle is the association of the software publisher, especially regarding the differentiation amongst businesspeople, rival(s), and less usual advantages,

2) Organizational difficulties:

- Cultural obstacles via using emerging techniques,
- Corporate level stability: the requirement for investment in the foundation, education, as well as emerging programming instruments,
- Unclear financial agreements for further range,
- Deficiency in moving the perspective of the proprietor relevant to design and construction,
- Scarcity of genuine instances to back up the welcoming profits of the investment." (Becerik-Gerber *et al.*, 2012)

**Level Of Development (LOD)**

Due to the lack of measurement in the library of digital models, similarities had to be launched to indicate the notion of geometric resolution and the extent of the formulation. Placing excessive focus on the geometric appearance, the formerly used term Level of Detail was found to be ambiguous; therefore, the term Level of Development (LOD) was created and is in well-known usage. A LOD specifies the requisite geometric detail, otherwise known as the level of geometry (LOG) _ along with the essential alphanumeric data, also indicated as Level of Information (LOI). A level of development gives not only the explication of the range of information bestowed but also shows its maturity and authenticity. A LOD can be connect with a specific design stage in most circumstances. An all-embracing catalogue illustrating the geometric section of the six LODs that are standardized has been issued by the American BIM Forum for standard structure modules. (Figure10). (Borrmann, et al., 2018)

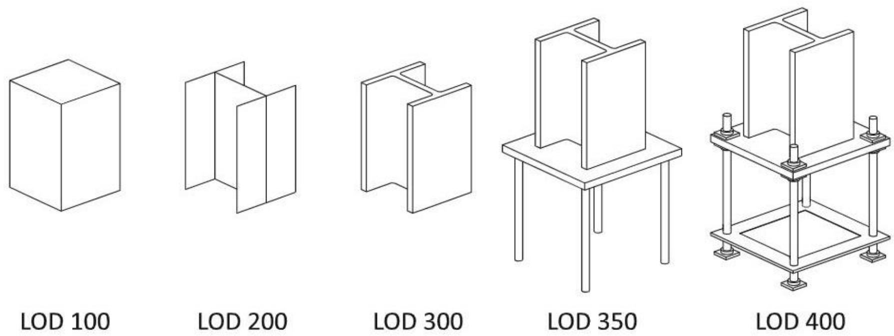



**Figure 10: Different Levels of Development. (Borrmann, et al., 2018)**

According to André (2018), “each Model Element expounded at six principle levels.

- LOD 100: The model element is delineated in graphic form through symbolization or generic demonstration. Specific data on components for instance expenses per square meter could be drawn from diverse model elements.
- LOD 200: The model element is expounded in graphic form with the means of a generic element with estimated orientation, position, and proportions.
- LOD 300: The model element is illustrated in graphic form through distinct object that specifies its dimension, magnitude, position, form, and direction.
- LOD 350: The model element is illustrated in graphic form through distinct object that specifies its dimension, magnitude, position, form, and direction along with its connectivity to various building systems.
- LOD 400: The model element is illustrated in graphic form through distinct object that specifies its dimension, magnitude, position, form, and direction coupled with particulars in reference to installation, production, and assembly.
- LOD 500: The model element has been verified on construction site comprising its position, dimension, orientation, magnitude, and form.” (Borrmann, et al., 2018)

This differentiation is geared to administer, the totality of the valuable data required by the procedures to subsist the building in time, comprising the layer stratigraphic of respective component category. Framing information and layer succession cannot be automatically employed to restore preservation management procedure on such linear manner increasingly allocating the BIM for data as well as a geometric side. It jeopardizes to retard the knowledge of geometry, the behavior of the structures, and state of the art with enforcing higher costs during the procedure as a result of the unexpected framework. Furthermore, insufficient information restricts the prospect of performing solutions for the design relevant to the high-tech and maintenance procedures. (Murphy, *et al.*, 2009)

### 2.1.3 Historical building information management

Managing and recording cultural heritage is a field that BIM has seriously evolved on since its beginning. The genuine conservation status of the studied buildings is now depicted in virtual environments. However, this virtual representation process of historical-cultural heritage is not carried out effortless since the BIM software libraries are

not well-stocked on those morphological, heterogeneous, and complex characteristics on Model objects. (Gigliarelli, *et al.*, 2017)

Accordingly, modeling various parametrical elements of the virtual accomplishing a "BIM as-is Model" of the historical-cultural assessment of heritage buildings, the BIM environment must essentially be presented with the point clouds as well as technical approaches. (Hardin & McCool, 2015)

Historical Building Information Modeling (HBIM) is an emerging answer whereby reciprocal parametric objects which depict architectural elements shaped from historical data. Carefully mapped on to a point cloud or image-based examination, these elements incorporate detailed behind the scan surface. The elements in architecture are depicted with the help of geometric descriptive language (GDL). (Psaltakis, *et al.*, 2019)

The HBIM is a novel approach, and as a result, all implementations of BIM are employed to design contemporary buildings, new initiations that focus on plug-ins for structure, energy, economic evaluation and scheduling of constituents as an attachment to recent architectural design. Excluding, very little effort has been made concerning historical building information modelling along with the generation of BIM models out of the data survey in laser scanning. However, they centered their work mainly on the challenges related to merging BIM and laser scanning in the form of generic library objects maneuvered in a BIM environment through laser scan-based survey. The procedure did not encompass the formation of parametric libraries or enhanced maneuvering of objects onto the scan surveys. (Hardin & McCool, 2015)

This library is the first library of historical data that included of point clouds data and some parametric objects. Drawing on new technologies such as laser scanning and photogrammetry, HBIM gathers the required data through remote collection. (Murphy, 2012)

The vantage point in HBIM over other modelling strategies is that the final output is automatically documented in the manner of engineering drawings with the intention of meticulous conservation of architectural heritage. In contrast to this is the too elaborate visualization products created from procedural and other parametric modelling endeavors in which a significant result is a visualization tool. HBIM deviates from these efforts as the finalized output is designed in a full 3D model containing detailed explication of

the object's surface regarding its fabrication method and material makeup. In order to add intelligence to point cloud data, 3D documentation is generated which embraces sections, orthographic projections, and details and planning (energy, cost decay, etc.). (Hardin & McCool, 2015)

Two of the critical problems in the heritage industry are the heterogeneity and accessibility of data across the different stages of the conservation phase. BIM is an integrated approach to planning, portraying, manufacturing and handling the built environment, applicable primarily to new building industries today. Owing to the magnitude of historical accounts affiliated with historical buildings, it is not an easy task to create a model for them. Far beyond the simple three-dimensional depiction due to which, many studies currently recognized in HBIM, can offer the most promising result in the evolution (still in progress) of BIM with the focus on the Heritage industry's needs and its specificity. The first HBIM studies distributed essentially with issues of geometry and representation, theorizing the construction in purposeful libraries of these monumental structures or else simplifying the procedures by which the understanding of point cloud information and geometry of the structure is made possible. (Hichri *et al.*, 2013)

The facilitating nature of HBIM are fourfold:

- Expressing and specifying the historical conception in high-quality digital investigation,
- Introduces a context collaborative teamwork exemplary of multi-disciplinary parties,
- Standardized numerical data comprising the structural physiognomy,
- Assimilating the ambiguous parts in a building. (Tang *et al.*, 2010)

### 2.1.4 “As-built” BIM definition

As-built BIM file or the so-called record BIM file is the solitary, present, composite reference mock-up that points out the details in the project. The procedure of carrying out a record BIM file includes considering the design and further inspection of the model in every part of the plan.(Wei *et al.*, 2019)

There is a distinction between a record BIM file and a record drawing; if there is updated facility information, the record BIM can modify over time. These associates are direct with notable savings in data finding and evaluations. Furthermore, it assists the

design teams with precise as-built information for improvements to the facility.(Edirisinghe *et al.*, 2017)

The non-automated process of “as-built” BIM formation is a monotonous, rigorous, idiosyncratic job that must be done with an experienced and professional person. In practical terms, manual modelling of uncomplicated primitives is time- consuming and labor- intensive so modelling an ancient, historic structure may be very complicated. On the other hand, it might be very demanding to automating or semi-automating the operation for some major reasons. First, digital modelling of a structure is challenging and contains the unconnected components. These unconnected components are referred to as clutter and cannot appear on the ultimate BIM. The input data may be inadequate so that the output can differ with modelling characteristics and users’ presupposition. Hence, all these complexities highlighted historic buildings. Historical buildings are marked by many different shapes.(Tang *et al.*, 2010)

Laser scanners potentiality of measuring the 3D shape of an environment in a fast and precise way lead to their acknowledgement and recognition of the Construction, engineering, architecture, and management of the industry facility for manufacturing as-built BIMs.

There are three main courses of action in employing laser scanners to create as-built BIM:

- **The data gathering:** in this step, the assessment for these compressed points are assembled with the utilization of laser scans which are derived from fundamental locations across the facility.
- **Data pre-processing:** At this stage all the compressed point clouds are merged in order to be screened and then transformed to a digital portrayal of the exterior scans in a time-based manner.
- **BIM modelling:** in the last step, there is a transition of surface representation of low-level point cloud into a semantically rich Building Information Model. These courses of action are clarified more comprehensively in next sub-sections. Modelling steps are the actual focal point of this research, but a short review of the first two steps has been given for thoroughness.(Tang *et al.*, 2010)

## 2.2 From laser scanning to Point cloud

Base on Mahmoud (2017), “the terrestrial three dimensional laser scanning technology, also named LADAR (Laser Detection and Ranging), is an imaging technology expanding in use since the 90’s.” (Mahmoud , et al., 2017)

Gathering information with laser scanning technologies has made the generation of as-built BIMs flexible. Other gathering methods are greatly inaccurate to be practice on large scale. Although recent results, using images has been reassuring. Laser scanners measure the distance from the sensor to approximate surfaces with millimeter to centimeter precision at great speed of point measurement. A single scan may comprise several million 3D points. However, to capture the surfaces accurately, scans must be from multiple locations, often accompanied by digital images from a camera which later is fused to 3D data to visualize more accurately. (Tang *et al.*, 2010)

Drawing on the works of Mill (2013), “terrestrial laser scanners (TLS) are narrowed down to the following groups:

- Triangular surveying scanner
- Time of flight (TOF)
- Phase-shift (PS) or phase-based (PB).

**Triangular surveying scanner** locates the object by means of shedding a light onto the object and then utilizing a camera to figure its place. The name triangular surveying scanner originates from the shape of the light shed onto the object. It is noteworthy to mention that this method is only applicable to procedures that demand no further range that 25 m.

**TOF laser scanners** project light to the surfaces of the objects they are examining and collect the reflection of the light and measure the time of flight and hence, calculating the distance. As the light pulse travels with the speed of light, and this speed is always constant, we figure out the distance between two objects. Interestingly, TOF laser scanners measure as many as 50,000 pints per second and operate to as far as 1 km of distance from the scanner.

**PB laser scanners** regulate the power at which the laser beams, hence the light flights to the surface of objects inconsistently. Interestingly this leads to time-delays that when

captured can facilitate measurements. Through this approach we are able to measure as many as 1,000,000 of points. However, not farther than 80 m since regulating beams of light to specific frequencies consumes power.” (Mill, et al., 2013)

In the Figure 11 shown the sample of the laser.

**Figure 11: laser scanner camera (Trimble, 2020)**

The following Table, shown the diversity of the laser scanner systems and their usage with accuracies and their range, it can help to selected to getting using one of them for each project. Hence, after knowing them, it is simple to choose one of them for assignment, and in most of the cases, it should be selected a couple of their tools.

**Table 2 : Laser scanner systems and their usage. (England, 2018)**

| Scanning System | | Usage | Typical Accuracies (mm) | Typical Range (m) |
|---|---|---|---|---|
| Triangulation | Rotation stage | Small objects taken to scanner. Replica production | 0.05 | 0.1 – 1 |
| | Arm mounted | Small objects. Lab or field. Replica production | 0.05 | 0.1 – 3 |
| | Tripod mounted | Small objects in the field. Replica production | 0.1 – 1 | 0.1 – 2.5 |
| | Close range handheld | Small objects. Lab. Replica production | 0.03 – 1 | 0.2 – 0.3 |
| | Mobile (handheld, backpack) | Awkward locations eg building interiors, caves | 0.03 – 30 | 0.3 – 20 |
| Pulse (TOF) | Terrestrial | Building exteriors/interiors. Drawings, analysis, 3D models | 1 – 6 | 0.5 – 1000 |
| | Mobile (vehicle) | Streetscapes, highways, railways. Drawings, analysis, 3D models | 10 – 50 | 10 – 200 |
| | UAS | Building roofscapes, archaeological sites. Mapping and 3D models | 20 – 200 | 10 - 125 |
| | Aerial | Large site prospecting and mapping | 50 – 300 | 100 – 3500 |
| Phase | Terrestrial | Building exteriors/interiors. Drawing, analysis, 3D models | 2 – 10 | 1 – 300 |

Because of their millimeter to centimeter accuracies plus their fast-paced nature, laser scanning employed for gather the necessary data on intricate surfaces or existing buildings.

Additionally, two domains of aerial and terrestrial are categorization of laser scanners with their respective range, precision, and use for which they are intended. (López *et al.*, 2018)

From a technical perspective, the point cloud is a database which comprises points in the three-dimensional coordinate system. Nevertheless, from the standpoint of a regular workflow, the essential item is that point cloud is a precise and reliable digital record that is made of an object or space. It is preserved in the pattern of a vast number of points that encompass surfaces of a scanned object. Since the light rays from the scanner reflect on the outer surfaces of visible objects, points in the point cloud are located continuously there. (Ciępka, 2016)

The data extracted from the different scans creates partial-point clouds {(xi, yi, zi)}, and then each one of these point clouds is merged to give rise to an overall cloud that will characterize the site. This procedure is known as point cloud registration. In order to carry out the registration, a certain overlapping between approximate points sets (i.e., 20–30%) is compulsory. In this overlap, several common tie points or targets between point clouds must be specified. (López *et al.*, 2018)

If each point size is large enough in the view or zoom setting, the point cloud is potentially recognized as the persistent surface. In case that the space between points is lightly bigger than its size, then it would be possible to conceive the image, clearly, as individual points. However, shapes of an object are still quite readily grasped by our brain. It is critical to realize that the point cloud is a set of separated inconsistent points with specified color and position. This makes point clouds rather simple to edit, filter, and demonstrate. (Ciępka, 2016)

The figure12 can show Point cloud data with colored stations style.

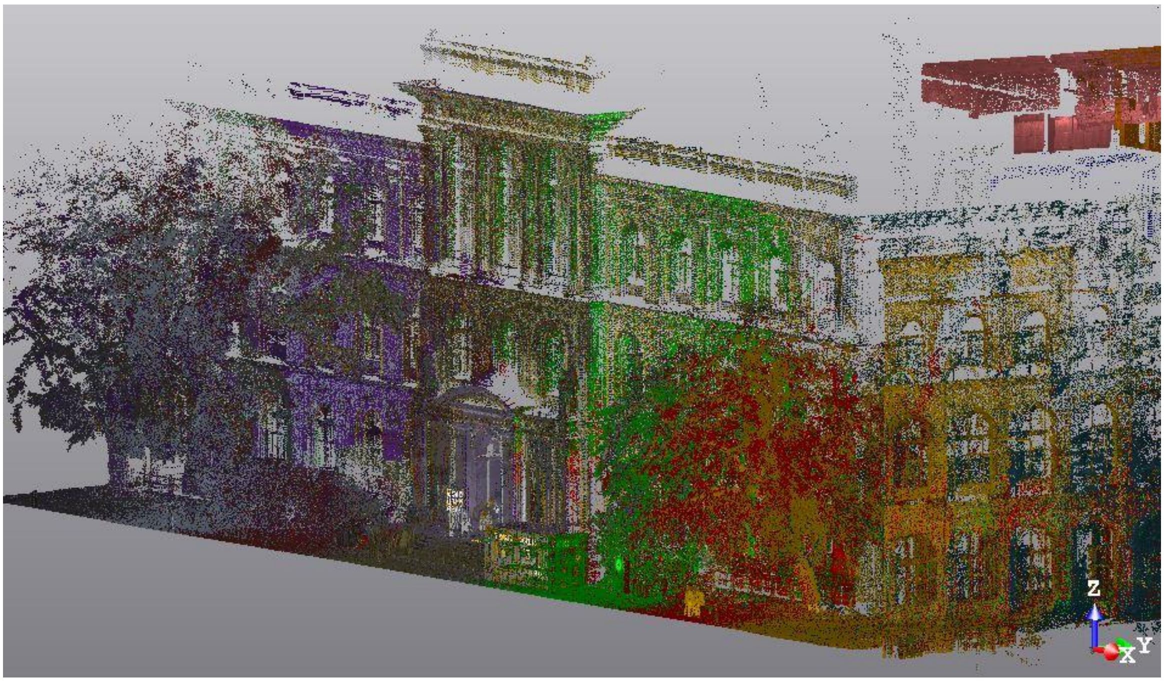



**Figure 12: Point cloud Data (By author)**

According to (Ciępka, 2016) Through these separated, inconsistent points, the point clouds are driven useful. Since, points are objects that are the simplest to tackle a

great amount of them, a computer does not have to concern with scale, rotation, and association to other objects. Position and color are the only things that are significant for computation. This makes point clouds rather simple to edit, demonstrate, as well as for filtering data. Requiring human engagement in almost every case could be said to be the real drawback in point cloud interpretation procedure. There are pieces of software that are capable to locate certain patterns and characteristics; however, they require human knowledge to sort and convert contents of these point cloud data.

**ACQUISITION OF POINT CLOUDS**

The access/visibility to scanned areas is the principal element in collecting point cloud data. It is vital to notice that point cloud is captured by visible access to actual items. Indifferent to the approach of gathering (scanner or photos), it is not feasible to capture points on the exteriors that are not visible from the direction at which we capture data. In other words, we must integrate several scanning positions to have full coverage of the objects. The term density is used to illustrate resolution on the collected dataset that is commonly known as the space between two points. Needless to say, capturing of less dense point clouds are much faster. Majority of point cloud databases comprise of not only point position, but also of explanation of visual features, which are for instance the object color or its reflectivity. These might not be part of point cloud and it is another element that impacts the time of collecting scan. (Ciępka, 2016)

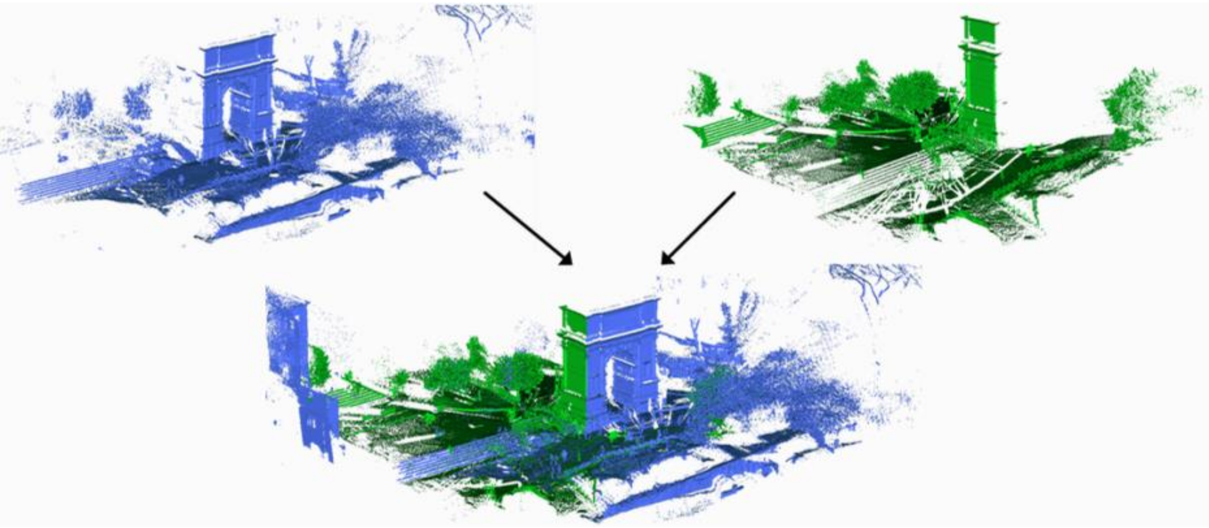


**Figure 13: Coverage the objects with the Integrating scanning positions (Theiler & Schindler, 2012)**

## 2.3 Comparison case studies

Obtaining accurate and practical approaches to evaluation and comparison should help to define the concept of corporate reliability and provide professional tools in this field.

