Vs.01.5

Metropolia
University of Applied Sciences

Hochschule für Technik
und Wirtschaft Berlin
University of Applied Sciences

Application of BIM in Renovation Projects in Europe

Master Thesis

Name of the Study Programme

Construction and Real Estate Managemant

Faculty 2

from

Fatemeh Daneshvartarigh

Date:

Berlin, 18.07.2021

1st Supervisor: Sergio Rossi

2nd Supervisor: Hannu Hakkarainen

The accomplishment of this research involved the support of several people. As a result, I would like to express my thanks to the following individuals:

First, I would like to express my sincere gratitude to my first supervisor Sergio Rossi for his continuous support, patience, motivation, and immense knowledge.

Special thanks to my second supervisor Hannu Hakkarainen. Especially the lectures I had with him at the Metropolia University of Applied Science in Helsinki inspired me to choose this research topic.

Further, I would like to express my gratitude to all the experts for kindly participating in the questionnaire and interviews. It gives me great pleasure to thank everyone who contributed to the success of this study and made it an amazing experience for me.

Last but not least, I would especially like to thank my family, Hamid, Nasrin, and Alireza, for giving me love and being incredibly supportive.

Berlin, July 2021

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

date 04.04.2020

Conceptual Formulation
Master Thesis for Mr./Ms. Fatemeh Daneshvartarigh
Student number 1913018

Topic: **Application of BIM in Renovation projects in Europe**

Background

In European countries, about 40% of buildings are over 60 years old and More than 80% of residential buildings were constructed before 1990 [1]. Currently, 57% of all construction activities are renovation projects. However, the building renovation rate is low (about 1-2%) [2]. Unfortunately, maximum potential energy savings are not achieved in many of these renovations [3]. As a result, new and upcoming building programs in Europe are mainly focusing on renovation.

According to the European Commission strategy published on 14 October 2020 that intends to double yearly energy renovation rates in the next decade, a renovation wave is expected in Europe. However, the capacity of renovation companies is limited to respond to this wave.

On the other hand, achieving maximum energy saving and minimum environmental impact in renovation projects is essential. Several studies have pointed out that renovation projects come with a unique set of risks and complexities that are not present in new construction and impact project success [4].

With integrative project delivery and energy management, BIM may increase project cooperation, coordination, performance, and creativity moreover enable project delivery with fewer mistakes, omissions, and rework [5].

Consequently, building information modeling can facilitate the renovation procedure to obtain the optimum solutions. However, it is stated that BIM is not widely applied in renovation projects because of a lack of awareness of BIM, related case studies, procedures, and structured knowledge [6].

In recent years, some effort is placed to increase awareness and education. Additionally, new technologies are integrated with BIM that can efficiently facilitate its use in renovation projects.

This study will try to screen the state of using BIM software in renovation by the companies involved to point out the benefits and barriers of BIM use through extensive research. On the other hand, it will highlight the correlation between company profile and BIM adoption in projects.

The experiential part of this thesis will be based on a survey methodology perpetrated as an online questionnaire, followed by interviews with the experts involved in the field.

Research Questions

1. What is the situation with use of BIM software in renovation projects?
2. What are the factors affecting BIM implementation in renovation projects?
3. How company profile (size and type of company) has effect on use of BIM in renovation projects?
4. How is the level of engagement of the company (being general contractor or subcontractor) in renovation phases effecting the feasibility of BIM implementation in the project?

Resources

http://metropolia.finna.fi/
http://scholar.google.com/
http://webofknowledge.com/
http://www.elsevier.com/

References

[1] BPIE, 2011. Europe's Building under the Microscope: A Country-by-Country Review of the Energy Performance of Buildings
[2] European Commission 2012a. Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. Official Journal of the European Union L81/18.
[3] Artola, I., Rademaekers, K., Williams, R. and Yearwood, J., 2016. Boosting building renovation: What potential and value for Europe. Study for the iTRE Committee, Commissioned by DG for Internal Policies Policy Department A, p.21.
[4] Elagiry, M., Marino, V., Lasarte, N., Elguezabal, P. and Messervey, T., 2019. BIM4Ren: Barriers to BIM implementation in renovation processes in the Italian market. Buildings, 9(9), p.200.
[5] Porwal A, Hewage KN. Building Information Modeling (BIM) partnering framework for public construction projects. Autom ConStruct May 2013;31: 204e14.
[6] Gökgür, A., 2015. Current and future use of BIM in renovation projects (Master's thesis).

Signature of the Supervisor

htw.
Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

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

HTW Berlin Registration Number: s0572586
Surname: Daneshvartarigh First Name(s): Fatemeh

Specifications for the Master Examination
according to § 9 and 10 Examination Regulations for the Master Study Programme
Construction and Real Estate Management

1. Master Thesis, Examination Commission

(1) Topic of the Master Thesis
Energy Efficient and Cost-Optimized Renovations for Residential Blocks

(2) Examination Commission
Chairperson Prof. Dr. Dieter Bunke
1. Supervisor Hannu Hakkarainen
2. Supervisor Sergio Rossi

(3) Thesis Period
Date of Issue 01.07.2020
Closing Date 02.07.2021
Deadline

Berlin, 02. JULI 2020
Signature of the Chairperson of the Examination Board

2. Issue of the Topic of the Master Thesis

Date of Issue 02. JULI 2020 issued by

I have taken note of the subject and the deadline of the master thesis as well as the formation of the examination commission. It is known to me that I have to submit three (3) written and bound copies of the master thesis alongside a digital version as well as the additional statuary declaration at Metropolia Helsinki or HTW Berlin.

Berlin, 06/30/2020
Signature of the student

3. Release of the Master Thesis

Date of Release received by

Distribution: original for the student, copies for audit file, chairperson and supervisors of the examination commission and chairperson of the examination board

For the
Chairperson of the Examination Board

15. JUNI 2021
Received by faculty

of the **Programme** Construction and Real Estate Management
at the Hochschule für Technik und Wirtschaft

REQUEST TO CHANGE THE TITLE OF THE FINAL THESIS

Family Name: Daneshvartarigh First Name: Fatemeh

Telephone: +358453166985 Email: Fatemeh.DaneshvarTarigh@Student.HTW-Berlin.de

Street address: Kurkisuontie 12, D 033 Postal Code/City: 00940 Helsinki

1st Supervisor: Sergio Rossi 2nd Supervisor: Hannu Hakkarainen

I wish to request for the following change to the title of my thesis.

Previous title:

Energy Efficient and Cost-Optimized Renovations for Residential Blocks

New title to be confirmed:

Application of BIM in Renovation projects in Europe

Please note that changing the title of the final thesis does not constitute a rejection of the topic as defined by § 21, no. 2 of HTW's Examination Framework Regulations!

Agreement of the 1st examiner: Sergio Rossi

Agreement of the 2nd examiner: H K

Agreement of the examination board: on behalf of

Berlin,

Signature of the candidate Fatemeh 05/15/2021

Abstract

Today, because of its benefits in designing and implementing construction projects for employers, contractors, and consultants, BIM is used along the life cycle of the projects. The BIM usage approach has made significant progress globally in the last ten years, but it is inadequately incorporated, especially in building renovation projects. Therefore, one of the necessary measures to increase the use of this new approach is to examine the challenges and obstacles facing it. In this research, based on the Delphi method, at first, the background and related literature are reviewed. Then, using the knowledge obtained from the literature, a primary questionnaire is generated and filled by experts who are selected using snowball sampling. It covered the experts' attitudes towards implementing BIM in renovation projects and their view of the benefits and obstacles in this regard. By analyzing the primary questionnaire, the second group of experts is selected among the participants to be interviewed. The results are analyzed using Theme analysis. Six themes, including Management support, staff resistance, client willingness, Cost of software and implementation, the difficulty of implementation, and other reasons, are obtained. Then a final questionnaire is generated from the themes and filled by the same group of experts. The result is analyzed by the Fuzzy Delphi method, showing the exact ranking of the obtained themes. The final results show that management support, staff resistance, and client willingness are the most critical barrier to BIM usage in renovation projects.