With investigating throw the seven case studies, related to scanning to BIM procedures that are shown in the following table, it reaches how some tools can help the maintaining the heritage and historical buildings.

Since HBIM is a novel technology; it is still at its early years. Therefore, some of the case studies in this field are yet to be practiced thoroughly. In order to have a more precise grasp of the future of this technology, it is advisable to use the case studies that have been examined by means of this technology and also inspect its achievements that have been accomplished so far. Undoubtedly, they can lay the foundations to be used in future studies. HBIM could be used for various ends and objectives, so it can be employed differently in projects.

The purposes of this comparison are:

- Find out how scan to BIM and scanning is helpful for H-BIM,

- How can H-BIM get help historical building to improve their structure and maintenance the disasters or issues?

- To get a look what H-BIM can do in the future steps?

The following table (Table 3) shown the summaries of some case studies that worked on HBIM technology.

**Table 3: Comparing the case studies in H-BIM**

| Case study | Software | Summary Methodology | Deliverable output | References |
|---|---|---|---|---|
| The Restoration and Re-building of **Notre Dame,** France | Trimble point could regis-tration software | "Creates a point cloud model with more than one billion points data by the tripod laser scanner and drone." | "Point cloud Data with the high level of detail for modelling in BIM software in future." | (Trimble, 2020) |
| Leicester Cathedral – scanning the interior, UK | real-time, Autodesk Revit | "Create an H-BIM library with laser scanning and photos for design-ing a tomb and reorder the cathedral." | "3D parametric design in Revit with a high level of data, the point cloud data is a comprehensive archive record that can be reached at any time throughout the project life cycle or for future projects." | (England, 2018) |
| Scanning of Bujang Val-ley archaeological mu-seum | Geometric studio<br>Faro scene<br>AutoCAD | "Create an H-BIM library by using 3Dlaser scanning and point cloud." | "3D photorealistic model in a 3D PDF document for representing of cultural heritage to a larger audience." | (Wei *et al.*, 2019) |
| Uphill Manor – combining terrestrial laser scan and aerial SfM point cloud data | Geometric studio<br>Faro scene<br>Adobe RAW | "Terrestrial laser scan and aerial SfM point cloud data combined." | "High detail level 2D floor plans, eleva-tions and parts of the building in DWG format, and 3D texture model in OBJ for-mat." | (England, 2018) |
| Priory House – laser scanning and modelling | Faro Scene<br>Autodesk Recap<br>AutoCAD<br>Autodesk Revit | "Laser scanning and Modeling in BIM." | "In each section of the design group work, the BIM model document with the exact measurement is available for use and a full archive record for the future project developer that can be accessed at any point during the project life cycle or for future schemes." | (England, 2018) |

After investigating between some case studies, it has observed that regarding to using the H-BIM approaches some advantage and disadvantages exist.

Advantages using H-BIM approaches, in most of them were that these historical buildings need some renovation, maintenance, and improving the quality building or need the virtual reality for showing them in the virtual spaces. Hence, H-BIM could help them in enhancing their structures in a wide range of activities.

On the other hands, due to complexity in the heritage's buildings, they need a simple and accurate approach for harvesting the data. In hence all the activities need to use the new technology.

New technologies could work adequately in surviving information on complex structure such as historical and old buildings. In all of them, examiners tried to do in a point cloud spatial and completed their process with the BIM software; therefore, they believe that HBIM can help them in facility management and virtual remodeling and future projects.

There are many reported challenges and problems in this process, a large amount of collected data in the form of point clouds, especially for the projects that have to be performed in large areas is an example. Another problem might be the incapability to test the data validity and affectivity so quickly while collecting data because these problems require a substantial collected data sample or real-life experience on the job. Nevertheless, another problem is that in some projects there are some parts of the building that are not readily accessible, which would make it harder and more time-consuming to pinpoint whether the captured point clouds have the standard quality or not.

## 2.4 Summary

The examination of the arguments of this chapter illuminates the significant role of facility management in the maintenance of heritages buildings as well as the importance of BIM technology for employing it in the as-built method and modelling. Furthermore, the accomplished projects and outstanding achievements in this field of the study prove that in the present time, users attempt to make use of fast and precise approaches with a minimum amount of effort to take in order to obtain the most desirable outcome such as in the automatic techniques in the identification and modelling process. The reasons, as mentioned above, promote the rapid expansion of developing technologies.

Hence, according to the Trimble, “throughout the building workflow, 3D scanning is regularly used on both type of buildings, new builds and remodels or on renovation projects. Scanning a structure prior to renovation may help register, preserve, and reconstruct the appearance of existing building elements. Complete 3D site models generated from these scans will assist in planning the specifics of a new structure during the design and construction process. They may also document spatial and physical details about a building in the areas of preservation and heritage, or help conservationists identify problems and find solutions.” (Trimble, 2020)

Concerning the points mentioned above, it can be concluded that this interdisciplinary technology struggles to connect every field of technology from laser systems, identification of data, and management to practical software to be used in projects.

Once the notions of these principles have been grasped, their significance in the developing construction industry and the ways of preserving the structures, mainly historical and cultural heritage, would be revealed.

In the following chapter, novel technologies for rapid and accurate modelling will be studied. After thorough analysis, a decision would be made to perform a case study by means of laser scanning technology in this field.

# 3. Qualitative data analyzing methods

## 3.1 Introduction

While advocating that the majority of research addresses providing BIM in new buildings Edirisinghe (2017) also mentions that these studies are still very rare for existing buildings. Since they exhibit fresh challenges for FM, plans should be digitized as a BIM model for ease of work, and 3D laser scanning should be employed to create a digital model. Delineating information requirements and data harvesting, missions and liabilities for stocking these data into the model and sustaining the model are fresh challenges for BIM-enabled FM, exposed through interviews with people involved on the ground. (Edirisinghe *et al.*, 2017)

According to this definition, BIM-related systems for existing buildings will be examined in the following. These buildings can be significant because they are heritage and historical buildings. In this chapter, we will learn how to use different tools and methods to harvest and implement an existing model.

## 3.2 Collection and processing Data from point cloud data

As mentioned in the previous discussion, BIM can be used in different models of constructions in the new buildings or the ones that previously exist. Hence, the process of using BIM is different in building structures. The existing building has rarely used BIM in their construction process, therefore, for preparing the model, updating information is required. Therefore, in order to organize the model renovating data is a prerequisite. Therefore, the process of preparing a BIM model in this type of construction will start from extracting the existing building data.

BIM model generation of an available structure mandates preconditions such as gathering geometrics of both the building and its components.

Afterwards, BIM group object formation decrees a thorough provision as well as validation of information. Here, a meticulous, solid technique can significantly diminish the cost and time for creating BIM model through automation and remarkably expedite the tasks by enhancing documentation and visualization. Most of the structures are

grouped into the third class; accordingly, preconditioning a preliminary scan for the sake of BIM model formation. (López *et al.*, 2018)

The following diagram (Figure 14), drawn from Krämer and Besenyoi (2018) vindicates the notion of similarity in the general workflow in the as-built digital capturing methodologies regardless of their gathering approach. There is more information apparently noticeable on the diagram such as the exact subprocesses. The associated time involved along with the pivotal other factors. This is the totality in the task performances in As-Built Digital information collection as well as the steps in point cloud implementation procedures. (Krämer & Besenyoi, 2018)

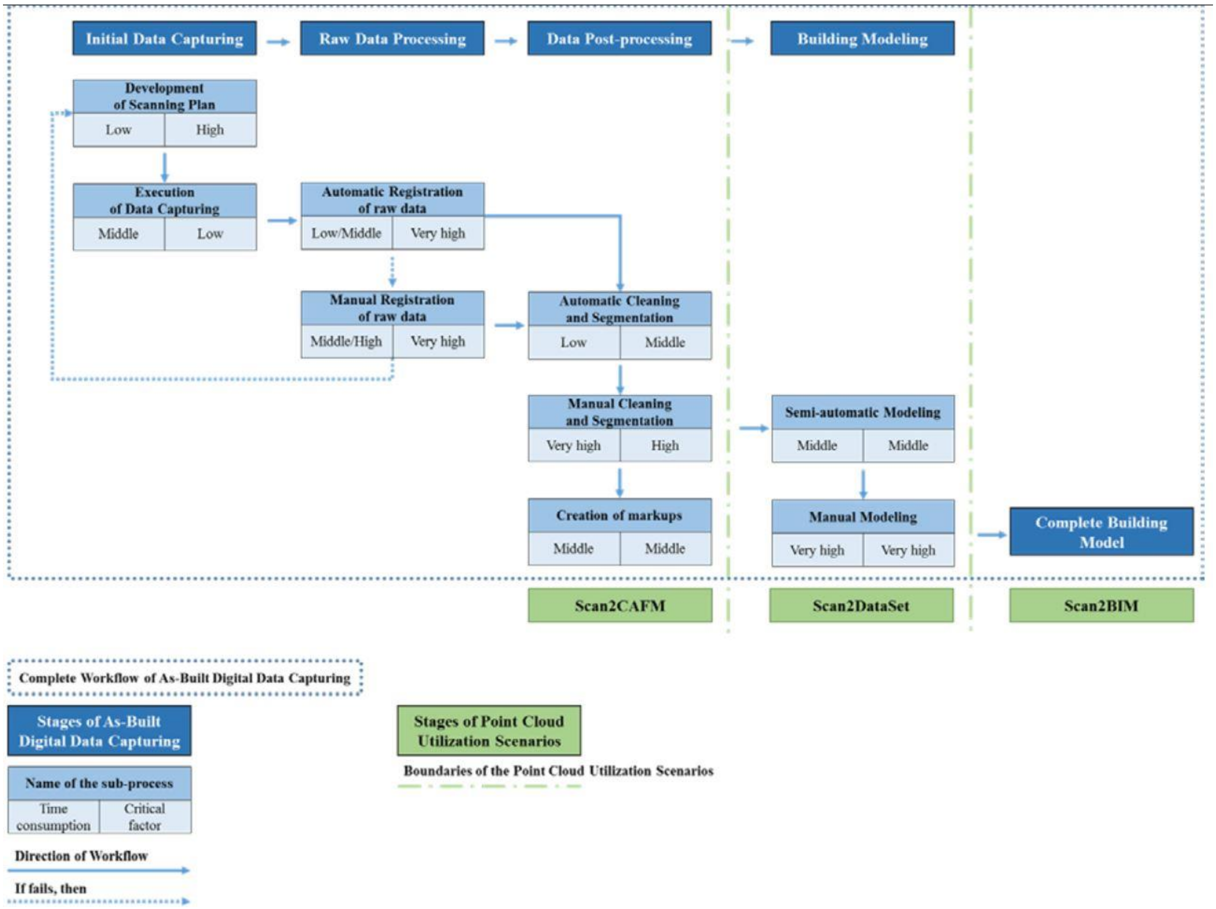



**Figure 14: The overall workflow of Scan to BIM and the Steps of Point Cloud Utilization Scenarios** (Krämer & Besenyoi, 2018)

The surface of the scanned elements is outlined in detail through the captured and treated point clouds. Unfortunately, further information on the object`s geometry is not contained. Consequently, capturing topological, geometrical, and semantic attributes necessitates 3D parametric objects or geometric models. This 3D modelling is outlined as a reverse engineering procedure. Determining the correct surfaces and promoting the modelling or tracing of parametric objects is rudimentary steps recognized as the

recognition and segmentation of point clouds. Thanks to advances plugged into the BIM, together with new algorithms of object recognition and point cloud segmentation, these steps are now carried out both automatically and semi-automatically. (López *et al.*, 2018)

### 3.2.1 Data capturing

Data capture technology or survey is to be employed when data formation is not meeting the necessary procedures. Owing to its vast impact on necessary data quality, data volume and processing effort, LOD establishes the entire oncoming steps ranging from the selection of technique to the formation of the model. (Volk, *et al.*, 2014)

The data exacted from the different scans constitute partial-point clouds {(xi, yi, zi)}, and then each one of these point clouds are merged to generate a comprehensive cloud that will portray the site. This procedure is termed point cloud registration. A good overlapping between proximate point sets (i.e., 20–30%) is requisite. In this overlap, various common tie points or targets between point clouds must be disclosed. (López *et al.*, 2018)

### 3.2.2. Data processing

Coupled together following the overlapping regions, the rough data within the second phase offers a singular. point cloud information documented. It is as well viable to couple the rough data arising from various capturing approaches in this procedure. This registration procedure initiates either manually or automatically (or according to targets / tie points in special cases). For its part, documenting automatically saves more labor time that its counterpart, but also demands greater similarity factor (above 55-60%crissroccing) from the data couplets upcoming to be registered. (Krämer & Besenyoi, 2018)

Semi-Automatic Modeling Approach: the user conducts this process in the fashion of modifications, extractions, sections and extrusions of surfaces created to buy the point cloud. Hypothetically, the process involves the application of the formulation programming tools that would be setting up the succession of these stages manually at geo-

metric sections of X<Y and Z correlations of the point clouds. Considering to the sections and levels, the planes and planarly viewpoints of the described geometric profile are in fact the captured scanned objects. (López *et al.*, 2018)

The same author López (2018) goes on to say that, “the geometric modelling of the scanned architectural is precious for documenting and publicizing information concerned to the existing buildings. Nevertheless, the realization of its implementation is a demanding and time-consuming task that assumes competent workers. These obstacles are put forward by the orthogonal constraints that are introduced primarily as a result of the design software and the high numbers of unavoidable steps to parametrically model the complex geometries that are present in point clouds. This is caused by the deficiencies in algorithm in their inability to segment and model autonomously the point clouds which present plane surfaces, as they create inaccurate results when presenting intricate and irregular geometries of historical buildings. Of course, it should be observed that no algorithm or complement has yet been totally verified. As a result, the semi-automatic process is at present the most viable procedure for documentation projects and the parametric modeling of historical buildings.” (López *et al.*, 2018)

The point clouds of every scanned object are first of all located in the scanner`s internal regulation structure. Using scan to BIM approach as registration, all these data must be harmonized in a common, universal coordinate system. In spite of the automated registration techniques, documentation procedures are nevertheless mainly semi-automatic. (Tang *et al.*, 2010)

In order to boost the registration procedure, the user must manually specify, in 3D data, the general locations of particular targets that have been planted in the context. Preprocessing these data, whether automatically or manually helps to eliminate unwanted data, such as reflections, points from moving objects or sensor artifacts. Depending on the software or the modeling algorithm, the point cloud data is subject to conversion into surface data, normally in the form of a triangular surface network. This process may be carried out at each particular scan level, then, the outcomes are blended, or the point clouds can be registered first, finally the surfaces could be evaluated from the blended point cloud.(Tang *et al.*, 2010)

Correspondingly, when raw data initiates from the differing methods of data gathering as well as resembling parts of the building such as the staircase steps there is the necessity for manual registration.  Accordingly, the overall point cloud formation attainment substantially rests on this procedure; this factor is absolutely critical. Interestingly, it might last for a short time or extend for a while in accordance with the number of preliminary data and the overlaying areas. (Krämer & Besenyoi, 2018)

### 3.2.2 Data post-processing

Cleaning the point cloud data is an essential post-processing step after sensing the infrastructure spatially and ahead of further 3D modelling. (Rashidi *et al.*, 2016)

At this time there are two actions to be taken, firstly to eliminate the unwanted point in the point cloud and secondly, formation of the separate district segments out of the vestigial (Figure 15 a). Additionally, this stage can be carried out manually or semi-automatically. Whereas the total point cloud is documented automatically relevant to their specific building group such as Building group, poles, plants, and ground the parts that resemble each other must be segmented semi-automatically (Figure 15b).   Moreover, there are still some other noises left of the windows reflection or shadows that needs manual deletion (figure 15 c). (Krämer & Besenyoi, 2018)

a b C

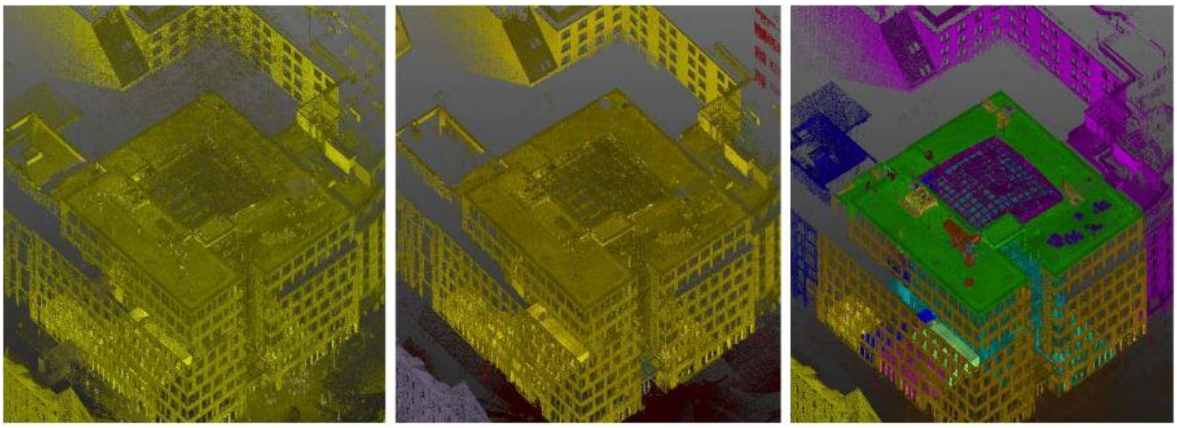


**Figure 15: Data post-processing of point cloud data**(Krämer & Besenyoi, 2018)

Processing these data, whether automatically or manually helps to eliminate unwanted data, such as reflections, points from moving objects or sensor artefacts. Depending on the software or the modelling algorithm, the point cloud data is subject to conversion into surface data, generally in the form of a triangular surface network. This process

may be carried out at each particular scan level, then, the outcomes are blended, or the point clouds can be registered first. Finally, the surfaces could be evaluated from the blended point cloud. (Tang *et al.*, 2010)

### 3.2.3 Building Modeling

During the last stage, the digital building model will be generated consistent with the accepted point cloud data. This creation can also be carried out in semi-automatic or in a traditional, manual way. Through the first alternative, the building modelling is increasingly improved by a semi-automatic modelling system which is capable of modifying the whole point cloud data into parametric building objects (native Revit Family objects). (Krämer & Besenyoi, 2018)

Creating BIM objects in a manner that illustrates building elements comprising both non-geometric as well as geometric factors and correlations implies modelling. BIM herald data quality by means of the implemented machinery and LOD arrangement if it is modeled former data collection and identification. For the sake of comparing the modelling potential of diverse approaches, model creations are susceptible to assessment with BIM modelling software released by a few primary companies such as Navisworks, Graphisoft ArchiCAD, Bentley Architecture, Autodesk Revit, Tekla or Nemetschek All plan. (López *et al.*, 2018)

As it investigates in chapter 2 as it investigates in chapter 2, BIM technologies enable the introduction, creation, documentation, or manipulation of three- dimensional models. (Table 4) can show the different type of technics with their software and their formats exportations.