Keywords: Building Information Modeling, BIM, BIM implementation, BIM barriers, BIM in renovation

Table of Contents

Table of Figures

List of Tabulations

List of Abbreviations

AEC	Architecture, Engineering, and Construction
BIM	Building Information Modeling
EU	European Union
FM	Facility Management
HVAC	Heating, Ventilation, Air Conditioning
LOD	Level of Development
RFID	Radio Frequency Identification
AGC	American General Contractors
CAGR	Compound Annual Growth Rate
ITRE	The Committee on Industry, Research and Energy of the European Parliament
IFC	Industry Foundation Classes
IPD	Integrated Project Delivery
IAQ	Indoor Air Quality
SBS	Sick Building Syndrome
TFN	Triangular Fuzzy Numbers
VBA	Visual Basic for Applications

List of Symbols

α is the Cronbach's alpha coefficient,

k is the number of questions,

$\sigma^2 Y_i$ is the sum of the variance of scores of each respondent,

$\sigma^2 X$ is the variance of the scores of question number *i*.

l, m and u real numbers

$\mu =$ the membership function of l, m and u

$x_{ij}^{defuzzy}$ The defuzzyficated result of ij

1. Introduction

Nowadays, the construction industry, like other industries, has undergone many growths and transformations, which has caused it to be divided into various categories. From residential to commercial or industrial areas, all have experienced fundamental changes. Construction trends in recent years show that intelligence, productivity, and profitability are the main factors that are improved. Understanding the developments in the construction industry and recognizing solutions to overcome business barriers will help construction companies to scale their company effectively for the upcoming decades.

New technologies and applications have radically altered construction techniques in recent years. In order to anticipate how the building will act, perform, and appear, these technologies encompass a wide range of visualization, simulation, and analytic tools. These new technologies and applications have a considerable impact on completing construction projects in today's AEC[1] industries.

Business owners, contractors, consultants, architects, engineers, and subcontractors use communication platforms to standardize business procedures to manage and exchange information.

BIM[2] is a digital depiction of a facility's physical and functional characteristics and a shared database for information about decisions made throughout its life cycle (Jensen and Maslesa 2015, p. 2). Simulating and analyzing the structure with the aid of modern modeling technologies allows project stakeholders to see how a building behaves, how it will function, or how it will look far more realistic than ever before.

However, it is critical to determine the shareholders' duties, the range of information to be exchanged in the project, and the supporting software utilized in the construction execution procedures.

To summarize, the technology and uses of BIM Systems aid in the completion of building projects in less time, at a lower cost, and in a more sustainable manner.

---

[1] Architectural, Engineering, and Construction

[2] Building Information Modeling

The volume and complexity of all construction projects, including renovation, have risen substantially in recent years. Coordination between different parts becomes extremely difficult, if not impossible, without BIM. Various building engineers, such as designers, architects, structural engineers, HVAC[3] engineers, electrical engineers, etc., use BIM instead of constantly sending their calculations to others, explaining their work to them, and coordinating with them. Each group accurately uses BIM in its work, while BIM coordinates all information and prevents interference, inconsonance, and Inconsistency between the sections.

The advantage of utilizing BIM is that it allows the "virtually construction" of a project with all components and facilities before putting it on the ground and analyzing all the positive and negative dimensions and effects on the project's details. In this way, there is no need to pay exorbitant costs and trial and error in the real world. The whole process is done in a completely virtual environment.

On the other hand, most construction or renovation projects face changes, which lead to delays, increased costs, severe quality reductions, and other adverse effects. These changes usually occur by the client for a variety of reasons. These include new ideas in the design, reducing or increasing the budget, and not having a clear view of the project in the design phase. All of these disrupt the manufacturing process and the final product.

One of the purposes of BIM is change management, as design changes are inevitable. The difference is that with the new BIM approach, these changes are managed optimally, and the adverse effects are significantly reduced.

1.1. Problem description

The AEC industries are progressively developing BIM projects. The worldwide building information modeling market is expected to grow. Even the COVID-19 pandemic has not influenced the expansion of the building information modeling business. (Wang et

[3] Heating, Ventilation, and Air Conditioning

al. 2021, p. 13). In contrast, BIM's widespread adoption allowed projects to proceed in a virtual and digital environment even when participants could not meet in person.

BIM is being used in the construction sector to increase efficiency in all elements of the asset delivery lifecycle, including cost, risk, carbon emissions, and time. Although it is a universally acknowledged technology in the building construction sector, many small businesses are hesitant to use it, believing it is essential for major construction companies, high-end architects, and government projects.

On the other hand, more than 90 percent of buildings in Europe were constructed earlier than 1990. Therefore, current and future construction projects will increasingly focus on renovation all over Europe (the Committee on Industry, Research and Energy (ITRE) of the European Parliament 2016). And because the majority of existing buildings are constructed before the advent of BIM, they lack a 3D model.

Although researchers and practitioners recognize the need for BIM in renovation projects, it is still not being used effectively. (Ilter and Ergen 2015)

1.2. Aims and Objectives

Today, because of its benefits in designing and implementing construction projects for employers, contractors, and consultants, BIM is used along the life cycle of the projects. Extensive research on BIM has shown that the main benefits of using BIM include reducing costs and time, improving communication and coordination, and improving project quality. The BIM usage approach has made significant progress globally in the last ten years, but it is inadequately incorporated, especially in building renovation projects. Therefore, Reasons for reluctance to use BIM in renovation projects are the focus of this research.

In recent years, some research is performed concerning the use of BIM in renovation projects. However, the rate of changes and new technologies introduced to the industry shows the necessity of further investigation.

The rate of changes in BIM-related topics is different worldwide, and it depends on many factors, e.g., the national policies of each country. Therefore, there is a need for comprehensive research focused on a specific area with common characteristics.

This research aims at a focused investigation of the current situation with the use of BIM in renovation projects and the factors affecting it, aiming to develop an up-to-date knowledge base by presenting the status and suggesting future path for research. Since each area needs specific analysis based on the facts and conditions, the scope of the study is limited to northern and western Europe.

1.3. Research Questions

To fulfill the study's objectives following questions should be addressed:

a) What is the situation with the use of BIM software in renovation projects?

b) What are the factors affecting BIM implementation in renovation projects?

c) How company profile (size and type of company) affects the use of BIM in renovation projects?

d) How is the company's level of engagement (being a general contractor or subcontractor) in renovation phases affecting the feasibility of BIM implementation in the project?

Answering these questions could help investigate the state of using BIM in renovation projects to point out the benefits and barriers of BIM use. On the other hand, it will highlight the correlation between participation extent and BIM adoption in renovation projects.

The third question of this thesis is considering the effects of company profile on using BIM in renovation projects.

Due to the time limits and the nature of the question which is different from two other research questions and because it can be better answered if using another methodology, this topic is kept for another study.

1.4. Structure of the research and methodology

In the first chapter, a short history of issue, knowledge gap, aims, questions that this study attempt to address, the methodologies, and ultimately the scope of the study are described.

The two main areas involved in this study, Renovation and BIM, are defined in the second chapter. Then, the recent research in this field is reviewed, and finally, the problem discussed in this study is presented.

Chapter three explains the method used in this study and its related considerations. The reasons for choosing this method are explained, and the study's boundaries are clearly stated.

In chapter four, the research findings are described. The first part of this chapter includes analysis and findings. And the reliability of the results is examined in the second part.

Chapter five is presenting the summary of this study. The limitations and barriers which restricted this study are shown in the next part. Lastly, a recommendation is offered for the future study path in this area.

2. Literature review

The second chapter begins with an overview of the subject to provide some background information. The past research relevant to the study's title is then evaluated to summarize what has been addressed in this subject before. Lastly, the knowledge gap and problems that this work aims to solve are described.

2.1. Background

This section is divided into three subsections that include the broad description, definition, and history of the fields that make up the study's skeleton. Firstly, the renovation process is discussed in detail. Then, the definitions and advantages BIM as a new technology offered to the building industry are discussed. In the end, the integration of BIM within the renovation processes and new technological breakthroughs are studied.

2.1.1. Renovation

It is essential to understand the definitions and processes of the renovation project. And FM role in this process. An overview about status of renovation projects in Europe.

Definition

Building rehabilitation is the process of repairing or replacing existing structural components to enhance the building's performance, either to its original state or to a higher one. Building renovations also provide customers the option of changing the building's layout, functions, architectural expression, and so on to meet their present or future demands. (Jensen and Maslesa 2015, p. 2)

There are two types of construction activities in existing buildings: refurbishment and redevelopment. It is considered refurbishment or Revitalization if there is no change of use, And if the aim is modernization restoration and qualitative improvement Figure 1. (Schäfer and Conzen 2019)

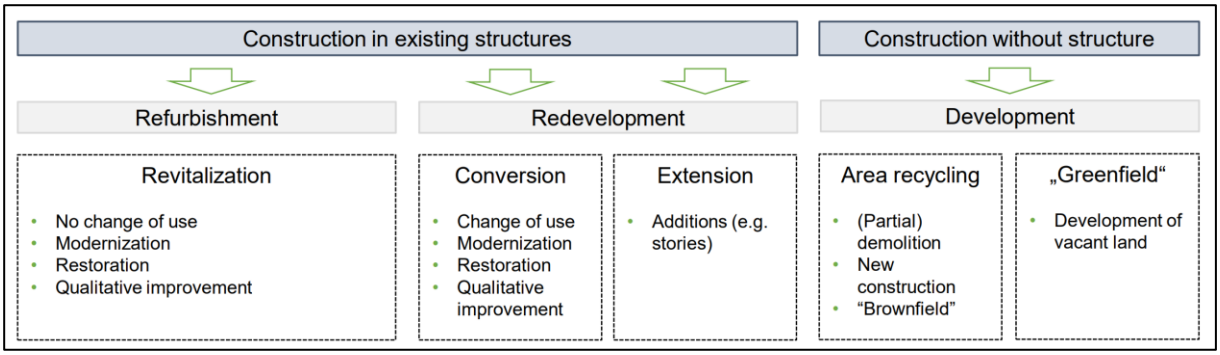

Figure 1: Typology of Project Developments[4]

Classification of Renovation Approaches

The scope of the renovation, or the number of renovation measures, determines how this procedure will influence the building's quality. As a result, three types of remodeling may be distinguished: partial, deep, and comprehensive.

Partial refurbishment denotes a procedure in which one or a few measures concentrating on a small target region are implemented. For a significant reduction in energy consumption, a deep renovation is required, which includes efforts to improve the building's active technological systems as well as a comprehensive set of actions to improve the thermal envelope's characteristics. Apart from the energy savings, which significantly impact decreasing environmental loads and maintenance costs, deep renovation increases interior thermal comfort and user satisfaction (social element of sustainability).

A comprehensive renovation aimed at enhancing various criteria of building quality and their related sustainability features can reach the maximum degree of improvement in terms of intensity and scope of treatments. As a result, comprehensive renovation may be viewed as an integrative sustainable solution. (Leskovar and Premrov 2019, p. 10)

Table 1 summarizes the renovation approaches considering the intensity and scope of interventions.

[4] Schäfer and Conzen 2019.

Table 1: Renovation approaches considering the intensity and scope of interventions[5]

Intensity and scope of renovation	Partial	Deep	Comprehensive
	One or few renovation measures	Set of requisite renovation measures	All requisite renovation measures
Achievement	Partial improvement of the building physical condition and functional performance	Thorough improvement of the building physical condition and functional performance	Improvement of the building quality from technical, functional, environmental, social and economic perspectives
Level of overall efficiency	Low	High	Excellent

Buildings have a lifespan and require frequent maintenance to maintain their performance. They can become outdated and, as a result, insufficient for their intended purpose over time. Langston et al. describe several reasons for obsolescence: physical, economic, functional, technical, social, and legal.

Buildings are deteriorated naturally over time, resulting in physical obsolescence. Economic obsolescence occurs when facilities do not meet cost-efficiency measures for investors. When the building no longer corresponds to its initial purpose, functional obsolescence occurs. If a structure or its components do not achieve the technological performance of modern solutions, technological obsolescence happens. Social obsolescence occurs when a building does not meet the behavioral trends or needs of users. And legal obsolescence occurs when a building no longer meets current building rules and regulations. (Langston et al. 2008, p. 1710)

Aside from the forms of obsolescence mentioned above, the building may be unfit for future use owing to damage caused by fire, earthquake, or hazardous pollution. The forms and reasons of building obsolescence are determining respective priorities in building renovation procedures. (Leskovar and Premrov 2019, p. 12) Table 2 summarizes the renovation approaches considering the main priorities.

[5] Leskovar and Premrov 2019, p. 10.

Table 2: Renovation approaches considering main priorities[6]

Approaches	Priorities
Minor renewal	Replacement of deteriorated building components or technical systems
Renovation within the context of historic buildings	Preservation Rehabilitation Restoration Reconstruction
Renovation targeting improvement of the building state and performance	Energy efficiency Structural resistance Indoor environment quality Fire safety
Functional renovation	Building biology Retention of use Building extension Conversion of use

Minor renewal approach is an urgent response to specific building defect without any design plan.

Renovation of Historical Building

In the historical building context, four policies apply to increasing their lifespan and maintaining their heritage and cultural significance: preservation, rehabilitation, restoration, and reconstruction.

During the preservation process, it is necessary to maintain the building's historical structure and the greatest quantity of fabric possible while focusing on safeguarding the property. This treatment does not cover any new annexes, such as replacement or new construction.

The rehabilitation process recognizes the change of a historic structure to accommodate ongoing or current uses while preserving the historical character, cultural and architectural qualities. Repairs, annexes, or replacements of severely deteriorated, cracked, or lost elements are examples of modification work. Only minor modifications to construction materials and spatial connections are permitted.

Restoration is a method of the precise depiction of the design and characteristics of a building as it was at a specific time through the removal of elements from other periods and reconstruction of the missing parts. In comparison, reconstruction depicts a non-

[6] Leskovar and Premrov 2019, p. 12.

surviving site to replicate its condition at a specific period and in its place, generally with new materials. (Leskovar and Premrov 2019, p. 13)

Enhancement of the State and Performance

The basic goal of the energy-efficient renovation is to reduce the energy consumption for heating, cooling, lighting, and electricity (Leskovar and Premrov 2019, p. 18). The combination of energy generation systems based on renewable energy is an additional objective.

Holistic energy renovation goes beyond typical energy renovation to address issues caused by poor building design standards, construction materials, procedures, incorrect usage, operation, or maintenance. As a result, in order to function appropriately in holistic energy renovation, knowledge about the building's use, surroundings, and history is required. (Stegnar and Cerovšek 2019, p. 318)

Structural renovation is required when the building does not match the load-bearing obligations defined by the contemporary building codes. The reason could be their original structural design, increased loads, long-term material degradation, damages to the structure caused by external reasons or modifications, annexes, etc., implemented due to the conversion of spatial arrangement or use.

The indoor environment quality improvement considers thermal, visual, acoustic comfort, and IAQ[7] factors to control harmful loads to prevent the existence of factors responsible for the SBS[8]. It is mainly produced by building materials, electromagnetic fields, other radiation origins, pure ventilation, and weak design. (Leskovar and Premrov 2019, p. 18)

Functional Renovation

Three types of renovation can be described concerning the building use; the retention of use building, extension and conversion of use.

Rehabilitation with Retention of the Building Use is due to the constant evolution of Lifestyle habits and the consequent demands of modern society. As a result, the existing living and working environments can become obsolete, unsuitable for the users, and therefore redundant. Another critical issue tackling the functional design of existing

[7] Indoor Air Quality
[8] Sick Building Syndrome

buildings is the necessity to adapt them to users with permanent or temporary disabilities. These buildings require rehabilitation where the original use of the building is retained or adapted to new purposes.

Building Extension is another solution that aims at increasing the usable building surface proportion as an option of increasing urban density. It is carried out through vertical structural upgrade or the so-called attic extension and horizontal volumes addition, such as the closure of existing balconies and loggias with the thermal envelope.

Conversion of the Building Use is another approach to building renovation which converts the existing building and adapts its use to new functions to prolong the building service-life and raise the building value. (Leskovar and Premrov 2019, p. 25)

All in all, the renovation approaches are implemented to preserve and enhance the existing building stock to have a better and sustainable built environment.

Renovation Process

The phases of pre-design, design, construction, and operation are mainly the same in construction and renovation projects. The primary difference is the restrictions of having an existing building and the facility's current users on the site (Nielsen et al. 2016, p. 166). Figure 2 shows the building renovation process phases.