**Table 4: BIM platform groups**

| | PRODUCT NAME | COMPANY | INITIAL FUNCTIONS | INTEROPERABILITY | WEB LINK |
|---|---|---|---|---|---|
| 3D MODELER | ArchiCAD | Graphisoft | Creating architectural models | DWG, DXF, IFC, SKP, | http://www.graphisoft.com |
| | Tekla structure | Tekla | Detailed design of 3Dstructures models | DWG, IFC, DGN, DXF,CIS/2, DTSV y SDNF | http://www.tekla.com/la |
| | Revit | Autodesk | Creating and reviewing 3D models, Design and structural review, Design and review of facilities | DWG,DGN, Dxf, Sat, SKP, IFC, DXF, gbXML | http://www.autodesk.com |
| | Bentley | Bentley system | Creating and reviewing 3D models | IFC, DWG, DGN, Dxf,PDF, gbXML | https://www.bentley.com/en |
| | Sketchup | Trimble | 3D conceptual modeling design | DWG, DXF | https://www.sketchup.com |
| 3D AND 4D VIEWERS | Naviswork | Autodesk | 4D Model Display and clash detector | IFC | http://www.autodesk.com |
| | Ecotect analysis | Autodesk | Energy, temperature, water and carbon emission analysis | IFC | http://www.autodesk.com |
| | Synchro | Bentley | 4D model display and clash detector | IFC | https://www.bentley.com/en |
| 5D AND 6D COST AND FM | Bentley | Bentley system | Analysis and structural detail.5D Materials calculation. | IFC, DWG, DGN, Dxf, PDF, gbXML | https://www.bentley.com/en |
| | Bexel manager | Bexel | 5D and 6D model display | IFC, DWG, DGN, Dxf, PDF, gbXML | www.bexel-manager.com |
| CLOUD BASE | real work | Trimble | photogrammetric processing and Point cloud manager | Las, E57 | www.trimble.com |
| | AGI soft | AGI soft | | TLS, | www.agisoft.com |
| | Recap | Autodesk | | Rcs, RCP, FLS, PTG, PTX, ZFS, RDS, OBJ | www.autodesk.com |
| | Eadgewise | Trimble | | | www.trimble.com |

## 3.3 The overview of the workflow for obtaining the HBIM case study approach

Base on the previous chapters regarding the study on HBIM process and Qualitative data analysing methods, the following workflow is obtained for processing the case study in the next chapter. Figure 16 shows six phases of workflow that has been explained as follows.

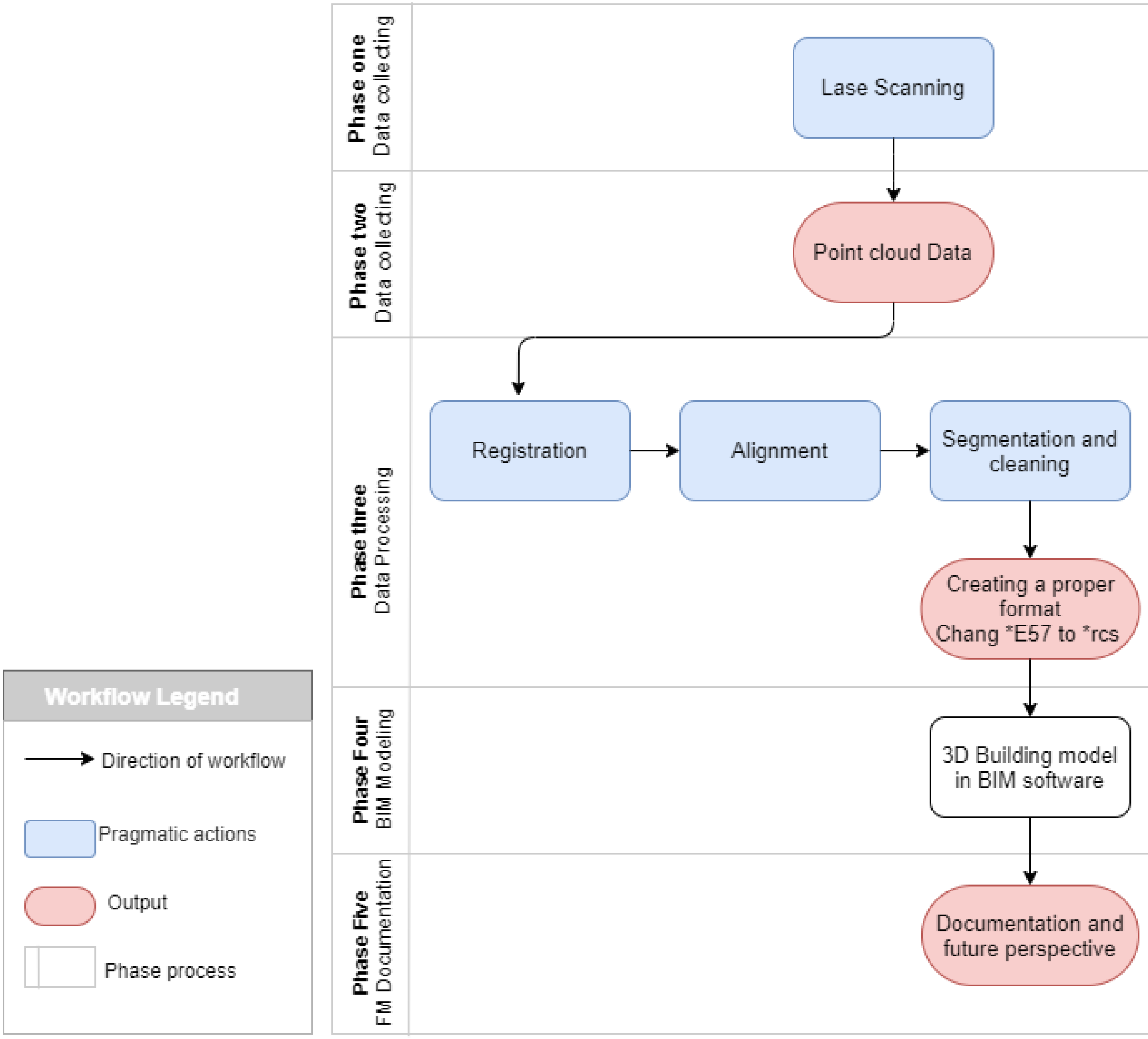



**Figure 16: Case Study workflow for H-BIM (By auther)**

**Phase one:** in this phase as it is selected the laser scanning approach it will be used the Trimble TX8 for scanning. The laser scanner field of view is 360x317, and for imaging, it is integrated HDR camera in 10MPixel resolution with a full field of view. (Trimble, 2013)

**Phase two:** the point cloud is obtained from the laser scanner.

**Phase three:** after obtaining the point cloud it should be managing in some special software that in this case study it will be used Trimble Real Work for aligning, segmentation and cleaning the point clouds.

in order for the point clouds to be formed precisely it has to be tuned to a *.rcs format. In this case study, it is obtained the IFC file for importing to the BIM software by Autodesk Recap.

**Phase Four:** The IFC file obtained from phase three is ready for using in any BIM software for remodeling a structure in each level as the owner wants. Like, 3D, 4D,5D or 6D, in the continue for modelling the museum building it will be using the Revit software, and the obtained final file is used for converting in any BIM software for the future work.

**Phase five:** Meta information is the building block of historical projects considered as heritage. A category of data is portrayed concerning the descriptions of survey data. Thus, enabling perspective studies on the subject and a clear method for the interested users. Additionally, a substantial amount of the information being submitted to the archive must consist meta data for future users. In this case study, the final format is *.RVT and *.IFC. In continue it will be work on a Museum für Naturkunde as a case study step by step.

## 3.4 Summary

As it surveyed in this chapter, achieving a BIM modelling for using in H-BIM contains diverse procedures. Hence in the first step the scanning location and the required planning should be observed. The number of laser scanning stations for calculating the LOD should be examined as well. Moreover, it is needed to prepare the building plan after visiting the site. Additionally, considering the obstacles are important for deciding about the station plan.

In this chapter, the mentioned methods and techniques were reviewed from some renowned articles and books. Base on figure 14, and what was stated in the second chapter, a model was obtained (Figure16) to perform a case study. This model will be used in the next chapter to review and model the case study of the Berlin Museum.

# 4. virtual modeling of Naturkundemuseum via HBIM process

In the continuation of this chapter, the natural history museum of Berlin will be examined using laser scanner technology and based on what we have learned so far.

## 4.1 Introduction and building history

According to the Naturkundemuseum (NKM) website, that explained about NKM history, “Friedrich-Wilhelms-Universität historical complex was founded in 1810. This museum was part of a university during its establishment. The complex was established as a research institute as well as a place of scholastic purposes to educate people. As a result of a remarkable growth in its importance there was a need for expansion of the building.

This building was constructed to include three research centers which are Prussian geological institution ‹agricultural college, and natural history museum. The architect of the complex intended to unite the three centers as one, therefore; it took sixteen years to complete the structure.

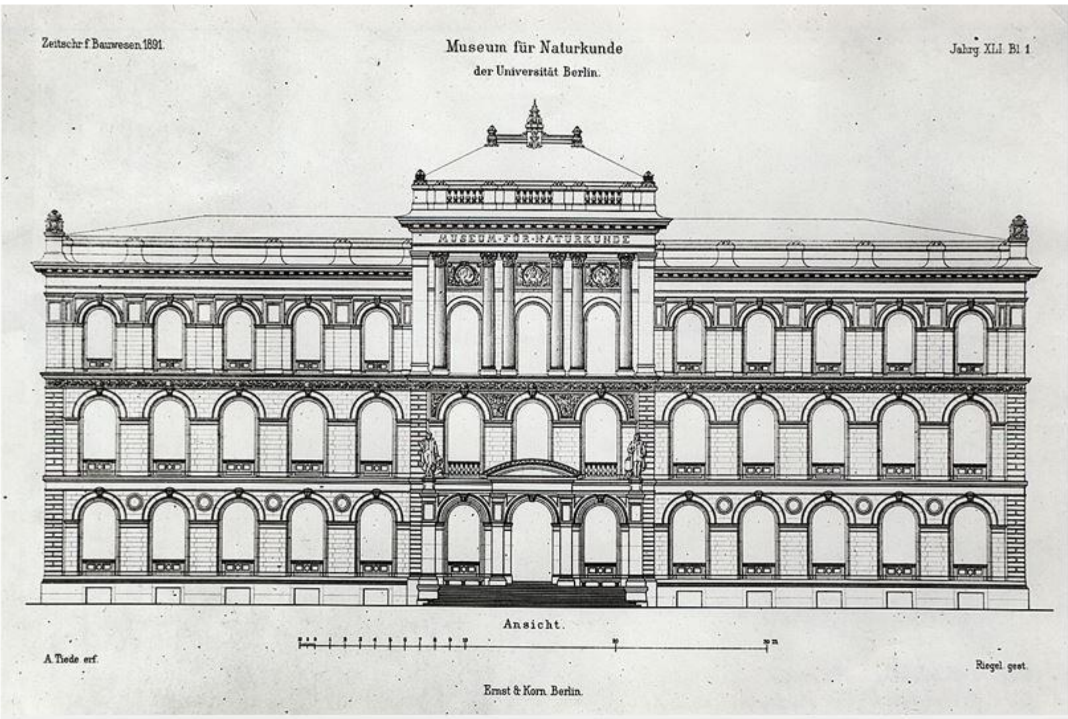
One December 2nd, 1889, the Emperor Kaiser Wilhelm Ⅱ opened the new building of the museum. This part was supposed to be a research-based center in order to attach the museum to the new institute of science and technology. The museum collections were expanded greatly through donations, purchases and discoveries from expeditions. Consequently, the need to enlarge the place to house all its properties was felt and a few years after the opening of the museum, the designs began to expand on and add extensions to the original building.

Although the new buildings were never built, a wing was added to the north side of the complex during 1913 to 1917. This new constructed part was designed to meet the requirements of museum exhibitions from 1918 to 1925. In consequence, the museum structure with its present look was formed.

The museum is more than 140 years old and was damaged during World War Ⅱ. It was timeworn by decades of constant activity. The war damages and the wearing away of the structure paved the way for reconstruction of the building. After examination of the building, the museum objects were transformed to a smaller space to preserve

them from destruction. (Figure17) is the façade plan that planned in 1891." (Naturkunde, 2020)

A




B


**Figure 17: The top photo (a) was Museum für Naturkunde façade plan in 1891, Bottum photo (b) is a recent picture from the Building Façade. (Naturkunde, 2020)**

Reconstruction project was a long-lasting plan, hence; within the museum research plans and its exhibitions the project was carried on. The renovation measures began on the exhibition halls during 2004 to 2007. It is followed by the rebuilding of eastern wing which was severely damaged during World War Ⅱ. Although the second step of renovation mission had been completed, it did not indicate that the rebuilding plan was totally accomplished because only 38 percent of the structure was renovated to meet the modern needs. At the present time, the third step of renovation is in progress. (Naturkunde, 2020)

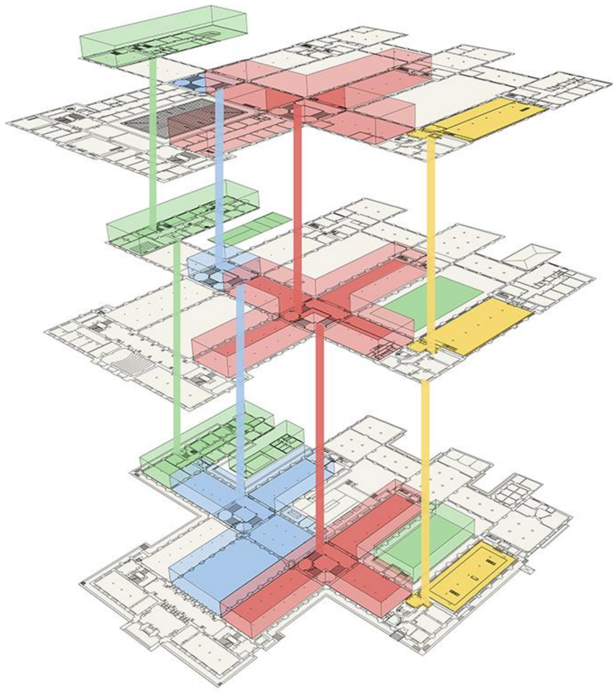


**Figure 18: Third step of NKM renovation. (Naturkunde, 2020)**

## 4.2 Naturkundemuseum analyzing process

As it surveyed in the previous chapters, achieving a BIM modelling for using in H-BIM, depends on some direct-acting. Which, within them, it can be mentioned CMP and preparing the site and supplying the facilities before the laser scanning task. CMP regards to fulfilling the owner needs, and after their offering from owners, thinking about three phases is most important for each project. Before scanning and choosing approaches for getting the point cloud, laser scanning and after laser scanning and inverting the point cloud to the visual modelling.in the following, it will be investigating for NKM project step by step.

### 4.2.1 Before laser scanning.

**Evaluation of laser scanning:**

According to the information, which was given in chapter3, laser stations are scanned and the distances between them are calculated through the specific formula. Then, with the help of AutoCAD software, the distances of the stations can be acquired and marked on a map. The laser device is placed in the chosen stations and because of the prominence of that part, the quality level of point picking is ranked. For spaces with a large number of objects but a low density, the sensitivity of the laser can be increased, which also increases the surveying time.

Due to this issue, the number of stations in this study was estimated to be about 91 with different sensitivities and qualities. It includes 62 indoor stations and 29 outdoor stations that were marked on aerial photographs and existing maps of the building.

**Building facade:**

In this studying case, 18 stations are considered for the main facade of the building, which has the priority of surveying according to the map (Figure 19) with different rankings.

To start work, the primary station is planned in front of the building's entrance door, and the other stations cover the facade of the building accordingly.

The building is about 40 meters high, which according to the length of the applied laser range, is suitable for surveying. It should be stated that in areas where the access to laser is difficult, the altitude is high or some obstacles block the laser path, we can use such alternative methods as Drone.

**The internal space**

The internal space of the museum building includes numerous rooms and corridors. The entrance of the building, which was the starting point for the measurement of cloud point, was covered by 4 stations.

For joining the points taken from one space to another, it is essential to overlap the surfaces, which can be formed by creating stations at the entrance threshold of the doors of each space, so that as shown in (Figur19 a), Five of the stations were located in the middle of the doors. To make it easier to link the two different spaces when registering points.

**The old room on the second floor of the building:**

As requested by the client, the building`s second floor space and its old pillar, which needed to be renovated, were also obtained by laser scanning of its cloud points through two points.

Due to the fact that this space is located on the second floor and there was no common space between it and the acquired points, it had to be connected to the building through a common zone. The window that is located on the west side of this room opens while facing the yard behind the building, so it can be used as a place to join two cloud points. Thus, one station is considered in front of the window and the other is next to the pillar.

**The external space around the building:**

In order to obtain the overall model as well as the commonalities for linking the internal points to the external ones, particularly the space that was surveyed separately on the second floor, it was vital to consider some stations outside the building to connect them. These points helped the created overlap between the stations to easily connect the separate spaces. (Figure19b)

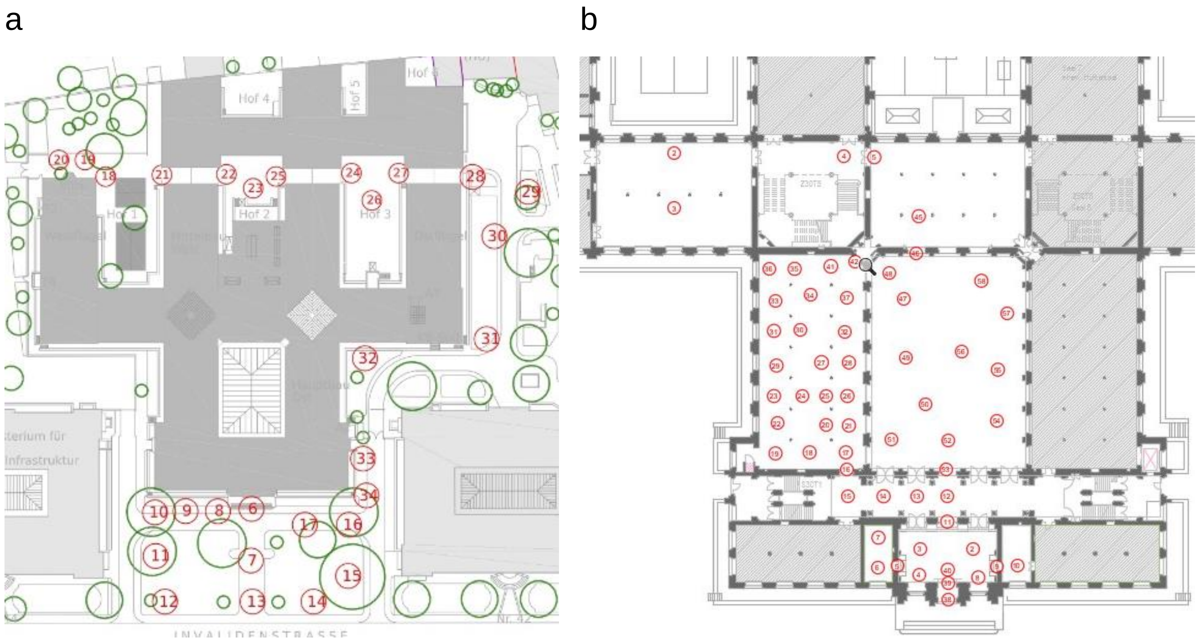



**Figure 19: Pre-planning for demonstration the stations place, (a) is outside stations plan, (b) inside stations plan (by author)**

### 4.2.2 Laser scanning

During the laser scanning and after full revision of the drawings and the number of stations calculated in the previous step, we should implement drawings in the building site.

According to the calculations founded on the exploration of the location, a whole range of scanning points and times are obtained following to their LOD.

Then, we should stand the device in locations determined on the plan. We worked with the Trimble tx8 laser scanner in our project, consisting of a tripod and upperparts, i.e., the camera and laser.

After indicating and analyzing the location, we will be present at the location and install the tripod. The tripod must be at a reference point, and the monitor on the scanner laser shall be in line with the viewer's direction while standing a bit higher elevation can also give optimal results.