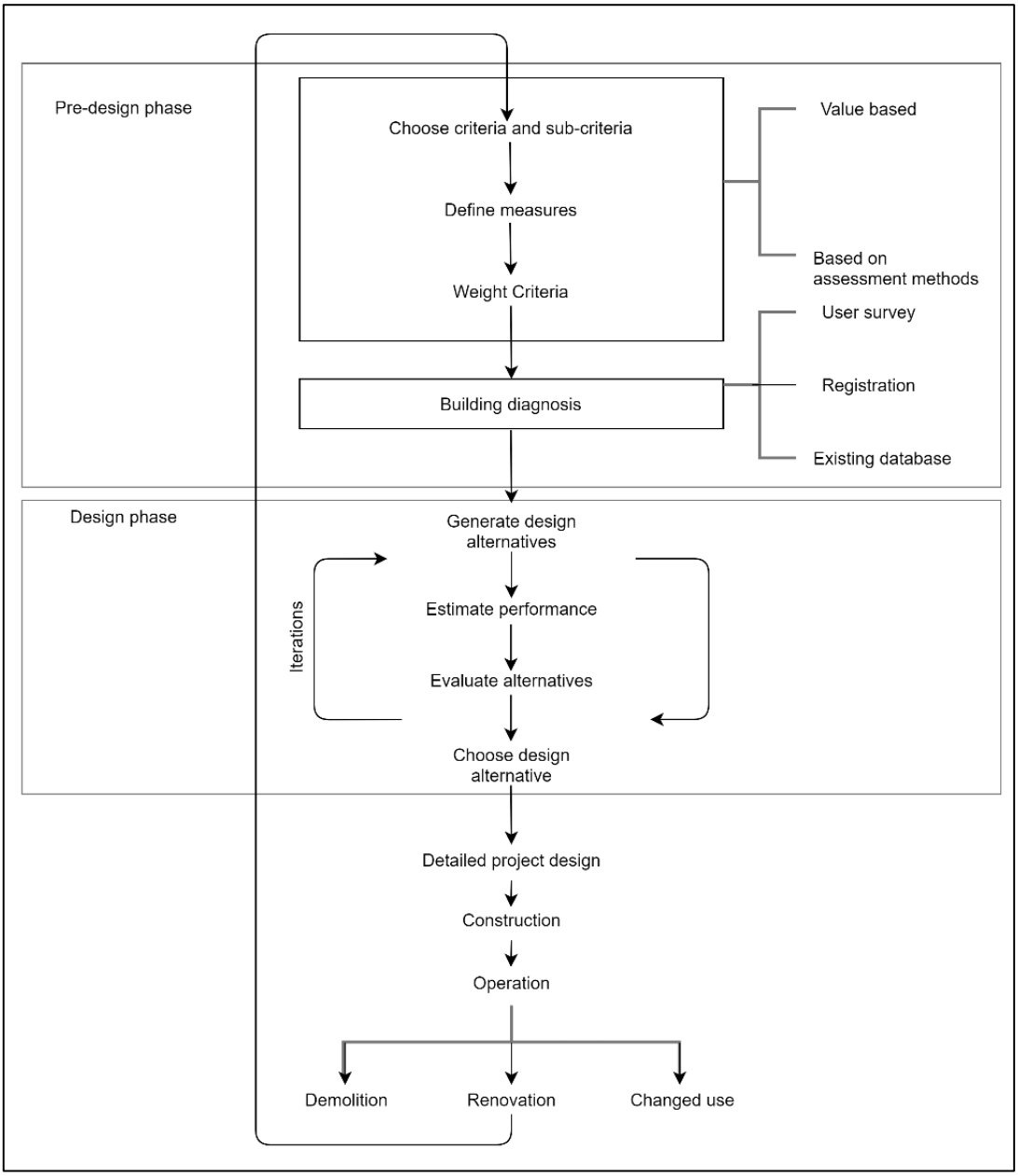

Figure 2: The building renovation process[9]

Renovation is multi-criteria decision-making field that deals with making decisions with many, often conflicting objectives. Countless decisions are made during the various phases of a building renovation project, from the initial decision on the design of rehabilitation scenarios to selecting design options through construction, operation, usage, and eventually demolition or reuse. (Nielsen et al. 2016, p. 166)

[9] In conformity with Nielsen et al. 2016, p. 167.

The six decision-making areas in the renovation are goal formulation, weighing of criteria, building diagnostic, development of design alternatives, calculation of performance, and lastly, evaluating design alternatives. (Nielsen et al. 2016, p. 166)

Building renovations typically address numerous issues in a single building at the same time, resulting in various advantages. Today, the focus is mostly on energy efficiency, but it may also provide non-energy advantages such as improved indoor climate, better lighting conditions, and enhanced working areas. (Jensen and Maslesa 2015, p. 2)

Renovation Wave in Europe

More than 80% of residential buildings in Europe were constructed before 1990 Figure 3. (Economidou et al. 2011)

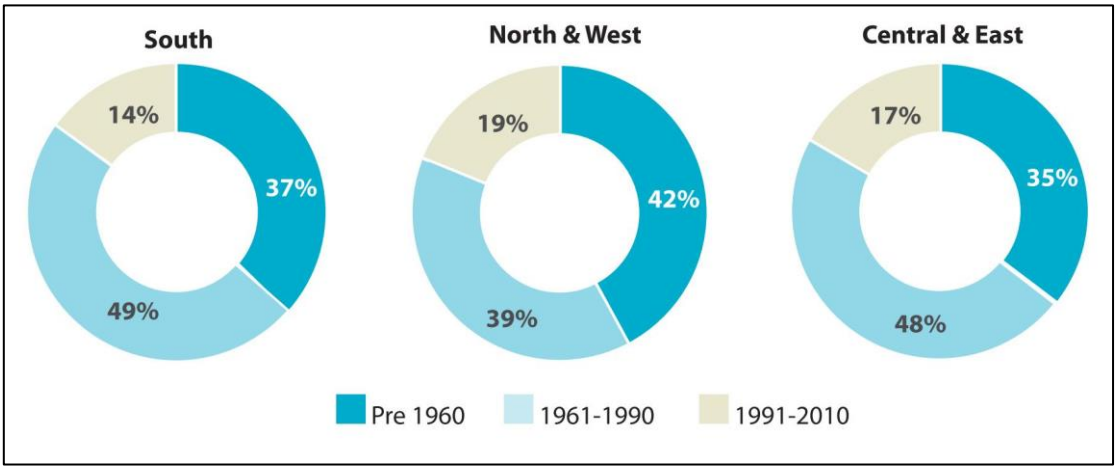

Figure 3: Age categorization of housing stock in Europe[10]

Building renovation is enhanced in the context of the European Green Deal to attain carbon neutrality by 2050 - not just in terms of the number of projects but also to accomplish more profound renovation.

In 2020, the Commission unveiled its “Renovation Wave” initiative to increase energy renovation in EU buildings (Energy Performance of Buildings Directive 2021). It established a target of at least doubling the yearly energy renovation rate by 2030, emphasizing the need for the appropriate legislative, financial, and supporting measures to achieve this.

[10] Economidou et al. 2011.

The European renovation wave’s positive outcomes include the revitalization of urban quarters, increased comfort levels and standard of living and working spaces, assisting people out of energy insecurity, and providing long-term jobs. Supporting initiatives are needed at all stages of the building supply chain, from a well-trained workforce (from builders to tradespeople) to a continuous and increasing variety of energy-efficient technologies, as well as information campaigns. (Economidou et al. 2011)

In Germany economy is dependent on the construction of new buildings, especially those of large sizes, which are the most economically desirable. Other operations such as renovation and similar building projects are affected by severe shortage of expertise, especially skilled labor on construction sites, resulting in high costs and delays for related activities. For owners lack of capital is one of the challenges preventing them from upgrading their properties. The most well-known initiatives to resolve this problem are the kfw-supported, energy-efficient refurbishment and construction programs (Ostermeyer et al. 2018). The schemes deliver grants, soft loans to found energy-efficient work during the general refurbishment of old buildings and promote energy efficiency in new buildings, higher than the technically mandated minimum.

Unfortunately, financial incentives are mostly preconditioned by the demonstration of energy savings achieved in the renovation. Still, sophisticated control of indoor environment quality improvement is not a question of financial incentives (Leskovar and Premrov 2019, p. 18). Even if the energy required for heating was decreased, indoor air quality might worsen if the ventilation strategy is not reviewed. The latter is especially essential because older buildings may include building materials containing hazardous solutions that might harm the users' health.

Barriers

There are various explanations why energy-saving policies are often ignored, rejected, or only partially implemented. Decades of experience have shown several obstacles to energy-saving investments. The key findings by the BPIE survey that have a specific effect on existing buildings are summarized in Figure 4 including financial, institutional, and administrative, awareness/information, and split incentives. (Economidou et al. 2011)

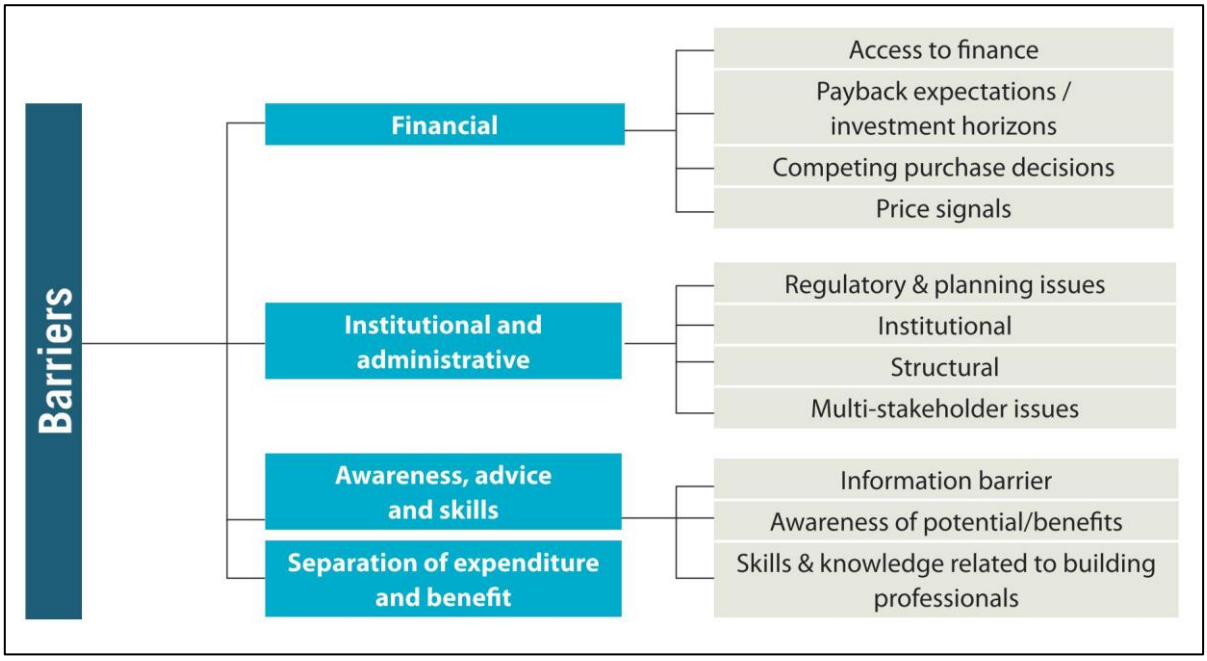

Figure 4: Classification of barriers as identified by the BPIE survey[11]