**Laser Scanner Trimble TX8:**

In this case study Trimble laser scanner (Figure 20) has been used to obtain the point cloud. According to the information on Trimble's official website about this model of laser scanner. The laser scanner field of view is 360x317, and processing speed is 1 million pts/sec, and its scanning range is 120m Stand, 340m Extended, also this camera has Integrated HDR camera in terms of image accuracy with a 10 MP resolution. Designed for production, the Trimble TX8 able to complete 3D laser scanning projects quicker than ever. (Trimble, 2020)

According to Trimble website, “The Trimble TX8 provides a 360° x 317° horizon and captures full high-density scans in only three minutes. The Trimble TX8 keeps its high precision over the entire range of 120 m with no need to reduce speed. Plus, it is available with an optional upgrade extending the range to an impressive 340 m.” (Trimble, 2020)

**Figure 20: A sample laser scanner camera the model Trimble TX8 (Trimble, n.d.)**

This device has a monitor on the main part that can help the operator to check the stations and change the LOD.

Base on Trimble website, “The Trimble TX8’s ability to capture precise high-density 3D data, combined with Trimble RealWorks software’s advanced modeling, analysis and data management tools, make the Trimble TX8 laser scanner the complete scanning solution for geospatial professionals.” (Trimble, 2020)

**Table 5: Trimble laser scanning TX8 LOD table. (Trimble, 2013)**

| Scan Parameters | Preview | Level 1 | Level 2 | Level 3 | Extended[1] |
|---|---|---|---|---|---|
| Max range | 120 m | 120 m | 120 m | 120 m | 340 m |
| Scan duration (minutes)[3] | 01:00 | 02:00 | 03:00 | 10:00 | 20:00 |
| Point spacing at 10 m | 15.1 mm | ——— | ——— | ——— | ——— |
| Point spacing at 30 m | ——— | 22.6 mm | 11.3 mm | 5.7 mm | ——— |
| Point spacing at 300 m | ——— | ——— | ——— | ——— | 75.4 mm |
| Number of points | 8.7 Mpts | 34 Mpts | 138 Mpts | 555 Mpts | 312 Mpts |

### Trimble RealWork software

For processing and analysis, the point clouds for importing to the other software, the most compatible software with 3D Trimble laser scanner is TrimbleRealWork software.

Trimble RealWork is specifically designed for the processing and analysis of point clouds. The software offers a complete solution for capturing, analysing, modelling, and generating deliverable data from virtually any source efficiently. Automated registration and point-cloud cleaning tools,

- Act effectively with instruments and workflows explicitly designed for point cloud processing.
- Be prepared for any project with one of the industry's largest range of tools for point cloud processing, including registration, surface formation, comparison of surface to surface and modelling. (Trimble, 2020)

**Levelling the scanner tripod:**

Following the changes made to the tripod we can install it so that the bubbles inside the levelling box are in their proper place.

We should perform levelling for all stations separately to ensure that the camera is perfectly levelled on the ground. The process of levelling the camera can be done with the help of buttons on both sides and also behind them. The purpose is to install the camera in a levelled position. (Figure21)

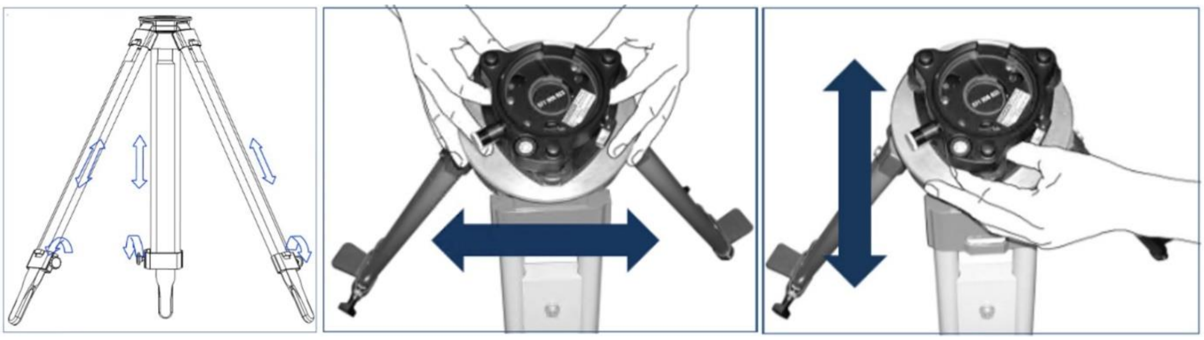


**Figure 21: Levelling the Laser scanner tripod.** (Trimble TX6-TX8, 2017)

All scanning lasers have a capacity of 360 degrees scanning, but this is not always enough. Therefore, we should define the scanning areas through multiple ways and measures.

There are multiple parameters in play during the laser scanning, one of which is the location where the device is installed. Since even a 360-degree scanning is not always necessary, we should precisely determine the areas to be laser scanned.

- **Laser scanner locations:** In this project, we altered these stations based on how high a specific building is, and how much surface area is its frontal view,

its access (shape), and the holes inside the building. Since we wanted to investigate the building's interior sections and facade, we had to choose laser stations so that they could overlap to can identify commonalities and connect the points during the registration of stations.

- **Point cloud resolutions:** The image resolution is another factor to consider during laser scanning, where the choice of image resolution and LODs depends on the importance and complexity of that part of the building. (Table 6) shows the time to obtain the locations of each station for points determined. More information on stations is visible on it.

**Table 6: Stations accuracy (by author)**

| **Area** | | **Number of stations** | **accuracy** | | |
|---|---|---|---|---|---|
| | | | 1 (2min) 35 million points | 2 (3min) 139 million points | 3 (10min) 555 million points |
| **First floor** | Entrance | 11 | 8 | 3 | - |
| | Corridor | 6 | 6 | - | - |
| | Main hall | 13 | 13 | - | - |
| | 1st Room | 25 | 25 | - | - |
| | 2nd Room | 4 | 4 | - | - |
| **Second floor** | | 2 | 2 | - | - |
| **Main façade** | | 13 | 5 | 4 | 4 |
| **Building surrounded** | | 17 | 16 | - | 1 |

According to the Trimble manufacturer instruction, the image resolution is measured according to the distance between two consecutive points and we can specify LODs on the scanning drawing. If we want a high-quality image, increasing the number of these stations with higher LOD can improve the quality. The point to consider here is that since increasing the distance between points and reducing the number of points negatively affects the image quality, we can reach an optimal resolution by more features and expanding the scanning time through the LODs.

In the museum project, we obtained the number and quantity of points in the form of the table below, according to the importance of some points and the distances between them, and the number of points specified.

- **Initial filters**: There may be barriers to each scan that affect the quality and quantity of points scanned. It is, therefore, recommended to check the places and stations and then start to laser scanning. Under this situation, we can change the points and their location after being at the project site and field survey.

In the project of scanning the museum building, there were some obstacles such as trees, paintings, ticket kiosks, and adjacent structures in exterior locations. And furniture, statues, art crafts and e.t in interior locations, that we had to consider them in the plan of stations. These hindrances led us to edit the initial locations plan. (Figure22) shows the external obstacles and (figure23) shows internal barriers.

**Figure 22: Exterior obstacles like Trees in front of the main view of the obstacles available for laser scanning operations. (photos by author)**

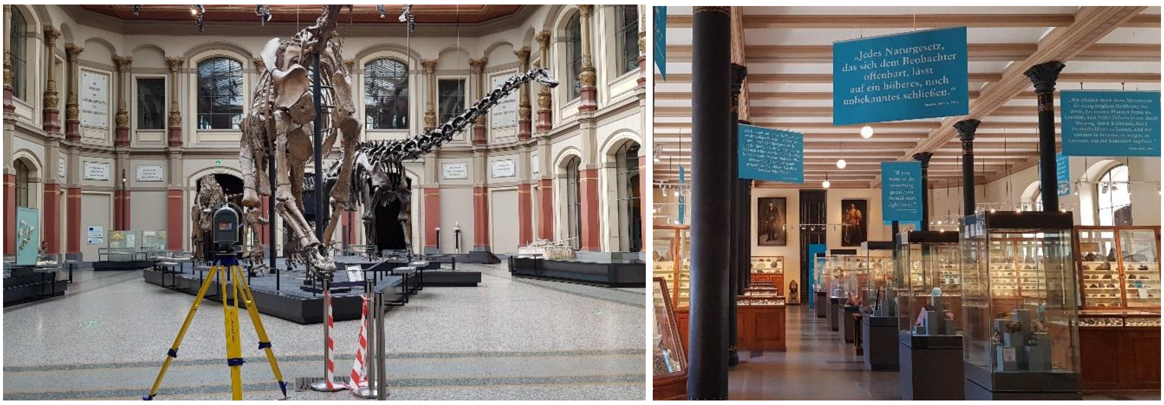



**Figure 23: Interior obstacles like furniture's, art craft, statues. (Photos by author)**

The number of estimated stations in the site was increased because of the presence of large and green trees in front of the building's facade.

once we have set an angle to start with, and found the most pertinent strategy, we can start automatically scanning the site. We should only check the levelling of the tripod on the ground and the quality of the images at each station.

**How to join the internal and external spaces:**

As mentioned before, the time to obtain clouds points varies depending on the level of the stations' sensitivity and accuracy, and these surveys (process) may take days. Also, in this case 96 laser scanning stations have been considered in order to acquire these cloud points which resulted in a set of points inside and outside the building done in two different days. Now there should be a tact to connect them in order to join these two spaces (internal and external) at the time of the points' registration. Therefore, there is a need for a common zone through which the external space is connected to the internal space that can be referred to the entrance door and the space in front of it.

This common zone can be windows, doors or elements which are common between both the external and internal spaces. In this museum building, it has a variety of windows and opening to attain this goal, which can help the process in the registration steps.

### 4.2.3 After laser scanning

All the data is prepared and archived for use after the project has been done in the museum building. It is suggested to work on the copied version of the data in order to keep the original version as a backup.

It is recommended to use more uncomplicated and recognizable formats for processing data. It should be noted that each laser scanner data and point cloud extraction technique possess their own specific format. In this project, the format used for the files is TZF-Daten. In this stage, it is needed to employ the prepared maps at the time of extracting points in the workroom.

Before processing data, environmental scans or deficiencies followed by human errors must be eliminated from data sets. Besides, all the files kept should be categorized according to the time of extraction and the order of the maps numbered chronologically. In this case study, data collecting was carried out in two successive days. In each day the first laser station captured the scans twice, the first one was for testing and the second one was for mere scanning. Therefore, it was required to withdraw extra files from the folders, and the data should be classified in accordance with the maps, date of extraction and the notes taken of the building.

Considering the fact that the scanned area was gigantic in the museum project, one

laser station could not cover all the space, so more laser stations were used to capture points from the site. In the following (Figure 24) which is of the building façade, the categorization, stations covering, and overlaps are somewhat illustrated.
From the plan view in (Figure 24 a), the stations and their overlaps are perceived. In (Figure 24b), the overlaps are depicted in the front view of the building and (Figure 24c) displays the way stations are categorized so as to be transferred to the software.

a b

c

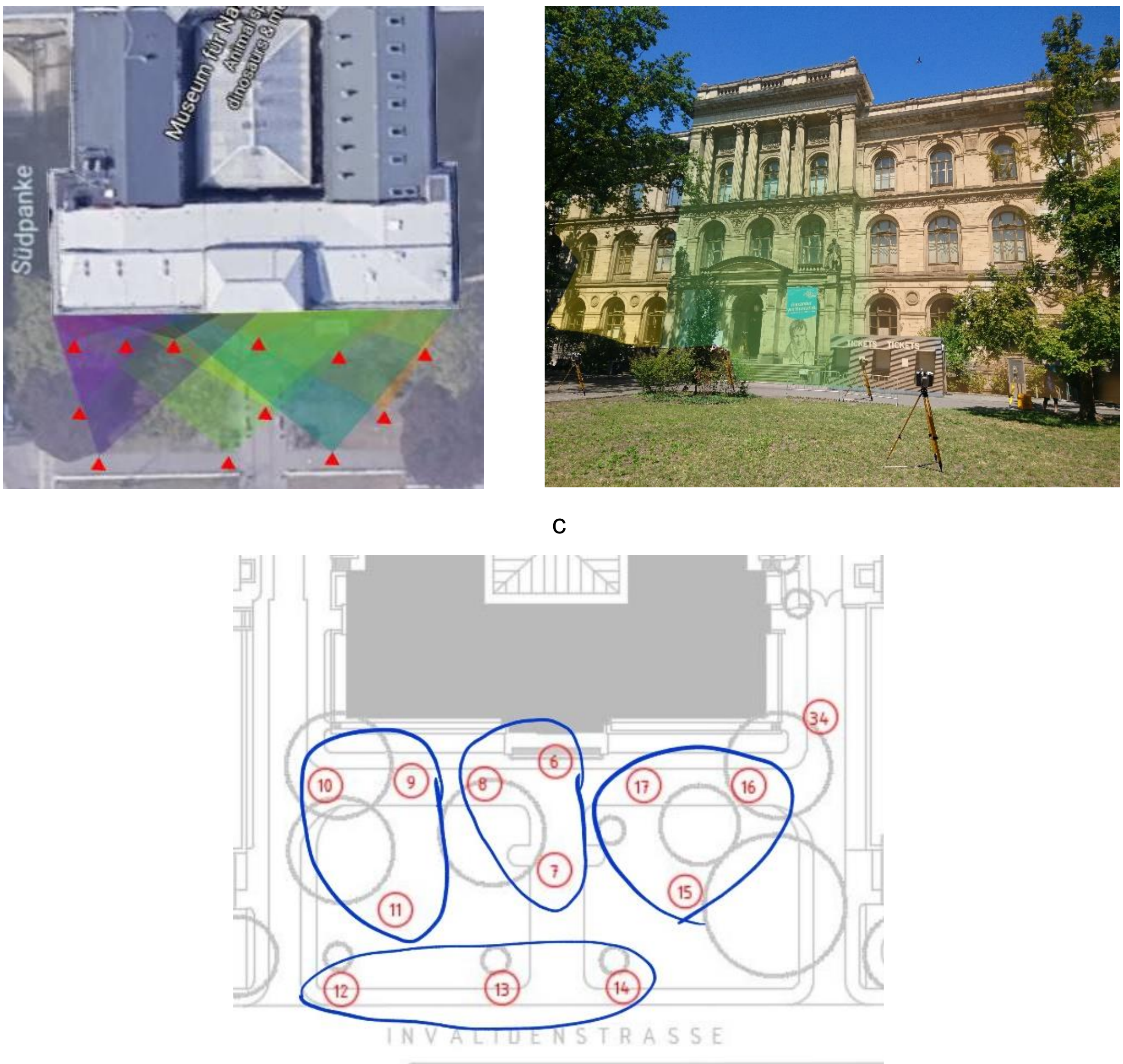



**Figure 24: (a) stations covering area in front of the site. (b) Façade of the building and stations benchmark. (c) The station grouping for importing to the computer. (By author)**

With respect to the station data which has been recorded on file information, it can be possible to group the stations based on the needs. Extracted data after being classified can be transferred to software on the basis of point cloud for processing

and integration. The topic of the formats and software was mentioned and explained earlier in the third chapter. In this project, it has been decided to utilize Trimble Real Works for analyzing the points.

In the first stage after the examination of the taken maps, adjacent stations which have an overlapping with each other must be selected. For a better result in this project, they have been divided into groups of 3 or 4. As it is displayed in the following image, data was imported in specific folders in Real Works software. (Figure 25)

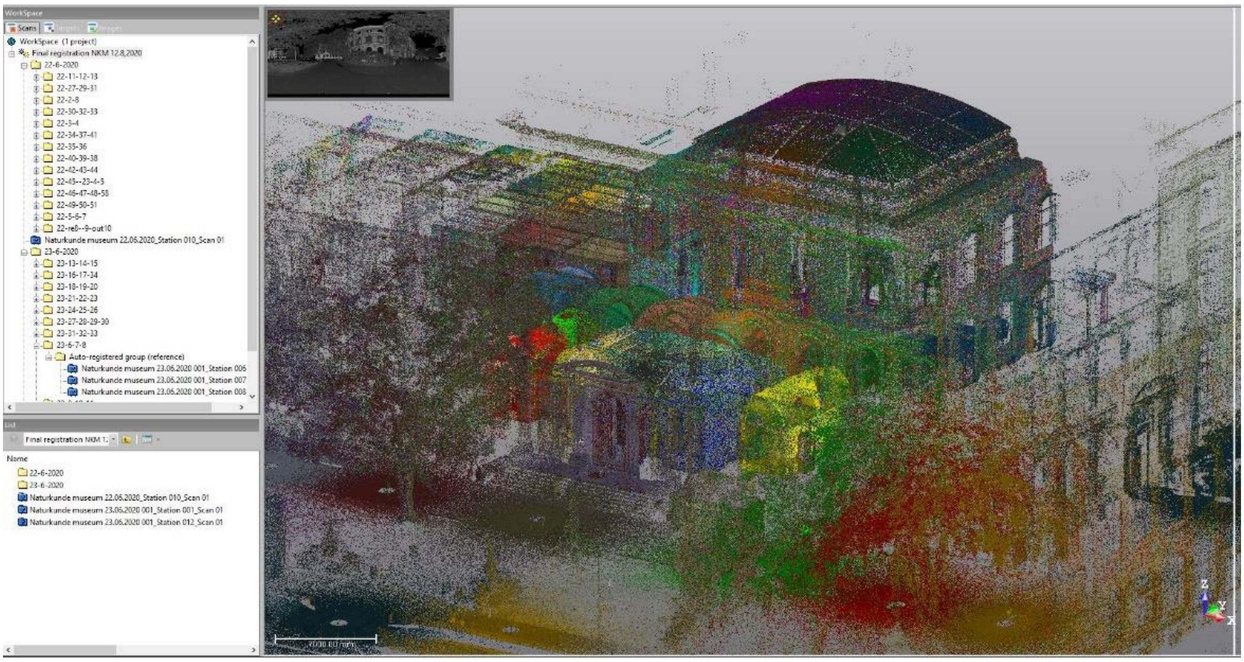


**Figure 25: Trimble Realwork display with groups of stations (By author)**

Up to this stage, it has been attempted to transfer data from laser scanner to a computer, in the next parts, the transferred data will be studied.

After entering the data in the software, in prepared folders based on the categories, it should be registered. It can be done both manually and automatically. Since the prepared folders are accessible, it is possible to register data consecutively. In an automatic registration, data is recognized and stitched together, hence; it would be applied to all groups sequentially. In (Figure 26), the registration of stations 6, 7 and 8 are observable in the building facade. As it is illustrated, the nearer is the object to the laser scanner, the lower is the point density, on the contrary; the further is the object to the laser scanner, the higher is the point density. This will happen to all the folders.

a

b

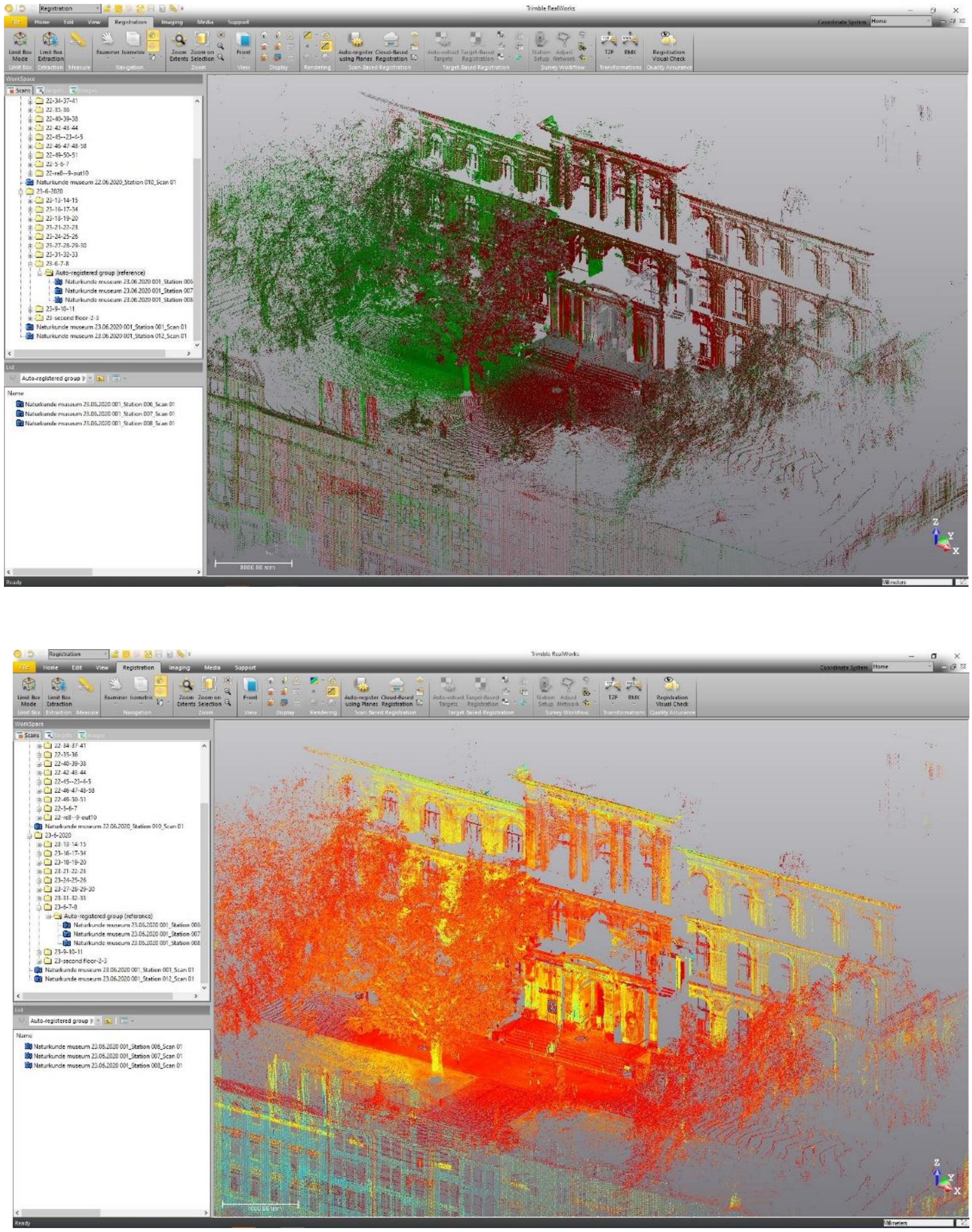


**Figure 26: Stations point cloud registration process. (By author)**

When the registration is completed, it is time to merge the final registration file to the other points for the purpose of obtaining an integrated and consistent mass. In this case, it would be possible to integrate the points by means of cloud base registration. In this instance, the first choice turns to a reference cloud, and the second one turns to a moving cloud. As depicted in the first image, by using three selected points from

everyone, green points are moving in accordance with red points. The result has been portrayed beneath them, which is in an overlapped cloud. (Figure 27)

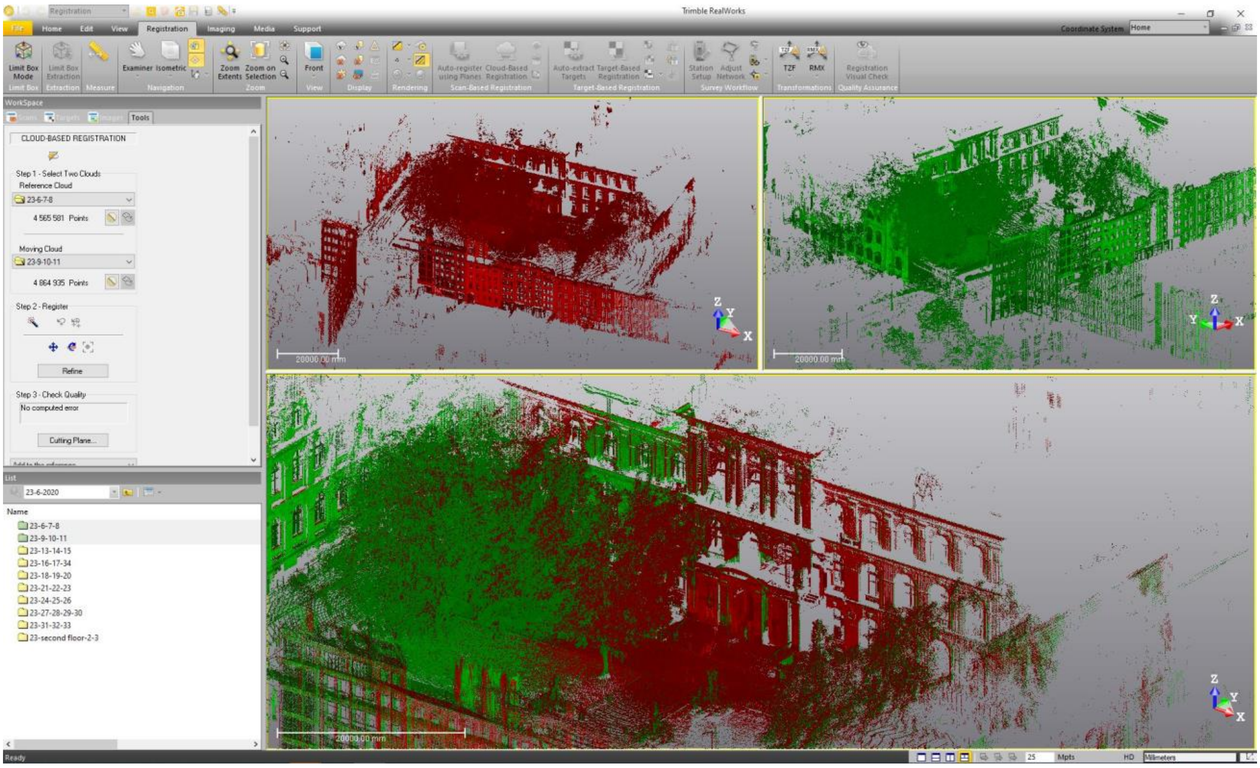


**Figure 27: Refinment of registration (By author)**

For achieving the high-quality result, the points can be refined, which can be operated in a cloud-based case. It must be noted that the primary refinements are performed during registration for stations, so this is only for improvements and the elimination of possible errors. The best way of refining overlaps is at least 30%, and the level difference between the two stations is less than 3 degrees.

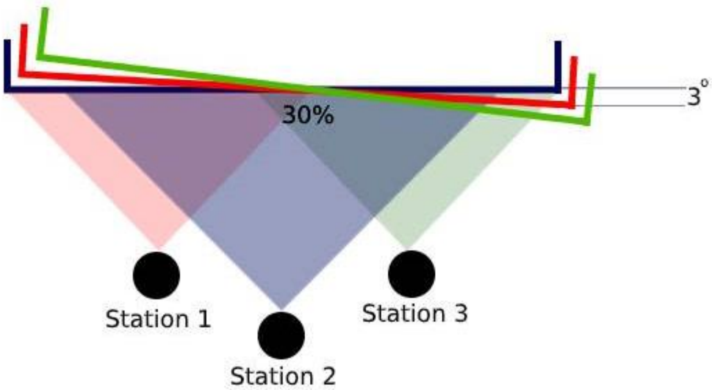



**Figure 28: Best refining overlap degree (By author)**

When it is completed, the file should be exported in *. E57 format. The outcome size is 2.45 Gigabyte from the initial 51.3 Megabyte. It would be used in the next stage, which is the revision of point clouds.

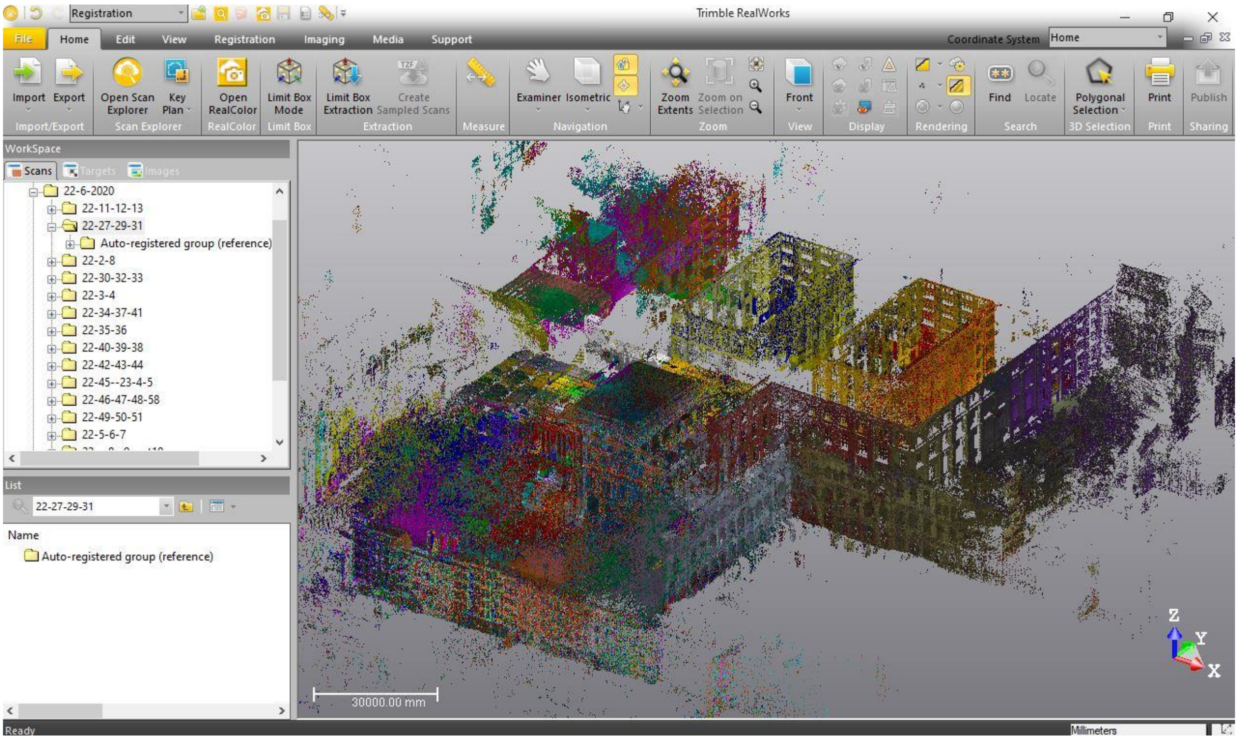



**Figure 29: NKM registration (By author)**

### Cleaning and segmentation

After the point capturing process and implementation on the computer and registering them, we have to eliminate the unwanted points that inevitably happen on the project. Since laser scanners do 360-degree imaging and they have to be on different levels, another challenge presents itself; the objects that exist at various heights. When we look at the main entrance of the museum, we see multiple objects that make modelling complicated; objects such as trees, vegetation, pedestrians, neighboring buildings, furniture and the reflections on the windows.

At this stage, after opening the *. E57 file in Trimble Real Works software, we will start with the production section. We could make different layers out of the projects, and this segmentation leads to improved access to these unwanted points in order to be eliminated. In the (Figure 30) it is simple to see a part of this building after segmentation and cleaning, in this case the plan of the main hall space (figure 30 a) shows walls and some lighting, this is depend to the user that is it necessary to see

or not, and in the (Figure 30 b) the section of the this room is available with the Dinosaurs skeleton and lighting that all of them separated as a deferent segment, moreover, in the (Figure 30c) the whole the room segmentation is shows as a perspective.

a b c

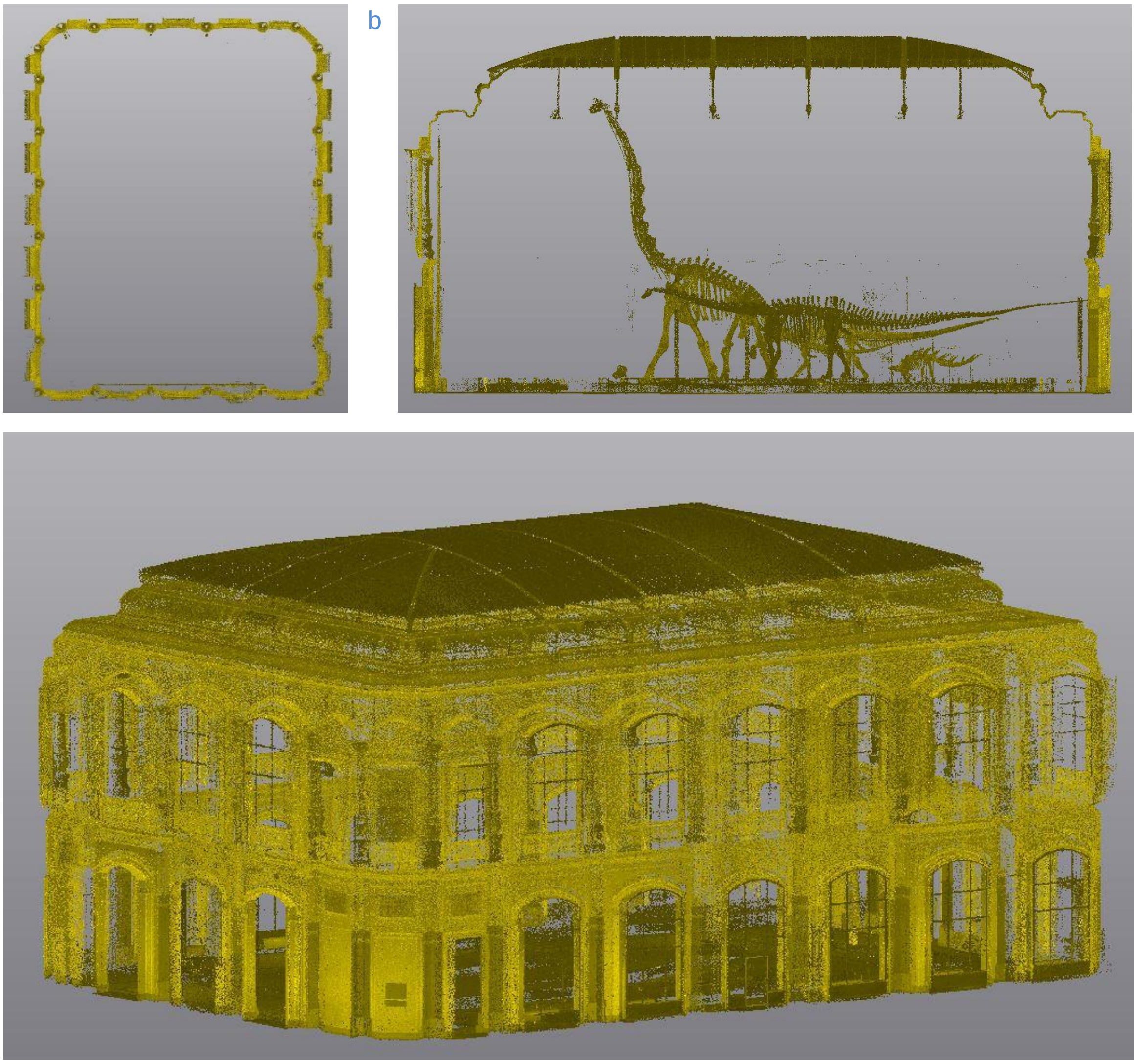


**Figure 30: Figure after segmentation and cleaning the main hall, a- plan, b- section, c-perspective view. (By author)**

Since we are studying the spaces, building facade, main entrance, first-floor corridor, gallery hall, and the main hall and also access to the staircase to capture a room on the second floor, first, we had to generate them in the software sequentially.

The procedures can be both automatic and manual, but due to the high-fidelity production, enormity, and the preciseness, the project has been done manually.

However, before starting the process of elimination and segmentation we have to

define the original file through auto-classification to make the software add the recognized spaces to the project, these spaces are buildings, poles, grounds, vegetation and we can create a new file named surrounded so as to segregate these spaces with the building itself. As the interior space of the museum contains precious items, such as sculptures, dinosaur skeleton and the like and their point clouds could be useful for future studies, we should watchfully classify them in order to differentiate them from the rest of the points and then create a separate folder for it. Auto-classification depends on two factors; what has to be individually (parametrically) modelled and the segmentation of rooms according to existing plans in order to be able to put it into Revit.

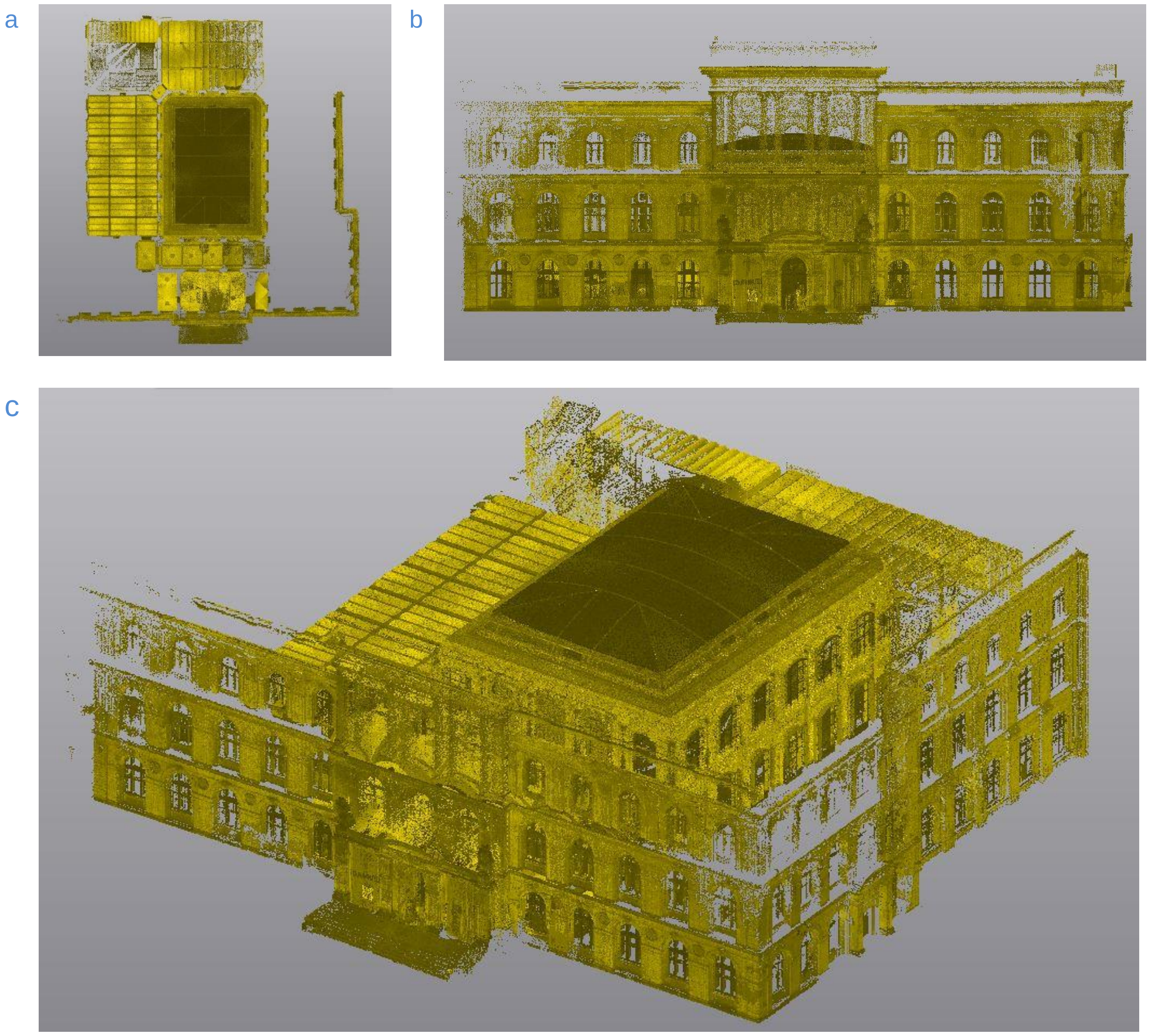



**Figure 31: Nturkundemuseum model after segmentation and cleaning a-scanning stations plan, b- Southern façade, c-Perspective view (By author)**

In this level of work, after cleaning and segmentation all of the point cloud data, the NKM model is getting ready for sending to the BIM software and documentation part as well. The final part can be saved in *.las format for using them in BIM software or other purposes. Indeed, various type of BIM software can work with point clouds and creating the model, but one of the usual and compatible working with many BIM software is Revit. Also, the final result in BIM software in the next steps can be saved in IFC format.