Inadequate communication among stakeholders is one of the primary causes of low productivity, schedule delays, and cost overruns. Renovation projects in occupied buildings are challenging because of the extra hazards and logistical needs imposed by the presence of inhabitants during renovation work, which is known to generate clashing activities between contractors and occupants. As a result, an efficient communication strategy and adequate health and safety measures are necessary.

Renovation projects include additional operational uncertainty due to surprises when old structures are uncovered during the construction stage, which exacerbates communication problems. Static plans that define when each apartment will be working are thus insufficient or, if significant time buffers are utilized, extremely wasteful. Because of the unpredictability, there is a need for real-time coordination solutions that allow for flexible and quick responses to newly found challenges. (Törmä et al. 2020, p. 1)

Existing buildings may contain toxic building materials. (Leskovar and Premrov 2019, p. 18) Common sources of pollutants in built environment include: Plywood/ compressed wood, Construction adhesives, Asbestos products, Insulation, Wall/floor coverings, Carpets/carpet adhesives, Wet-applied building products, Painting, roofing, sanding (Yang and Tepfer 2018)

[11] Economidou et al. 2011.

2.1.2. Building Information Modelling

Definition

A BIM is a digital representation of a facility's physical and functional features. As such, it acts as a shared knowledge repository for information about a facility, providing a solid foundation for choices made throughout its life cycle. A fundamental assumption of BIM is cooperation among multiple stakeholders at various stages of a facility's life cycle to input, remove, update, or alter information in the BIM process to support and represent each stakeholder's function. (NIBS and NBIMS Committee 2007) Figure 5 shows different phases of buildings lifecycle where BIM is involved.

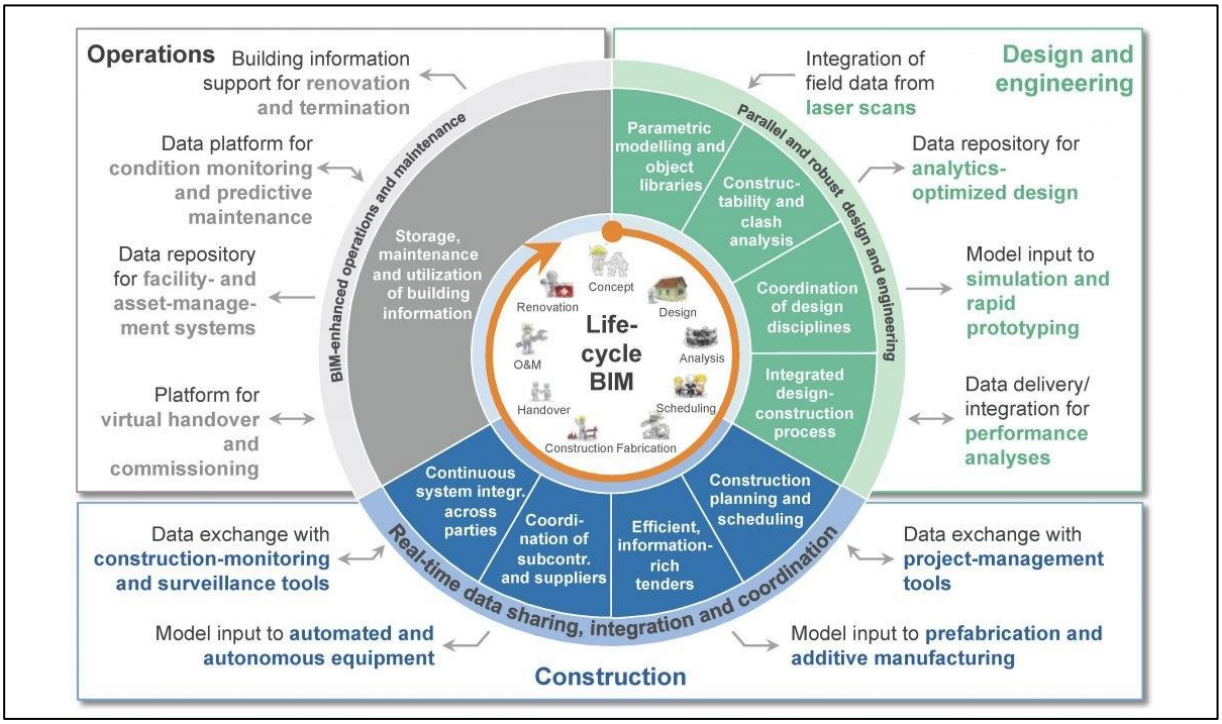

Figure 5: Different phases of buildings lifecycle where BIM is involved[12]

The AGC[13] defines a Building Information Model as a digital twin of the facility from which views and data tailored to the requirements of various stakeholders can be

[12] Catenda 2021.
[13] American General Contractors

derived and evaluated to generate information that is used for decision-making and delivery-process improvement.

“Building Information Modeling is the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model, a Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users’ needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility.”[14]

Eastman *et al* has defined BIM as “A modelling technology and associated set of processes to produce, communicate and analyses building models.”[15]

Potential Positive and Negative Aspects

Combining BIM with inclusive project execution and energy management will enhance project teamwork, communication, sustainability, and creativity while also reducing mistakes, inaccuracies, and rework. (Stegnar and Cerovšek 2019, p. 318) Figure 6 compares the traditional process versus the BIM process.

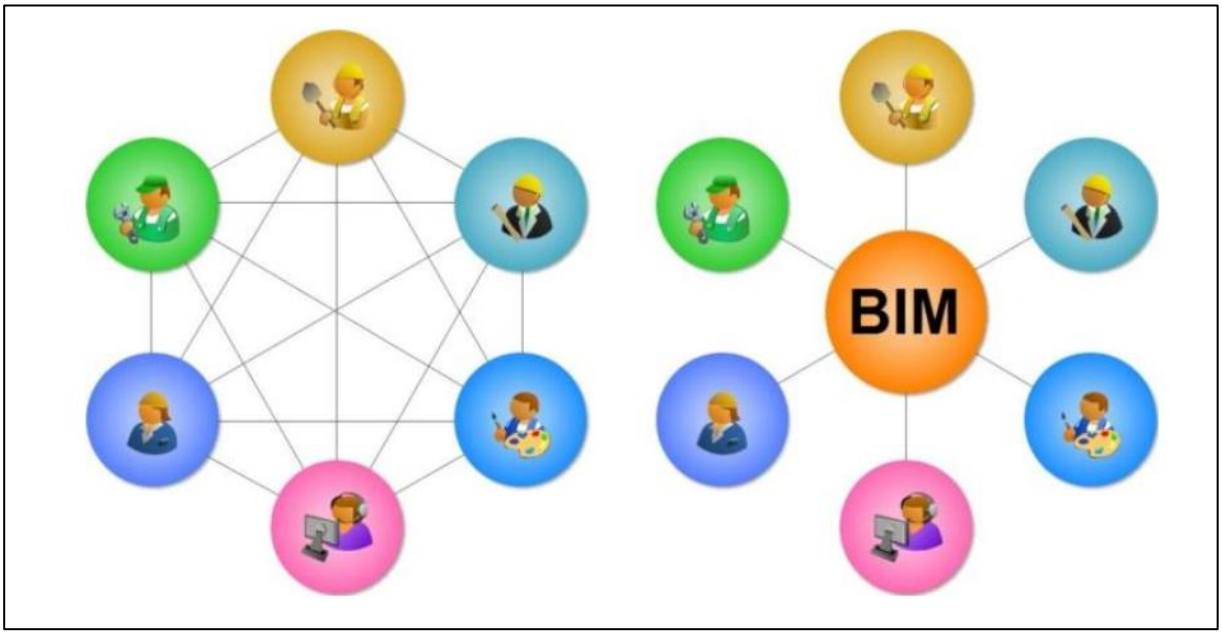

Figure 6: Traditional process versus BIM process[16]

[14] Reinhardt and Associated General Contractors of America 2008.
[15] Eastman et al. 2008.
[16] Birna Kjartansdóttir et al. 2017.