**Modelling**

In this step of work, one of the essential parts of this case study is the facade of the building. After laser scanning with the high accuracy and more stations due to this importance, part of this facade that is the main entrance of the museum will be remodeled in Revit. (Figure 32)


**Figure 32: Naturkundemuseum Facade (BY author)**

Firstly, the point cloud file that prepared with Trimble Real Work inserts to the Revit. That point clouds can insert to the Revit directly with *. E57 or *.las formats or getting help from other software like Recap to create the *.RCP or *.RCS (Figure 33).

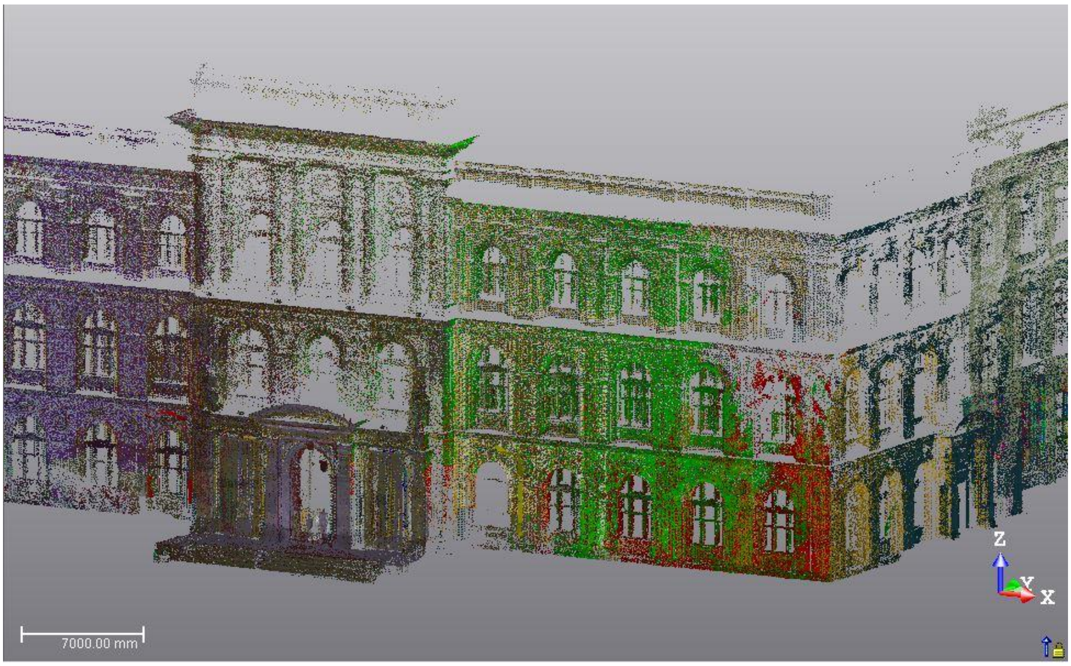



**Figure 33: Point cloud of NKM façade. (By Author)**

Indeed, modelling the whole project with detail and accuracy, will take much time and is beyond the scope of this thesis. Hence, after more cleaning the points in mentioned segmentation by Recap, the *RCP is ready for importing to the Revit. In this step of work, for modelling the part of NKM facade in Revit software. Firstly, the point cloud file that prepared with Trimble Real Work inserts to the Revit. That point clouds can insert to the Revit directly with *. E57 or *.las formats or getting help from other software like Recap to create the *.RCP or *.RCS (Figure 34).

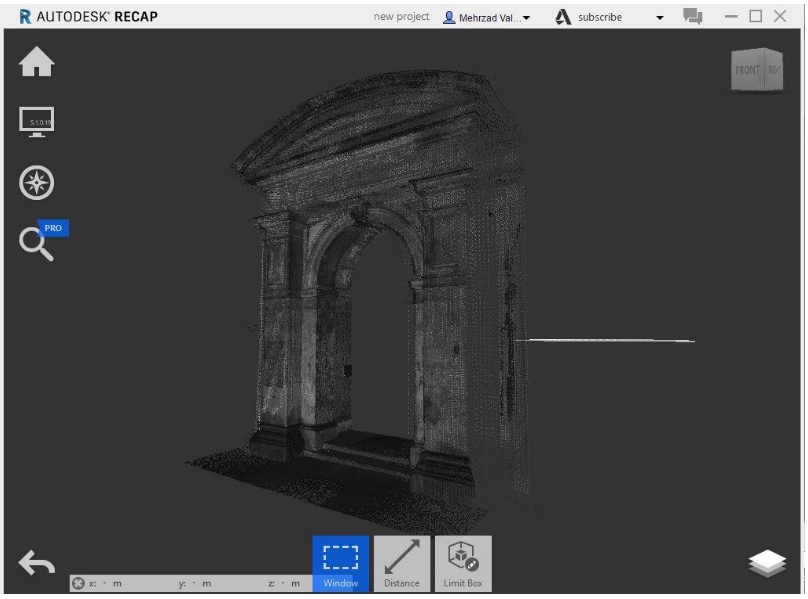



**Figure 34: Scheme Point cloud of NKM main entrance in Recap (By author)**

Therefore, one of the essential parts of this case study is the facade of the building. After laser scanning with the high accuracy and more stations due to this importance, decided to do visual remodel part of this facade that is the main entrance of the museum it in Revit. Indeed, modelling the whole project with great detail and accuracy will take much time and is beyond the scope of this thesis.

Hence, after more cleaning the points in mentioned segmentation by Recap, the *RCP is getting ready for importing to the Revit. (Figure 35)

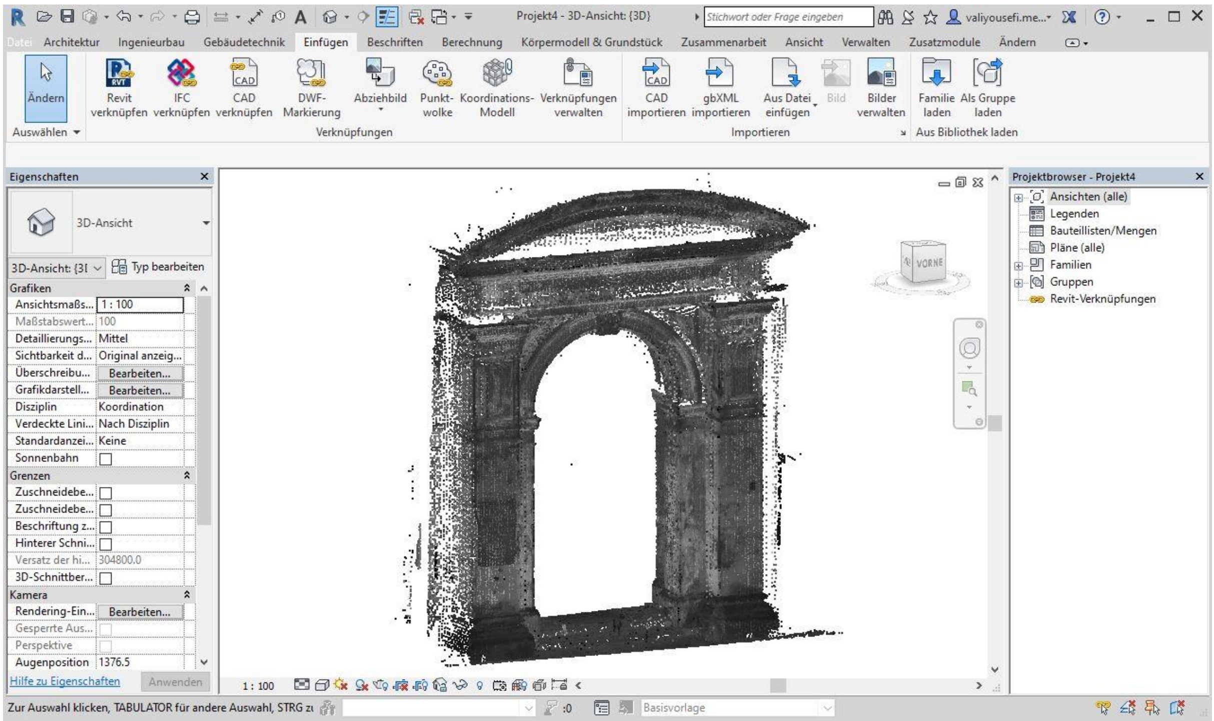



**Figure 35: Importing the point cloud into the Revit. (By author)**

The entrance of the building that is considered for modelling according to the details (refer to the figure 32) consists of several parts, walls, columns, roof arches and decorative sculpture and some stone arts on the columns.

The façade of the NKM Museum building, with its repetitive windows and columns, suggests that it can be more easily drawn by creating objects such as windows and columns.

As it shown in (Figure 36), the cloud points of the museum building show that we can create a model of a window in the view software and use it in all the same parts. So

modelling these objects can be used for remodeling the wide range of part of the model and played an important role. The new science of building design with BIM method helps the designer to combine the parametric method with BIM, for example, using the dynamo plugin in Revit software, to make the design process in repetitive shapes easier and faster.

The process of modelling in great details should create step by step. As can be seen in the figure below, the cloud points entered into Revit in the first phase should be seen in different views. Therefore, after importing the NKM point cloud to the Revit software, the first step is to set the plan from the top view (Figure 36a) and create walls (Figure 36b) in it.

a

b

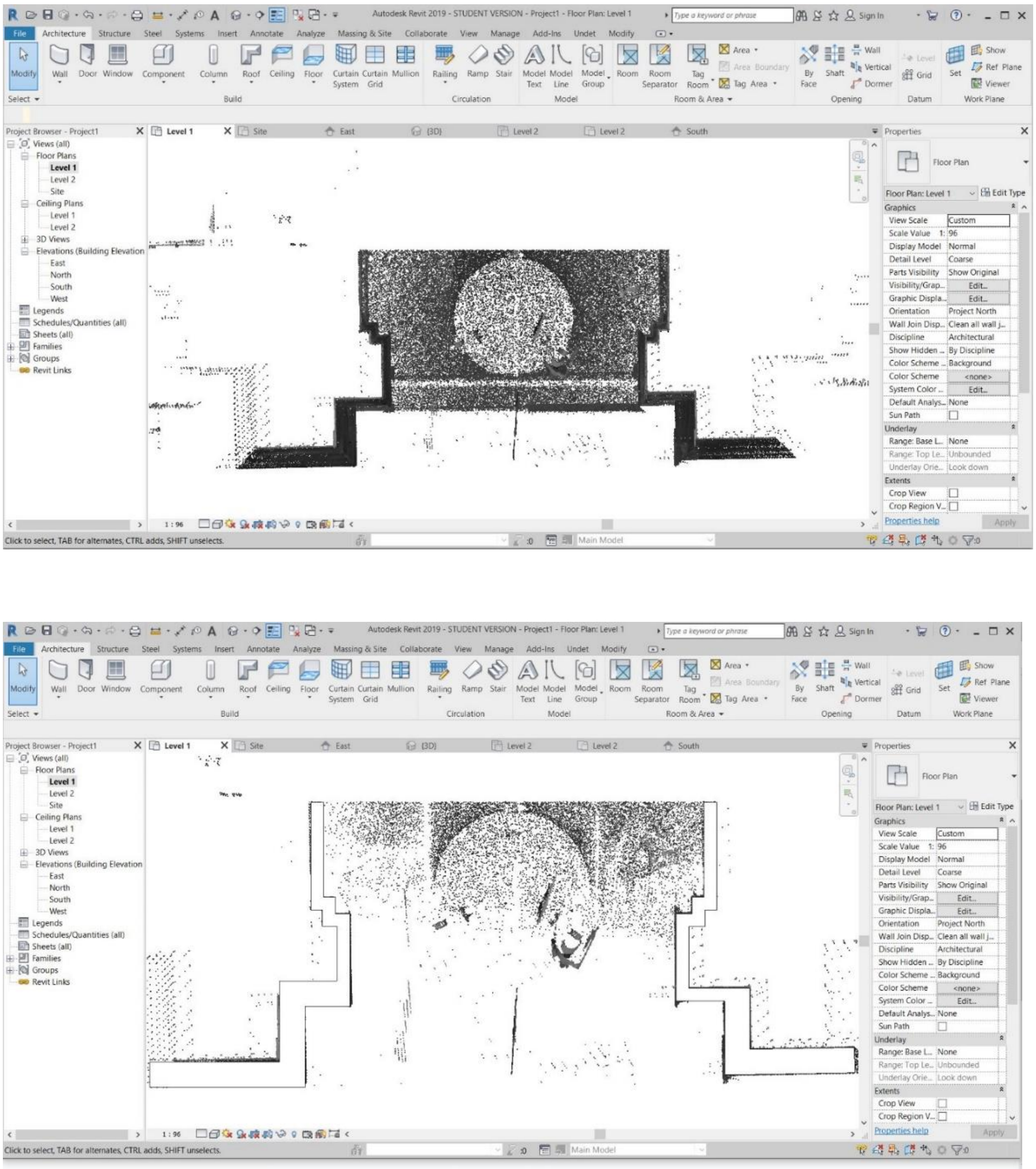


**Figure 36: (a) importing PCD into the Revit, (b) using PCD for creating walls in Revit. (By author)**

The next step is to make multiple sections in different levels, because of the elevation of this entrance has some artistic decoration. Hence, it is needed to check all of them via inserted PCD in many levels to getting a high LOD of this part and create it with satisfying accuracy. The (Figure 37), presented in three cases, shows the model obtained from the PCD.

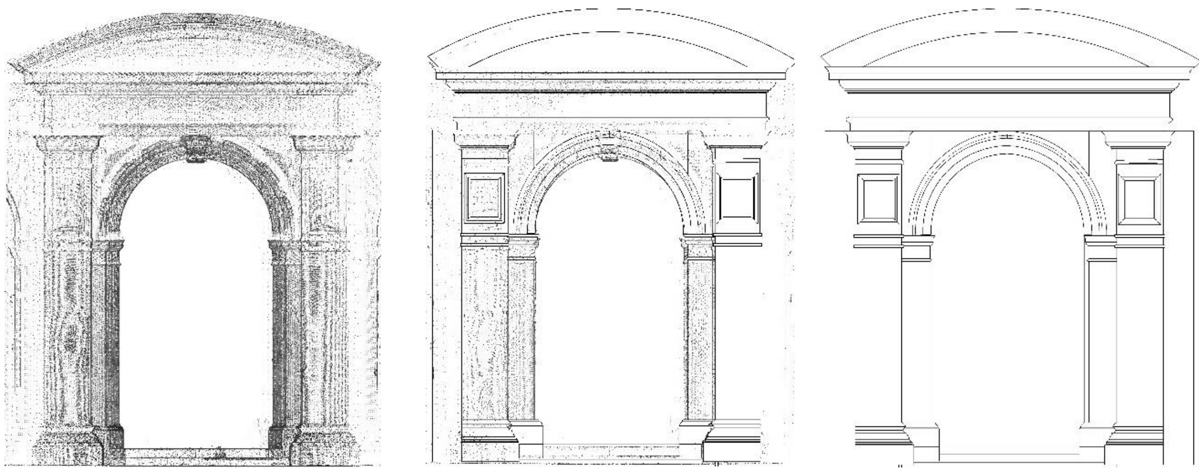
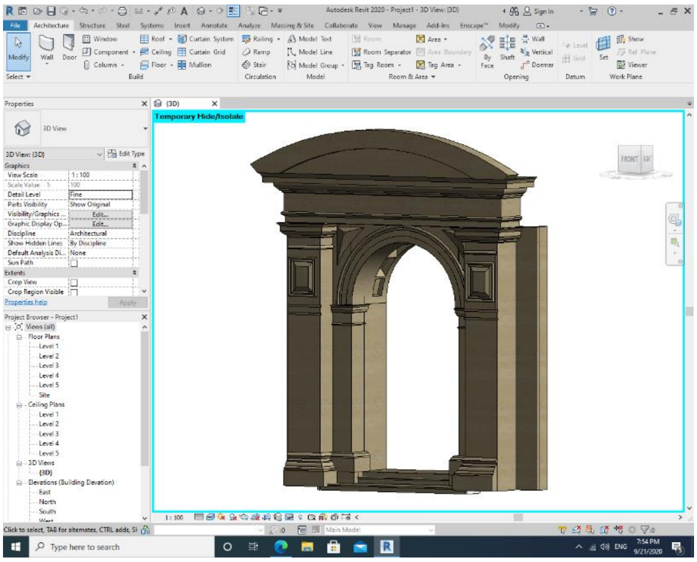


**Figure 37: Elevation of NKM entrance model in Revit (By author)**

After creating the model in the software, it was tried to select the model materials by the original type of materials used in the construction of the building and give them to them.

At this stage of the work, we assume that we have completed the model of the entire building. (Figure 38) shows the model prepared with the material and 3D rendering. The model made by the surface can be saved in *.IFC format. And then for other stages of modelling work to be used in 4D, 5D, 6D, 7D software.

a



b

**Figure 38: (a) result of NKM modeling in Revit, (b): NKM entrance 3D rendering (by author)**

## 4.3 Role of BIM in supporting FM requirements in NKM

In the NKM project, REVIT played an essential role in modelling. Nowadays, with contemporary amenities in software science, FM can be working in the BIM software directly regarding CAFM in chapter 2, so it just needs to import the FM plugin into the mentioned software. On the other hand, some FM software for keeping the data information individual exists. For the NKM project, all the data after as-build and implementations, are ready for importing to the BIM phase and will be import after BIM to the 7D phase, which means FM software. Which, somehow it is beyond the scope of this thesis. Furthermore, the obtained data should be updated from time to time.

The spaces that obtained in this thesis from the NKM laser scanning and segmented in the RealWork software are some essential parts such as facade, main entrance, and corridor, and two significant salons. Indeed, this approach can continue soon and will be achieved more places in this building and will be added to the existing data for recreated the whole project.

## 4.4 Summary

Firstly, the project location has been observed to examine and eliminate the potential obstacles, then based on the project requirements and the contractor's request, laser scanners stations were set in two separate maps which included interior and exterior spaces.

To extract the point cloud, a Trimble laser scanner was used. Laser scanners were in the preselected stations. Afterwards, laser scanning has been done with respect to the significance of that part of the building within two consecutive days.

It should be noted that due to some circumstances, it was required to change the station's positions in the place. After extracting points, any changes of the station have been written down. While extracting, it is necessary to consider an intersection or an overlapping space between building interior and exterior areas; therefore, the doors and windows were used for the purpose.

After the point clouds were collected from all stations, it is time to turn them into tangible data by using the software. Firstly, all the stations were transferred into Trimble Real Work software. Then, the final file was produced by the following two phases; the first phase was the point registration and integration to gain overlapping points and the second phase was the segmentation and cleaning. Finally, the file was exported and stored in an e57 format.

In light of the fact that modelling is voluminous and time-consuming, a particular part of the building had been selected to be modelled. This part was the main entrance of the building which was the best part to be examined because it provided us with the precise points for modelling hence it had the potentiality to represent the building complexities. Segmentation file was used for detaching this part of the building and transferring it to the Revit environment; the aforementioned part was saved under another name.

The file which is generated in Revit software should be turned to an understandable 3D shape. For doing so, at first, the file was entered in the recap environment and then was stored in RSC format. It is worth mentioning that the unwanted and unnecessary parts can be eliminated in the Recap environment. After registering the file in Revit, by creating some sections in different areas, the massing modelling process can be started. When completed, it was stored in IFC format for multiple usages with different

purposes; the most important one is using on FM. In the following image (Figure39), the schematic representation of the process is portrayed briefly.