Communication and the value of the information generated by the BIM process are two significant advantages of BIM. When BIM is carried out in a collaborative environment where analytical, decisional, and documentation activities are coordinated within an information model framework, the risks associated with today's business are avoided. At the same time, new income and service opportunities are created. (NIBS and NBIMS Committee 2007)

In 2021 European Innovation Council and SMEs Executive Agency (EISMEA) has published a handbook for Calculating Costs and Benefits of using BIM in Public tenders and has summarized the benefits of BIM as the following Table 3:

Table 3: Some benefits of BIM[17]

Potential advantages of BIM
Early clash detection
Prevention of changes in the construction phase
Savings associated with schedule reduction
Accuracy in quantity take-offs
Environmental benefits
Lower risks (enhanced certainty)
Savings realized in FM and maintenance activities
Savings related to better H&S
Reduced number of complaints
Enhanced communication and collaboration

Technological solutions unquestionably have cost and drawbacks as well. As a result, the BIM advantages is essentially a list of prospective benefits that may be realized if the technology is applied appropriately.

Some of the disadvantages of BIM are as follows: Technical issues, labor intensity, Reliance on software vendors, The difficulty of incorporating a universal system of duties performed by specialized software (Gamayunova and Vatin 2014).

[17] In conformity with European Innovation Council and SMEs Executive Agency 2021, p. 9.

Creating model

Creating a BIM model for existing buildings is challenging, especially for the old ones. Usually, there are no accurate and reliable as-design or as-built drawings and specifications for them. This information is extracted from the reports of design, maintenance, and renovation phases which is very time-consuming to extract the related information and use them for BIM model creation. According to ITRE[18], more than 80 percent of residential buildings in Europe were built before 1990 and did not have as-design or as-built BIM models. To equip these buildings with the BIM model, employing the "Point-to-BIM" or "Scan-to-BIM" process is necessary. (Volk et al. 2014)

The “points-to-BIM” method is used to collect and represent actual building conditions. Geometrical and topological information of architectural elements must be manually acquired, modeled, and supplemented with semantic property information to develop an as-built BIM from scratch. Existing buildings might benefit from BIM usage in terms of documentation, visualization, or facility management if a reliable data collection approach could offer an as-built BIM at an efficient time and cost. (Volk et al. 2014)

The Scan-to-BIM procedure is to scan the spatial information of a facility and create raw point clouds—Supplementary devices like cameras and RFID[19] capture facilities' semantic data like material, price, etc. The primary point clouds are registered in a coordinate system, and a unique point cloud is secured. The registered point cloud is segmented, and geometry is connected to surfaces or volumes. Finally, semantic data is linked, objects' attributes and relationships are set, and a BIM model of the scanned buildings is made. (Tzedaki and Kamara 2013, p. 487)

Level of Development

An appropriate informational structure and data interchange with the model is required to provide interoperability across various software systems without information loss, depending on the desired functionality. Functional and informational requirements define model features, needed model capacities through LOD[20], and as a result, required model development procedures. (Volk et al. 2014)

[18] The Committee on Industry, Research and Energy of the European Parliament.

[19] Radio Frequency Identifications

[20] Level of Development

The LOD of an element is the extent to which its geometry and characteristics have been developed. (Mekawy M. and Petzold F. 2018) Figure 7 summarizes the five levels of LODs.

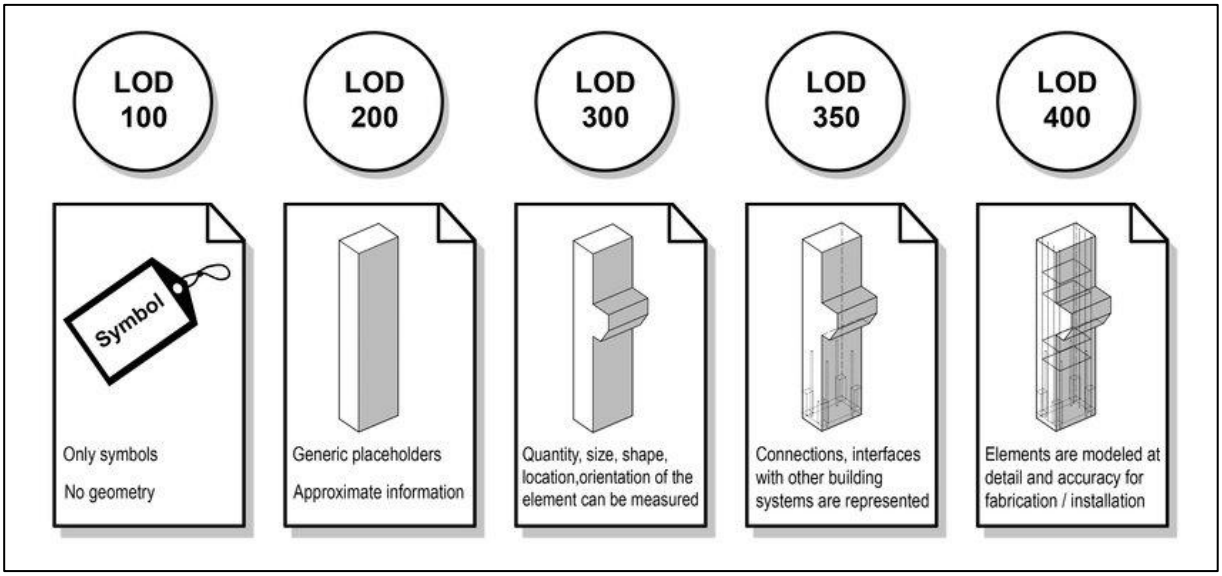

Figure 7: The different levels of LOD in BIM models[21]

In LOD100, elements are represented by a symbol or other general representation. While LOD350 visually shows the element inside the Model as a distinct system in terms of number, size, form, position, orientation, connection, and interfaces with other building systems.

Industry Foundation Classes

The IFC[22] data model comprises definitions, rules, and protocols that create data sets that represent capital facilities throughout their lifecycles in a unique way. These standards enable industrial software developers to create IFC interfaces for their software that allow for the interchange and sharing of the same data in the same format with other software applications, independent of the internal data structure of the particular software program. IFC interfaced software applications can interchange and share data with other IFC interfaced software applications. (NIBS and NBIMS Committee 2007). Many facility lifetime connections are depicted in Figure 8. Overlays, systems,

[21] Mekawy M. and Petzold F. 2018.
[22] Industry Foundation Classes

and space are all shown. Each system can function either independently or dependently on the other.

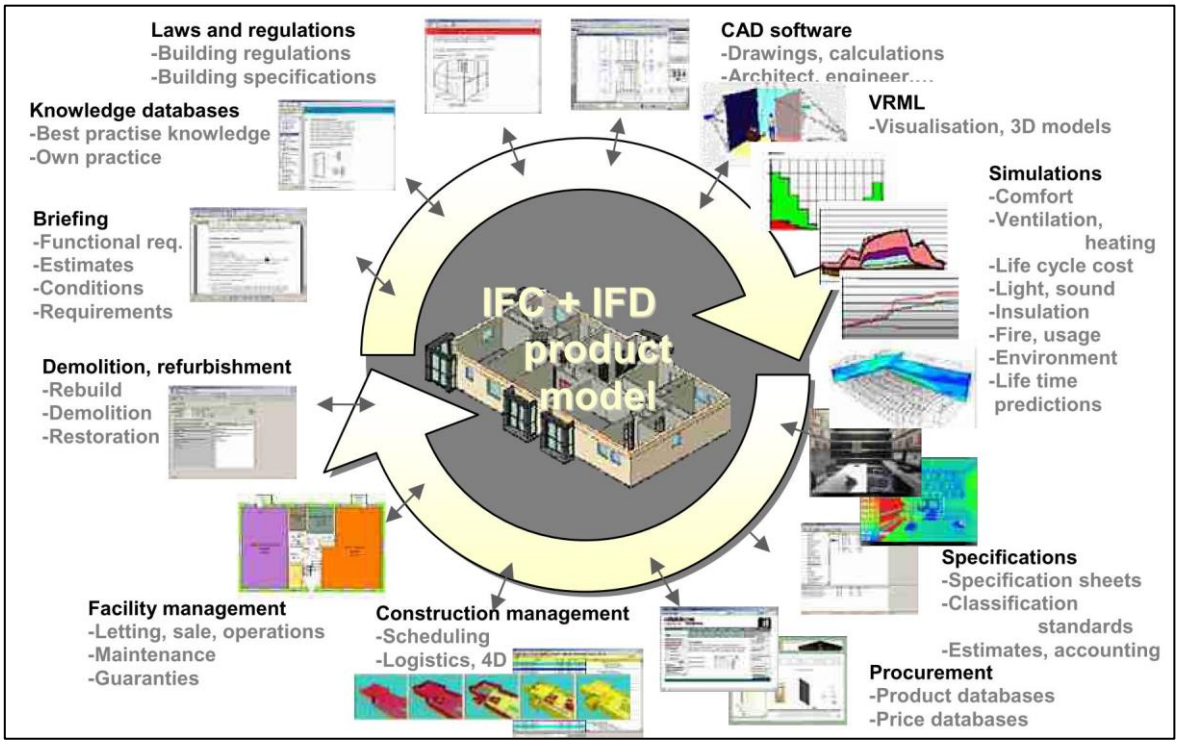

Figure 8: BIM Relationships[23]

Renovation Project Planning Tools

BIMPlanner is a planning, and management tool for housing restoration projects, and BIM4Occupants is a coordination tool between contractors and occupiers. Both are two renovation management tools presently developed under the BIM4EEB project. The technologies seek to improve information exchange among renovation stakeholders and augment BIM data in renovation projects with connections to other relevant data. (Törmä et al. 2020, p. 1)

It is used to facilitate contact between contractors and residents: the plans anticipate when activities will occur in each apartment on an ongoing basis, allowing for tailored alerts to occupants of a specific unit. Furthermore, tenants can give comments on plans. (Törmä et al. 2020, p. 1) Figure 9 shows the information sharing between BIMPlanner and BIM4Occupants through BIMMS.

[23] NIBS and NBIMS Committee 2007.

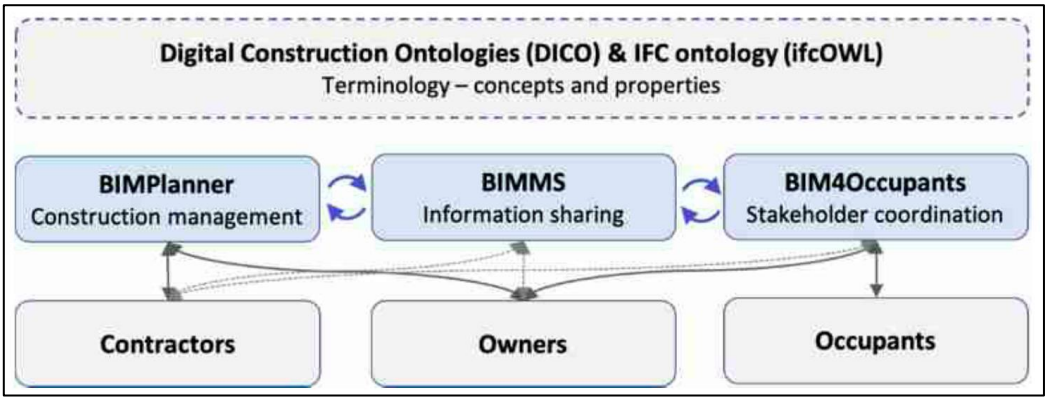

Figure 9: Information sharing between BIMPlanner and BIM4Occupants through BIMMS[24]

Scan-to-BIM

Point clouds are being utilized more and more as 3D as-is geometric representations of structures. A point cloud in its raw form, acquired via a laser scanner or by processing large photos, consists of millions of individual points, each with its own 3D relative coordinate information. (Wang et al. 2015)

Trimble Realworks is employed after the on-site laser scanning is completed. The files are imported in Realworks for additional processing to serve two functions: data format conversion and automatic registration.

Since Autodesk owns the most popular 3D modeling program (Revit), they created ReCap to assist their software package in the area of laser scanning and point cloud. (Sanei Sistani 2017)

Several software tools, such as EdgeWise Plant by ClearEdge3D, Leica CloudWorx by Leica Geosystems, and AutoCAD Plant 3D by Autodesk, were released in 2014 to help the existing manual process of 3D modeling. Provide several capabilities for manipulating laser-scan data in the form of 3D point clouds obtained from the existing buildings. (Son and Kim 2016, p. 203)

Trimble Realworks and ClearEdge3D are intended to generate a 3D model automatically by manually segmenting the point cloud and selecting the relevant catalogs to every segment of the point cloud. When the object detection in Edgewise is complete, the recognized objects are imported in Revit. (Wang et al. 2015)

In Germany, the “DBD-BIM” plug-in for Autodesk‘s widely used “Revit” program is developed by f:data. A web-based database with over 700 component classes and 2,000

[24] Törmä et al. 2020, p. 3.

component types are available through the plug-in. This plug-in can aid in the specification work or the estimation of expenses. For example, a designer may use DBD-BIM to properly define items for a new building by selecting attributes such as thickness, material, and strength class from a drop-down menu.

The plug-in also displays which DIN Standards and provisions of the German building contract processes (VOB) apply to a specific object. (DIN German Institute for Standardization)

The classification system defined in DIN SPEC 91400 is consistent with the IFC[25] provided in ISO 16739, an international standard syntax for sharing building information models. This standard format enables data sharing between different software systems and between stakeholders participating in a construction project. Architects, for example, can construct a digital architectural model and then use a plug-in like DBD-BIM to detail each object. This information may then be imported as an IFC file by the construction company, arranging material purchases and tenders.

In maintenance and repairs, this information is also incredibly beneficial for building owners. If a water pipeline or window breaks, they will not have to sift through lengthy files. Instead, a single click is required to retrieve the relevant data from the list of items. BIM makes it easier to manage buildings. (DIN German Institute for Standardization)

2.1.3. BIM in renovation

Gökgür demonstrated that the current state of BIM adoption in renovation projects is limited compared to new construction for various reasons, including customer desire and BIM illiteracy. However, the findings indicate that BIM adoption will undoubtedly arise in the future as individuals and clients become more aware of the potential benefits of BIM for restoration projects.

Even though studies showed that BIM might enhance collaboration and coordination among individuals, which would be beneficial throughout the renovation process, BIM would be a helpful tool for dealing with major difficulties and hazards throughout the project due to the complexities of restoration projects. (Gökgür 2015)

[25] Industry Foundation Classes

BIM is hailed as a possible solution for effective management and use of project-related information along the lifecycle. However, its function in the design and construction phases is currently disconnected from the FM phase, plus information loss between construction phases remains a critical challenge.

Currently, the needed data is split between systems or is manually moved from system to system following the building handover. Facility management systems have been around for a while and are extensively utilized. Either BIM must show more efficiency for FM than these existing systems, or BIM must become inter-operable with these current systems. In any scenario, the level of information requirements has to be defined.

However, so far, the BIM data needs for facility lifecycle management are not clearly defined. There is a lack of conceptual or theoretical understanding of how to tackle this problem. (Helander and Singh 2016, p. 66)

Model updates may be classified into two types based on BIM for FM guidelines and studies: project and periodic updates. When a building is renovated, a project update happens. The current model might be updated before the project as part of generating an inventory model or after the project as part of creating an as-built model. However, there are the minor modifications, periodic updates, made to the building continuously. Finally, the strategy and objectives for information management throughout facility usage, including what sorts of models should be produced and for what purpose, should be established from the start of the project. (Helander and Singh 2016, pp. 66–67)

Benefits of BIM in renovation projects

The advantages of BIM are well known. BIM will help to promote and pull together synergies from various project disciplines, energy sector, and software. New interactive digital workflows, which are well developed for new buildings, are enabled by BIM. Renovation works, on the other hand, have quite a long way to go.

BIM's primary goal is to digitally reflect building details and use it to convey specific geometric, physical, and functional features of a building for various purposes. In the planning, development, and service processes, BIM will facilitate coordination and information integration. (Stegnar and Cerovšek 2019, p. 318)

Steger et al. stated following advantages of BIM applicable to renovation projects (Stegnar and Cerovšek 2019, p. 318):

- Automation helps to ensure the confidentiality of records.
- Improved project specifications control and organization capability for building status monitoring and renovation planning.
- Improved contact among project participants at all stages of the project. Various design choices allow better decision making.
- Construction delays, mistakes, oversights, and wastage are reduced, thanks to interdisciplinary teamwork and verification, as well as assessment that leads to fruitful cooperation.

2.2. Previous works

According to Gökgür's research findings in 2015, the potential benefits of BIM for new construction are widely recognized by experts. However, there are still hurdles such as low client demand, the complexity of renovation projects, and a shortage of qualified labor to adopt BIM for renovation projects. The study's findings emphasize the potential for increased and improved BIM utilization in future renovation projects. (Gökgür 2015)

Ilter and Ergen, in an overview of the current literature on BIM for Building Refurbishment and Maintenance, found out that although researchers and practitioners have recognized the need for BIM in FM, studies related to BIM applications in maintenance and especially refurbishment are almost recent. However, the trend in published articles proves that the interest is continuously increasing. Existing research in this field can be classified into the following subtopics(Ilter and Ergen 2015):

1. Building survey and as-built BIM
2. Modeling and managing energy
3. Design assessment
4. Access to and integration of maintenance information and knowledge
5. Information exchange and interoperability

An extensive literature review in 2017 carried out by Joblot et al. found out that few scholarly references are devoted to this issue, highlighting that the renovation sector is not a key target of BIM publications (less than 2% specifically addressed renovation).