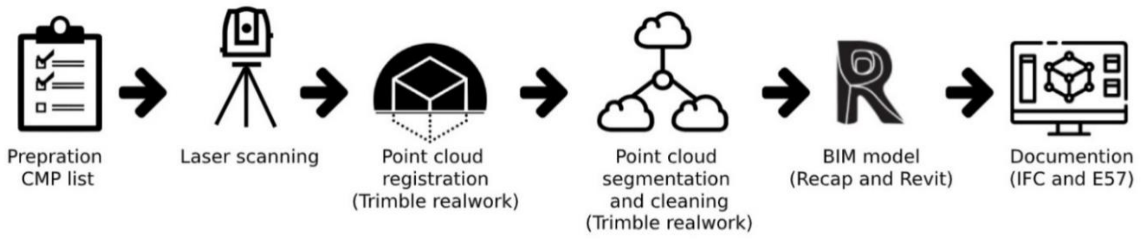



**Figure 39: Case Study process (by author)**

## 4.5 Case study Result

- Obtaining the point cloud model of building with high detail and accuracy,
- Ability to transfer point cloud into the BIM software,
- Easy way for transferring the model to the facility management software according to what is said in CAFM reasons in chapter two,
- Creating a building model with the help of BIM multifunction software and storing them in IFC format for long-term use,
- Creating documents at various historical intervals from the building model in an electronic library that allows architects and creators to show building changes over time,
- Improving the accuracy of as built using laser scanners compared to the traditional method,

Sub-objectives

- Implementing the building model in detail into the software in order to save time and cost.
- Creating the possibility for researchers and architects to study spaces and worn parts of the building and making a decision to repair and renovate it (such as the space on the second floor, which is in great need of renovation and restoration),
- achieving different parts of the building such as structures, architecture, decoration, and facilities through the laser scanning process
- Using the point cloud or BIM model file in advanced technologies such as VR or AR

# 5 Conclusion and recommendation

According to the topics presented and evaluated in this thesis and regarding the necessity to protect and maintain them, it is crucial to find the most accurate and accessible approach for modelling and reviving these buildings. For reaching the improved quality, it is therefore required to design a program to protect and study the works. As discussed in Chapter 2 (Figure 2), this CFM program helps the facility managers to gather comprehensive and relevant information about the building. The program examines the whole structure and building in detail, lists the spaces required for the project, fixes associated problems, and estimates the amount of LOD needed for them. Ultimately, in prepare and action plan, it is decided to satisfy all the demands of the project.

The building under study was the NKM Museum in Berlin. We first examined different parts and requirements of the project and used the laser scanning method to get a cloud of points from the spaces of interest. The data obtained in this project were massive in volume and highly accurate due to the use of multiple stations, indicating that this method can further help other building spaces with a lot of complexity or decoration. In order to generate clouds of points from captured sections, we used the TX8 laser scanner and Realwork software and obtained the final model of the cloud upon the modelling process. Ultimately, the results obtained from the field testing with laser scanning technology were promising. Though in some parts, there was a necessity to combine UAV technology with laser scanning, 3D laser scanning was efficient to scan physical and visible wide areas and surfaces within a short time. Considering the diversity in technologies, FM should have accurate information about the building to help decide on the use of tools and technology.

## 5.1 Limitation

As it was mentioned in the previous sections, some different companies have been used HBIM method within their projects. However, some critical factors make several limitations for this case study as a following:

Some obstacles made interruptions during of scanning the NKM building. Due to the Corona pandemic the access to the building of museum was too limited. Hence, the required laser scanning must be finished only in two working days. So, inside point

cloud took in one working day, and in the next day, outside façade point cloud was obtained.

There were some obstacles that masked the required special locations for the laser scanning, such as skeleton of dinosaurs, hanged pictures, art craft decorations and furniture for indoor (Figure 22).

In addition, there were some barriers in outdoor as well, such as plants, ticket kiosk, people who were walking around, a crowd street that reduced the work domain (Figure23).

Thus, in some parts of this case study, it was required to assess and model the building using a combination of some methods such as laser scanning and photogrammetry. However, in terms of the façade high, top of the facade was not completely in the scanning field of view. Indeed, photogrammetry could support this issue, and it should be obtaining by using drone. Furthermore, getting permits to scan some parts of the city using drone technology, required bureaucratic procedures.

In terms of the high cost of laser scanning machine, moving the device is too time consuming and needs lots of attention.

### 5.2 Implication and suggestion for future research

Regarding the previous chapters, data obtained, and the model developed for historic monuments need to be updated, as materials used in these buildings are too old and less diverse. Thus, BIM can efficiently be used in these projects. In BIM software, we can transfer the project to the 7D phase (facility management phase) after it was performed in 3D and 4D phases and keep it archived and updated for a long time.

In the NKM case study, one of the spaces that need more study and renovating is a room on the second floor (Figure 40), laser scanning approach can help the architect to achieve the plan with high accuracy and remodel it with all of the construction parts such as HVAC beams and columns in Revit in a short time. Moreover, after renovation, all the files are available in the documenting part.

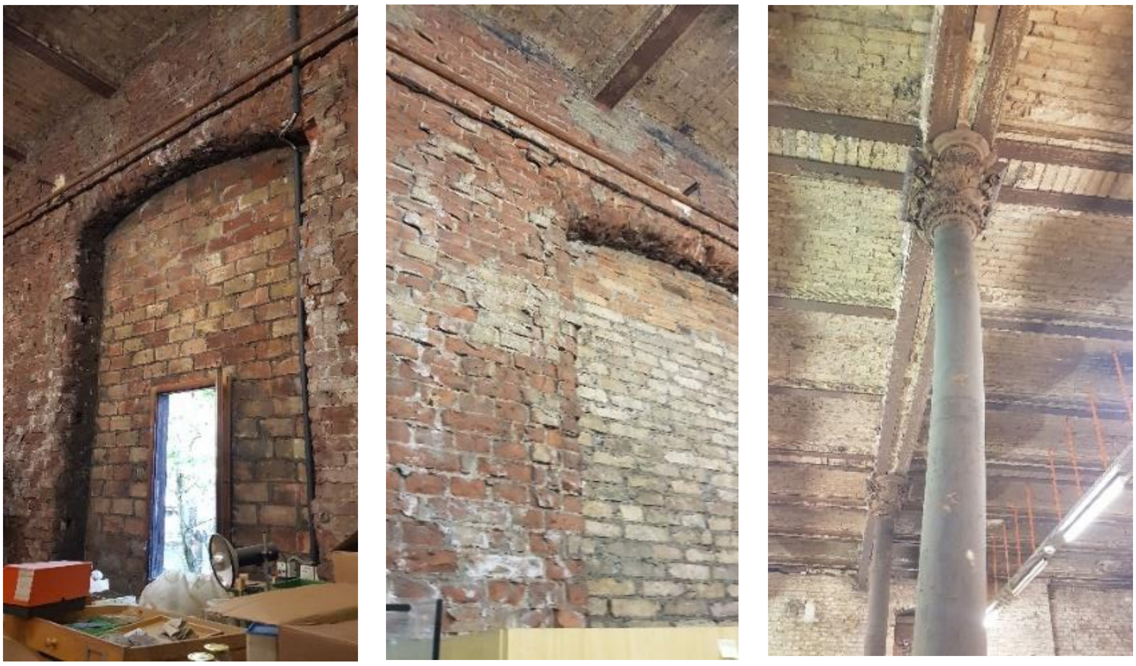


**Figure 40: Room wait for renovating in NKM (photo by author)**

The data obtained and the model developed for historic monuments need to be up-dated, as materials used in these buildings are too old and less diverse. Thus, BIM can efficiently be used in these projects. In BIM software, we can transfer the project to the 7D phase (facility management phase) after it was performed in 3D and 4D phases and keep it archived and updated for a long time. Today, this kind of software is rapidly evolving and developing, promising for future studies.

In the NKM project, the point clouds obtained and stored with *.IFC *.E57, *.Las, *.RCP, *.RCS extensions, besides the FM section, can be used in the future for application in the augmented reality (AR) or virtual reality (VR) sections or the game industry, 3D printers, audience attraction, and creation of virtual tours.

Now the question arises, how cloud points enter a tangible space and are used in AR and VR technologies?

## Declaration of Authorship

I hereby declare that the attached master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

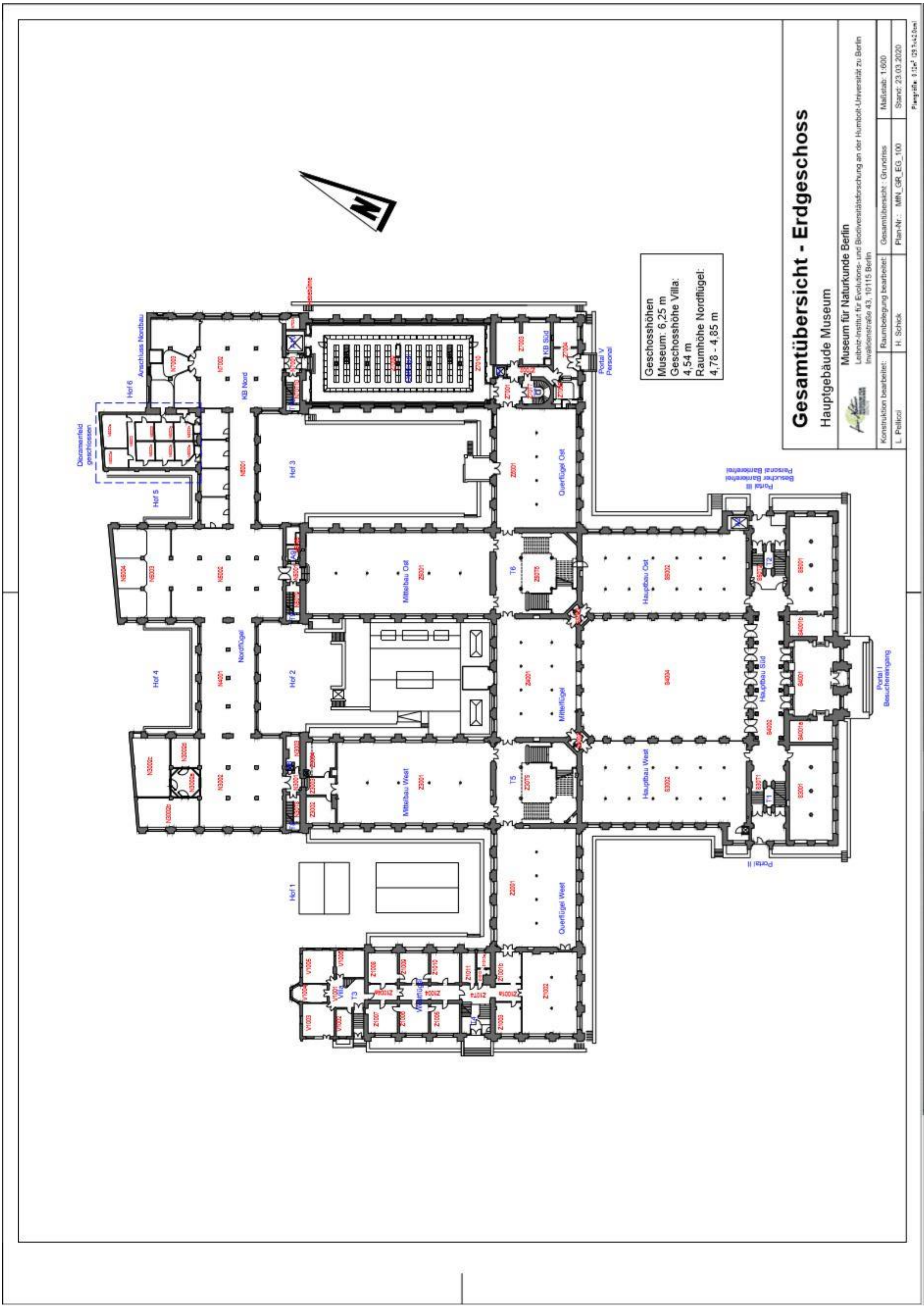
Berlin, 24/10/2020

Location, Date

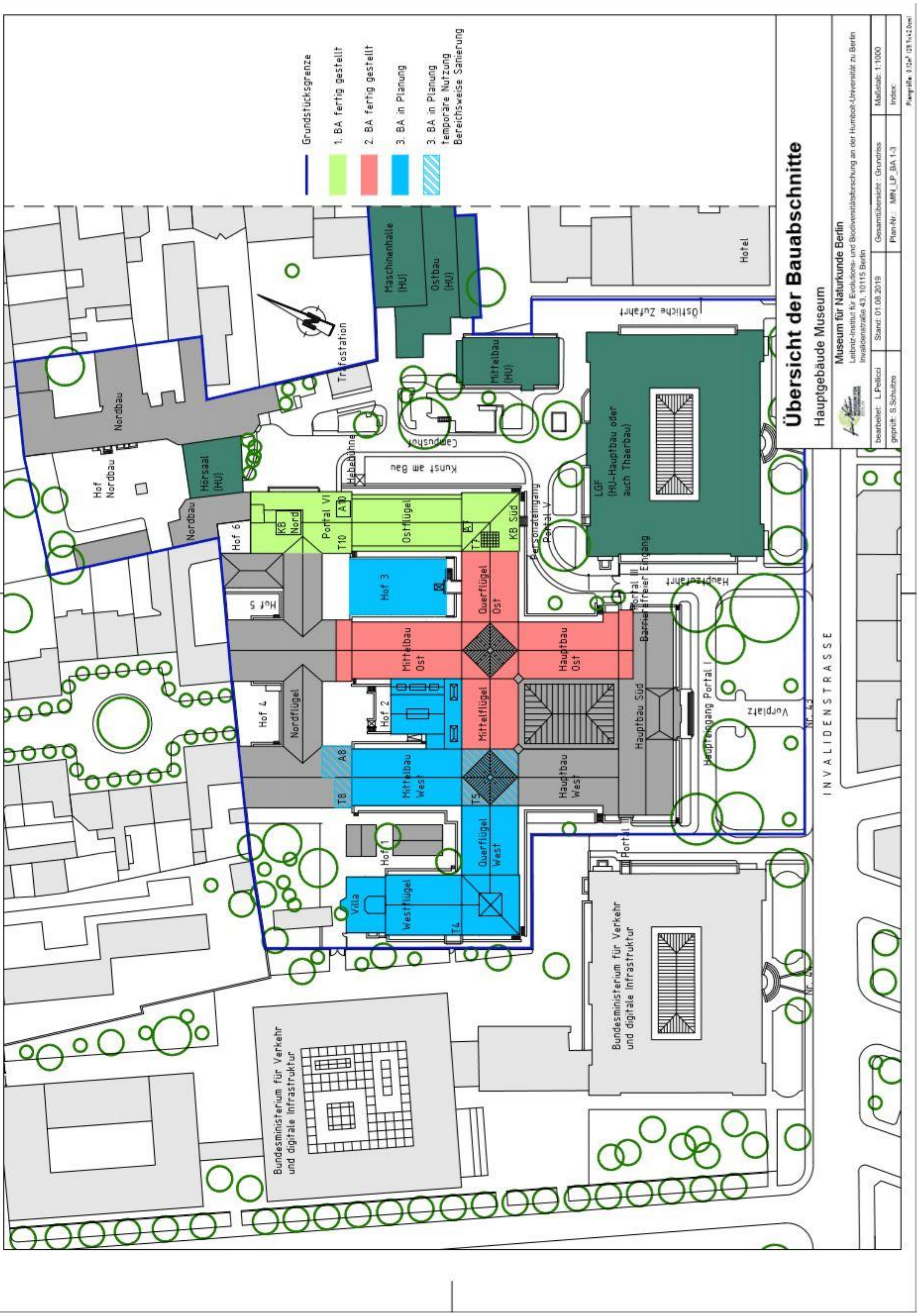
Signature of the student

# Appendix

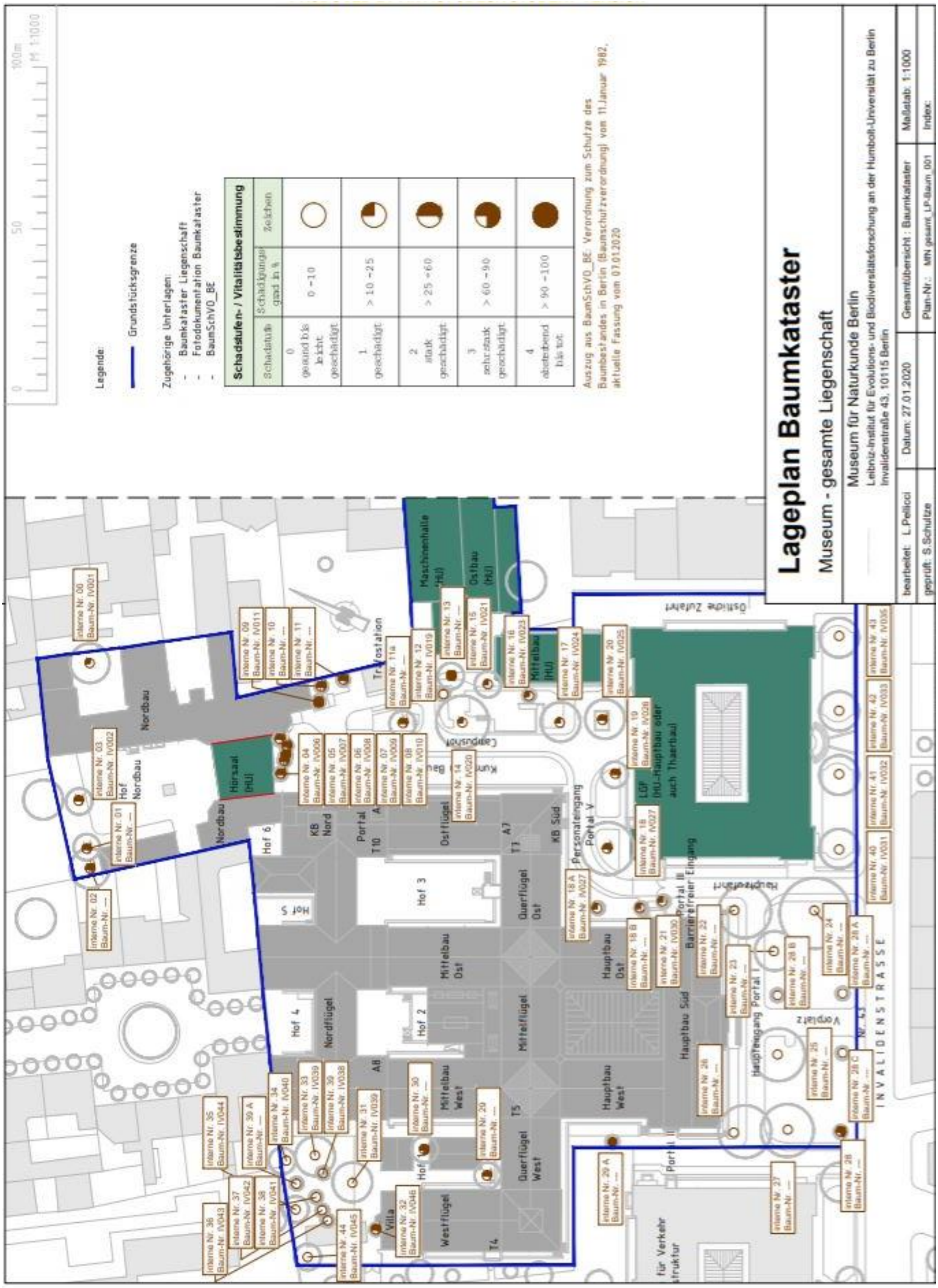
**Complete over view of NKM ground floor**



Over view of construction phases, Main building Museum

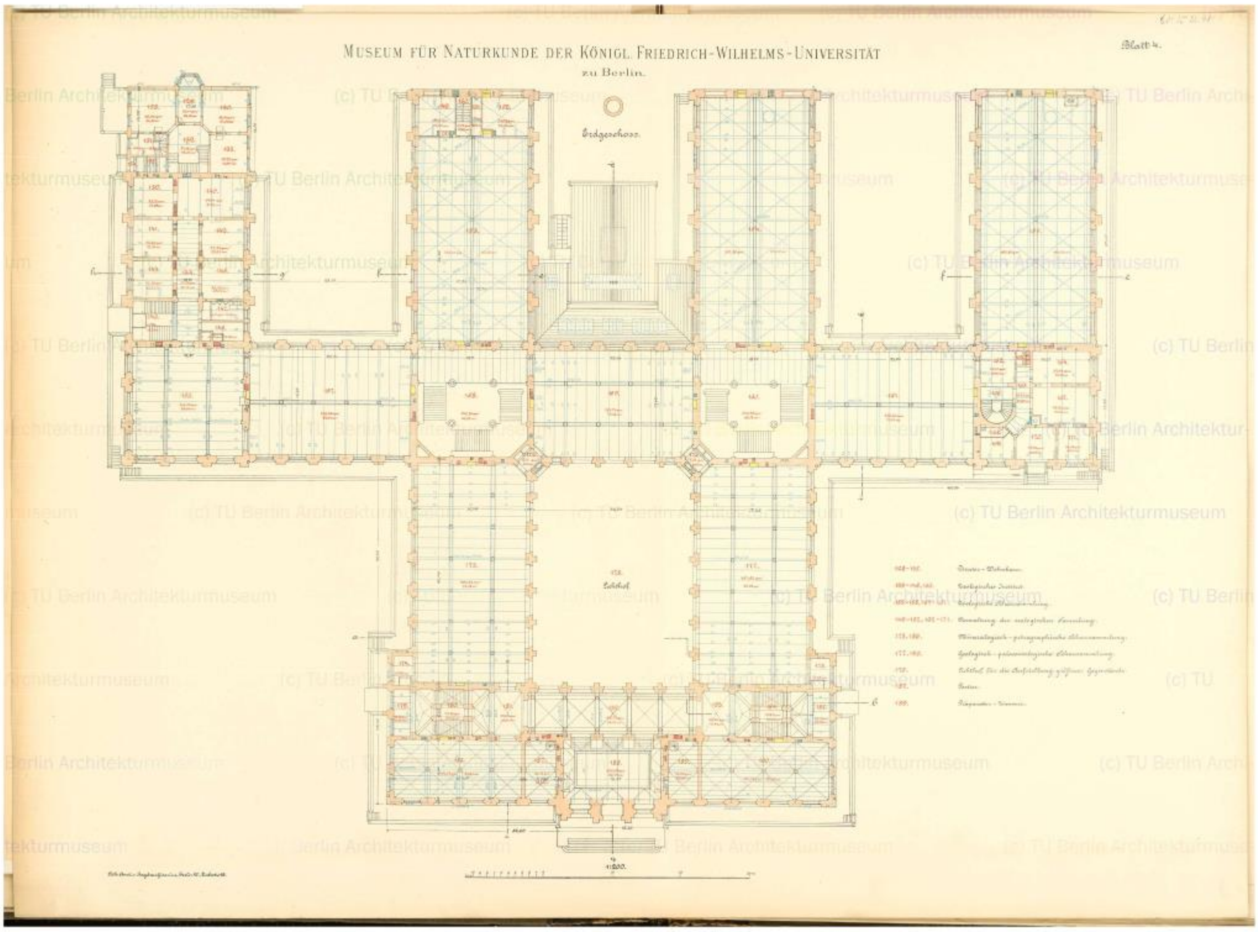


**Map of the three**



**August Tiede (1834-1911)**

Museum für Naturkunde, Berlin
Grundriss EG 1:200
Druck
Lithographie farbig auf Papier
66,9 x 90,9 cm
Inv.-Nr. BZ-H 15,041



**August Tiede (1834-1911)**

Museum für Naturkunde, Berlin. (Aus: Atlas zur Zeitschrift für Bauwesen, hrsg. v. Ministerium der öffentlichen Arbeiten, Jg. 41, 1891)

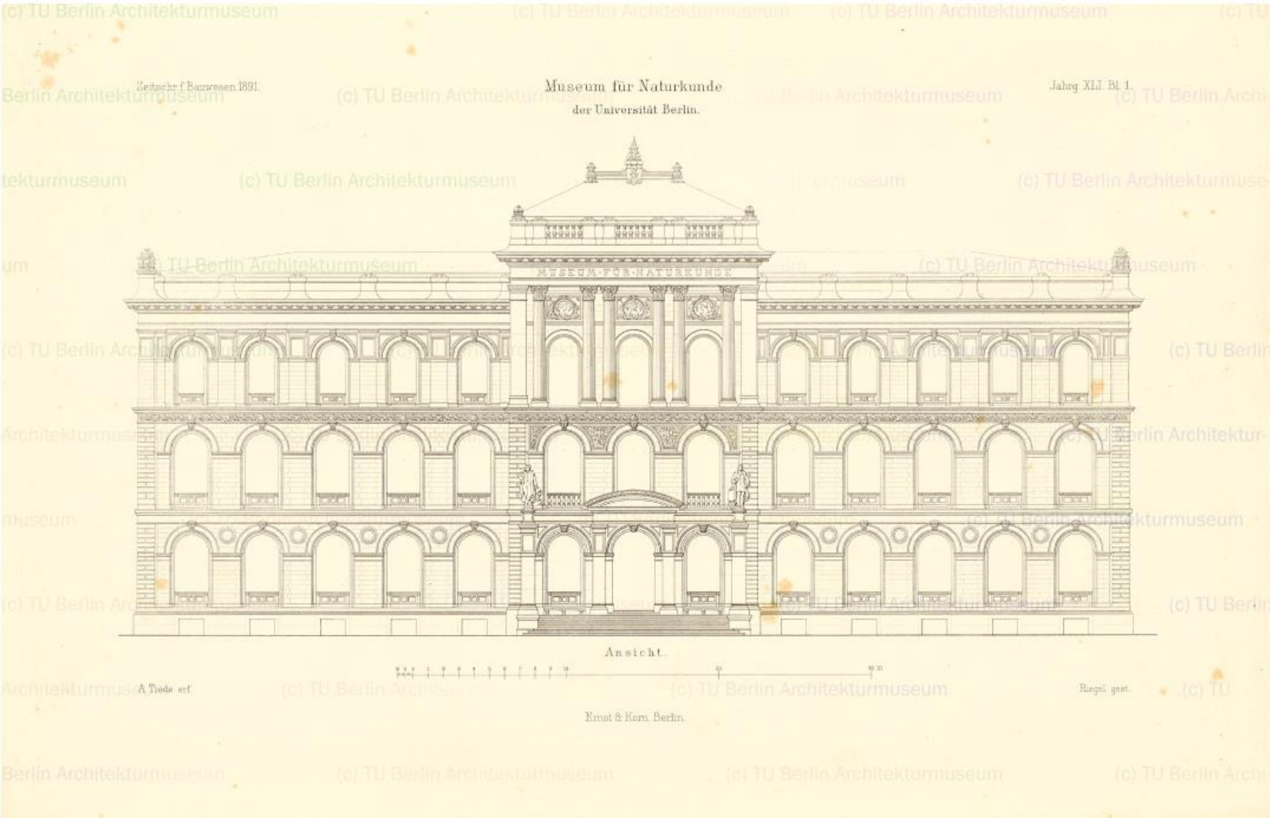
Ansicht

Druck

Stich auf Papier

29,4 x 45,7 cm

Inv.-Nr. ZFB 41,001



**August Tiede (1834-1911)**

Museum für Naturkunde, Berlin. (Aus: Atlas zur Zeitschrift für Bauwesen, hrsg. v. Ministerium der öffentlichen Arbeiten, Jg. 41, 1891)

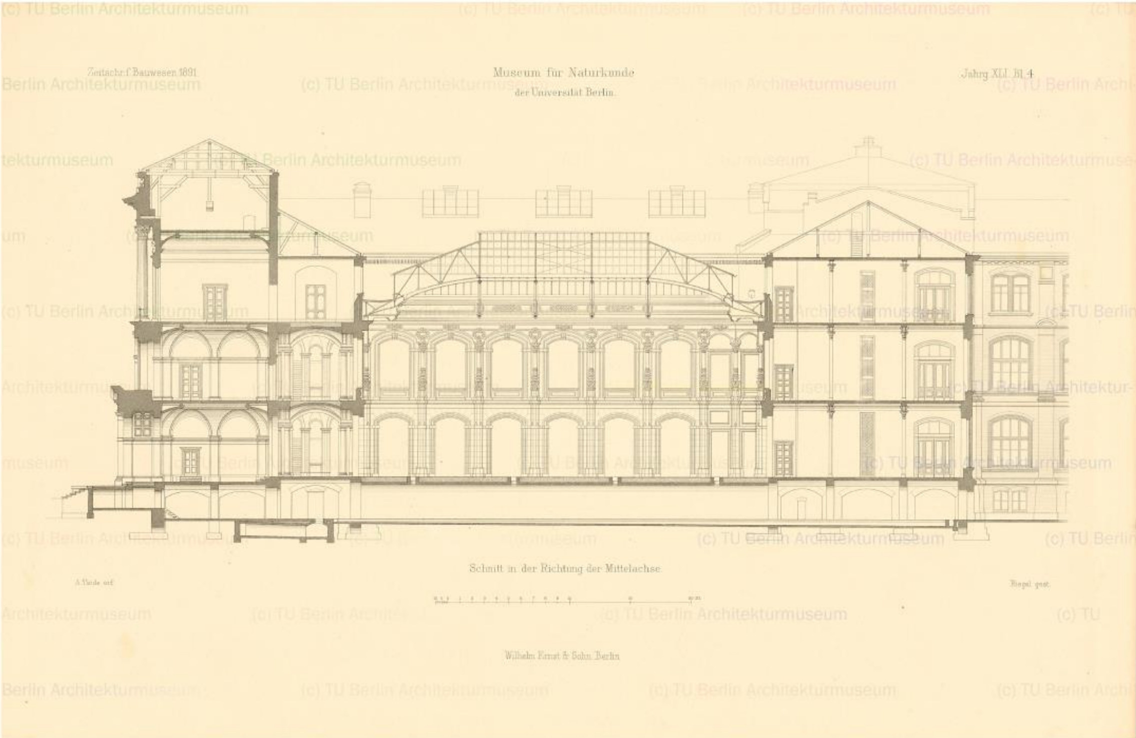
Schnitt entlang der Mittelachse

Druck

Stich auf Papier

29,9 x 46 cm

Inv.-Nr. ZFB 41,004



## List of Literature


Autodesk, 2020. Naviswork. [Online]
Available at:
https://www.autodesk.com/products/navisworks/overview?plc=NAVSIM&term=1-YEAR&support=ADVANCED&quantity=1
[Accessed 25 08 2020].

Autodesk, 2020. Revit. [Online]
Available at: https://www.autodesk.com/products/revit/overview?plc=RVT&term=1-YEAR&support=ADVANCED&quantity=1
[Accessed 25 08 2020].

Becerik-Gerber, B. et al. (2012) "Application areas and data requirements for BIM-enabled facilities management," Journal of Construction Engineering and Management, 138(3), pp. 431–442. doi: 10.1061/(ASCE)CO.1943-7862.0000433.

BIM, U., 2020. BIM Dimensions 3D, 4D, 5D, 6D, and 7D BIM Explained. [Online]
Available at: https://www.united-bim.com/what-are-bim-dimensions-3d-4d-5d-6d-7d-bim-explained-definition-benefits/
[Accessed 17 09 2020].

Borrmann, . A., König, . M. & Beetz, J., 2018. Building Information Modeling Technology Foundations and Industry Practice. Germany: Springer International publishing AG, part of springer Nature 2018.

Brumana, R. et al. (2018) "Generative HBIM modelling to embody complexity (LOD, LOG, LOA, LOI): surveying, preservation, site intervention—the Basilica di Collemaggio (L'Aquila)," Applied Geomatics. Springer Verlag, 10(4), pp. 545–567. doi: 10.1007/s12518-018-0233-3.

By Kathy Roper, R. P., 2014. The Facility Management Handbook. s.l.:ISBN-13: 978-0-8144-3215-0.

The Burra Charter: The Australia ICOMOS Charter for Places of Cultural Significance, 2013. Initial textual references should be in the form of the Australia ICOMOS Burra Charter, 2013 and later references in the short form.

Ciępka, G., 2016. 3Deling. [Online]
Available at: https://www.3deling.com/whta-is-a-point-cloud/
[Accessed 15 08 2020].

Church, S. J. A. & Carlton, 1968. Conservation Management Plans: Managing Heritage Places. *Heritage concil of Victoria,* Issue ISBN 978 1 921607 64 6, pp. 8-26.

council, H., 2013. An information guide to conservation management plans. [Online]
Available at: https://www.dplh.wa.gov.au/getmedia/4826138d-a744-4ef9-9b85-1d3c71fa2efc/HER-Guide-to-Conservation-Management-Plans
[Accessed 10 09 2020].

Desai, D., 2014. Benefits Of BIM To The Owner. [Online]
Available at: https://www.revitmodelingindia.com/latest-blog/benefits-bim-owner/
[Accessed 10 09 2020].

Eastman, Charles & And Others, 1974. An Outline of the Building Description System. *Carnegie-Mellon Univ., Pittsburgh, Pa. Inst. of,* Issue N/A, p. 23.

Edirisinghe, R. et al. (2017) "Building information modelling for facility management: Are we there yet," Engineering, Construction and Architectural Management. Emerald Group Publishing Ltd., 24(6), pp. 1119–1154. DOI: 10.1108/ECAM-06-2016-0139.

England, H., 2018. 3D laser scanning for heritage. [Online]
Available at: https://historicengland.org.uk/images-books/publications/3d-laser-scanning-heritage/heag155-3d-laser-scanning/
[Accessed 03 09 2020].

FMmanager, 2015. Maintenance of Heritage buildings: planning for forever. [Online]
Available at: https://www.fmmedia.com.au/sectors/maintenance-of%E2%80%A8-heritage-buildings-planning-for-forever/#
[Accessed 24 09 2020].

Gigliarelli, E., Calcerano, F. and Cessari, L., 2017. Heritage Bim, numerical simulation and decision support systems: *An integrated approach for historical buildings retrofit. Energy Procedia, 133, pp.135-144.*

Golabchi, A., Akula, M. and Kamat, V. R. (2013) *"Leveraging BIM for Automated Fault Detection in Operational Buildings," in. doi: 10.22260/ISARC2013/0020.*

Hardin, B. & McCool, D., 2015. *BIM and Construction Management: Proven Tools, Methods, and Workflows.* 2nd ed. s.l.:Wiley.

Hichri, N. et al. (2013) "REVIEW OF THE 'AS-BUILT BIM' APPROACHES," ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. *Copernicus GmbH, XL-5/W1, pp. 107–112. doi: 10.5194/isprsarchives-xl-5-w1-107-2013.*

ICOMOS, 2013. The Australia ICOMOS Charter for Places of Cultural Significance. [Online]
Available at: https://australia.icomos.org/wp-content/uploads/The-Burra-Charter-2013-Adopted-31.10.2013.pdf
[Accessed 5 09 2020].

IFMA, 2020. What is Facility Management?. [Online]
Available at: https://www.ifma.org/about/what-is-facility-management
[Accessed 15 08 2020].

Kia, S., 2013. *introduction to Building Information Modeling (BIM) (pp.101-139)Chapter: Review of Building Information Modeling (BIM) Software Packages Based on Assets Management.* 1st ed. s.l.:Amirkabir University of Technology.

Krämer, M. and Besenyoi, Z. (2018) "Towards Digitalization of Building Operations with BIM," IOP Conference Series: Materials Science and Engineering, 365(2). doi: 10.1088/1757-899X/365/2/022067.

Liu, X., Eybpoosh, M. & Akinci, B., 2012. *Developing As-Built Building Information Model Using Construction Process History Captured by a Laser Scanner and a Camera.* West Lafayette, https://doi.org/10.1061/9780784412329.124.

López, F. J. et al. (2018) "A review of heritage building information modeling (H-BIM)," Multimodal Technologies and Interaction. MDPI AG. doi: 10.3390/mti2020021.

Love, P. E. D. et al. (2011) "Design error reduction: Toward the effective utilization of building information modeling," Research in Engineering Design, 22(3), pp. 173–187. doi: 10.1007/s00163-011-0105-x.

Mahmoud , A. et al., 2017. Comparison of Point-Cloud Acquisition from Laser-Scanning and Photogrammetry Based on Field Experimentatio. Ottawa, Ontario, Civil and Environmental Engineering, University of Waterloo, Waterloo, ON, Canada, p. 3.

Mark Saunders, P. L. A. T., 2009. Research methods for business students. 5 ed. Harlow: Pearson Education Limited.

Mill, T., Aivars, A. & Roode, L., 2013. COMBINED 3D BUILDING SURVEYING TECHNIQUES TERRESTRIAL. JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT, 19(Jan 9, 2014), p. 25.

Murphy, M., Mcgovern, E. and Pavia, S. (2009) "Historic building information modelling (HBIM)," Structural Survey, 27(4), pp. 311–327. doi: 10.1108/02630800910985108.

Murphy, C. D. &. M., 2012. Integration of Historic Building Information Modeling (HBIM) and 3D GIS for Recording and Managing Cultural Heritage Sites. s.l., IEEE, p. 370.

M. Wggins, J., 2014. *Facilities Manager's Desk Reference.* 2nd ed. N/A: John Wiley & Sons, Ltd..

Naturkunde, M. f., 2020. Architectural history: A building concept developed 140 years ago setting the course for a natural history museum in the 21st century.. [Online]
Available at: https://www.museumfuernaturkunde.berlin
[Accessed 5 08 2020].

Nicholas Burt (2012) Multi-Unit Residential Multi-Unit Residential Facilities Management Good Practice Guide. Australia. Available at: www.melbourne.vic.gov.au.

O.Roper, K. & P.Payant, R., 2014. The facility managment Handbook. fourth edition ed. USA: Library of Congress Catalog-in-Publication Data.

Psaltakis, D. I. et al. (2019) "3D Survey of a Neoclassical Building Using a Handheld Laser Scanner as Basis for the Development of a BIM-Ready Model," in Communications in Computer and Information Science. Springer Verlag, pp. 119–127. doi: 10.1007/978-3-030-12957-6_8.

Rashidi, A. et al. (2016) Point Cloud Data Cleaning and Refining for 3D As-Built Modeling of Built Infrastructure Unmanned Aerial Systems (UAS) for Construction Safety Applications View project Transport for London View project Point Cloud Data Cleaning and Refining for 3D As-Built Modeling of Built Infrastructure. Available at: https://www.researchgate.net/publication/317240609.

Talamo, C. and Bonanomi, M. (2015) Knowledge management and information tools for building maintenance and facility management, Knowledge Management and Information Tools for Building Maintenance and Facility Management. Springer International Publishing. doi: 10.1007/978-3-319-23959-0.

Tang, P. et al. (2010) “Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques,” Automation in Construction. Elsevier B.V., pp. 829–843. doi: 10.1016/j.autcon.2010.06.007.

Teicholz, P., 2013. *BIM for Facility Managers.* New Jersy: John Wiley & Sons, Inc..

Theiler, P. W. & Schindler, K., 2012. Automatic registration of partially overlapping terrestrial laser scanner point clouds. [Online]
Available at:
https://prs.igp.ethz.ch/research/completed_projects/automatic_registration_of_point_clouds.html
[Accessed 24 08 2020].

Trimble, 2020. constructible. [Online]
Available at: https://constructible.trimble.com/construction-industry/bim-to-the-rescue-the-restoration-and-rebuilding-of-notre-dame
[Accessed 18 09 2020].

Trimble (2013) Key Features High Performance for Demanding Applications. Available at: www.gc.trimble.com.

Trimble TX6-TX8 (2017) “TX6_TX8_UserGde_1B_44431_ENG.”

[Accessed 18 09 2020].

UNESCO, 2020. World Heritage. [Online]
Available at: www.unesco.org
[Accessed 23 09 2020].

Volk, R., Stengel, J. and Schultmann, F. (2014) “Building Information Modeling (BIM) for existing buildings - Literature review and future needs,” Automation in Construction, pp. 109–127. doi: 10.1016/j.autcon.2013.10.023.

Wei, O. C. et al. (2019) “THREE-DIMENSIONAL RECORDING and PHOTOREALISTIC MODEL RECONSTRUCTION for VIRTUAL MUSEUM APPLICATION - AN EX-

PERIENCE in MALAYSIA,” in ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Copernicus GmbH, pp. 763–771. doi: 10.5194/isprs-archives-XLII-2-W9-763-2019.