It stated that the current technology and tools, which are sometimes quite expensive, have not shown their profitability for this business type.

It confirms the conclusions of Ilter & Ergen (2015) that obtained about five results among 500 articles by querying other databases with these same research topics. It shows that nearly 60% of the publications focused on energy optimization, and there is a very fair coverage of the entire scope defined. Finally, it suggested that it is necessary to map the different observable renovation processes and highlights some gaps that need future works. (Joblot et al. 2017)

Table 4 summarizes some of the recent works related to BIM use in renovation projects and presents information about their area of focus, methodology, and findings.

Table 4: Summary of some recent publications[26]

Area & Method	**Source**	**Findings**
Adaptive Design of Formwork in BIM (Case study)	(Mésároš et al. 2021)	The BIM environment enables fast and precise adaptation of the formwork design to changing lighting, ventilation, heating, and temperature conditions during the design phase.
Management of information (development of an innovative BIM-based toolkit)	(Daniotti et al. 2021)	Realization of BIM-based tools targeted at resolving renovation-related issues.
Collaboration and optimize efficiency (Case study)	(Brahmi et al. 2020)	It investigates the possible benefits of using the IPDish[27]+BIM application to manage the renovation project and improve its sustainability features.
GHG emissions (Case study)	(Feng et al. 2020)	a BIM-based life cycle assessment shows that the material production stage accounts for around 40% of the emissions in the reconstruction scenarios. Renovations lower the life cycle GHG emissions of an existing house, with the degree of retrofitting increasing the emissions savings. In terms of life cycle emissions reduction, the passive house reconstruction seems the most beneficial among all scenarios.

[26] Reference: own tabulation
[27] Integrated Project Delivery

Barriers (Survey & interview in Italian Market)	(Elagiry et al. 2019)	Technological innovation in BIM tools is not enough as a stand-alone action to achieve full digitalization of the renovation sector; rather, it must be accompanied by increased awareness among the actors involved, improved skills and competencies, and a significant shift in current construction practice approach.
Tool's development (Workshop report)	(Elagiry et al. 2020)	A post-workshop report summarized the main innovative digital tools for energy-efficient renovation demonstrated during the workshop.
Tool Development (Creating a BIM management system)	(Signorini et al. 2021)	This study presents the digital logbook produced under BIM4EEB, an ongoing Horizon2020 project that first assessed the needs and requirements for its creation before defining its structure to be stored and accessible within the BIM management system.
Tool development	(Törmä et al. 2020)	The technologies seek to improve information exchange among renovation stakeholders and augment BIM data in renovation projects with linkages to other relevant data.
Feasibility of BIM in public housing renovation (Case study)	(Acampa et al. 2021)	The findings reveal that the transformability of public apartments is mainly connected to the Constructive Modifiability index, and structures with reinforced concrete frames score better. Widespread use of such a methodology on a prominent real estate portfolio may allow stakeholders in housing management investments to make clear decisions about building maintenance.
processes optimization (established 6-dimensional intercommunication framework)	(Karlapudi et al. 2020, p. 738)	This study yielded a 6-dimensional intercommunication framework (LOD, BLS, Scenarios, Stakeholders, Use Cases, BIM model data) based on the Linked Building Data methodology and concentrating on renovation process optimization. Based on the framework, a new Product-Process Modelling ontology is created to link current components and facilitate new interoperable applications.
energy savings and enhance citizen engagement (Case study)	(Fernandez et al. 2020)	This case study investigates Eckart Vaartbroek's housing restoration use-case as a model for a co-creative architectural and urbanism process utilizing ICT and 3D BIM-based technologies.
processing and management of	(Empler et al. 2021, p. 109)	Following the earthquake that rocked central Italy in 2016, it explores the possibilities in new forms of modeling or

heterogeneous data (Case study)		information on heritages using visual algorithms (VPL) on specific portions of the Municipality of Accumoli.
Integration of BIM and Reverse Engineering for renovation projects	(Ding et al. 2019, p. 45)	Integrating BIM and Reverse Engineering with 3D Laser scanning to enhance information utilization at different stages of renovation.
The advantages and disadvantages of BIM technology in sustainable renovation projects	(Di Mascio and Wang 2013, p. 205)	Difficulties and benefits of using digital tools, particularly BIM, in order to improve the design and manage the renovation projects better.

As shown in the table, the research in this area is mainly concentrated on case studies and software developments.

2.3. Problem Statement

Based on the review of previous works, most of the efforts have focused either on case studies where BIM is implemented in renovation projects or the development of BIM tools. Previously, the research is conducted by focusing on the specific individual benefits of using BIM in a renovation project; however, the overall and actual percentage of BIM use in renovation companies has not been studied yet. Based on the current situation of renovation projects and focusing on a specific market, analyzing the experts' ideas about the applicability of BIM in renovation projects seems essential.

While some comparative case studies identified some potential benefits on BIM in the renovation, investigating the reasons for the limited use of BIM in renovation projects through surveys and interviews with experts has not been considered in academia recently.

And due to the rapid advancement in BIM technologies, there is a need for continued research to clear the path for future improvements in this area.

This study aims to find out the barriers and benefits of BIM in the ongoing projects after all recent solutions and technologies introduced to the market to bridge this gap and investigate the status of BIM in renovation projects in Europe. And to identify the

decisive company and project-related factors in decision-making for implementation of BIM in renovation projects.

3. Methodology

Science develops with research, and the scientific methods used by researchers play an essential role in the effectiveness of results and validation of their findings. Each research comprises goals, questions, and, most notably, a problem with which the researcher's mind is faced. The researcher's method for the study has to be chosen to respond to the problem understudy in the best and most accurate way.

Scientific research is a standard set of activities that address questions that arise in the researcher's mind based on a particular theoretical perspective, which is influenced by a specific methodology. Method, theory, and methodology are the three elements of each research. The systematic relationship of these three elements with each other can lead to a scientific research presentation. Among the three mentioned elements, the methodology has a fundamental role in which the theory is determined. In the research process, a methodology and research method are selected according to the prevailing subject. Therefore, the validity and reliability evaluation of any research is related to the methodology and more objectively to the assessment of its theoretical executive instructions. Any theoretical ambiguity in the research can lead to a decrease in its validity. Defects in the research validity indicate a mismatch between the theoretical and experimental levels, which will result in ambiguity at either level or both.

Therefore, the research methodology is defined as a systematic way to solve a research problem by collecting data using various techniques, interpreting the collected data, and drawing conclusions about the research data. “The research philosophy you adopt contains important assumptions about the way in which you view the world. These assumptions will underpin your research strategy and the methods you choose as part of that strategy.”[28] The research method is the map of research or study. The issue of research methodology is a part that is discussed in any research, and the researcher must determine it from the very beginning of the research. When we talk about methodology, the main point is the method of performing the research, including the data collection, and classifying and analyzing the collected information.

[28] Saunders et al. 2009.

3.1. Research Overview

Followings are the delimitation of the research in which the researcher explains the definite aspects of the subject.

a) Thematic scope: Usually, the researcher identifies the research topics in all research. In other words, the subject and the problem of research are stated in general and in particular. In this research, the scope is to find an answer to the following questions:

- What is the situation with the use of BIM software in renovation projects?
- What are the factors affecting BIM implementation in renovation projects?
- How company profile (size and type of company) affects the use of BIM in renovation projects?
- How is the company's level of engagement (being a general contractor or subcontractor) in renovation phases affecting the feasibility of BIM implementation in the project?

b) Spatial or location scope: location Scope or research environment is where the research is conducted. In this research, the study covers Northern and Western Europe.

c) Time scope: As mentioned before, the research is a Cross-sectional study and is done in 2021.

3.2. The Purpose of Research

Since the researcher wants to research the building information modeling and find out the answer to questions like “the situation with the use of BIM in renovation projects”, the purpose of the research is an exploratory study. Exploratory research is a helpful tool for determining what is occurring, seeking fresh ideas, asking questions, and assessing phenomena in a new light. It is especially beneficial for clarifying an understanding of an issue, such as when the specific nature of the problem is unknown (Saunders et al. 2009). The exploratory study can be done by reading various texts and searching the literature, talking to experts, conducting interviews and questionnaires, consulting with professors, etc.

3.3. Research Philosophy and Approach

To describe the research philosophy and approach, the researcher starts explaining it using the research onion illustrated in Figure 10.

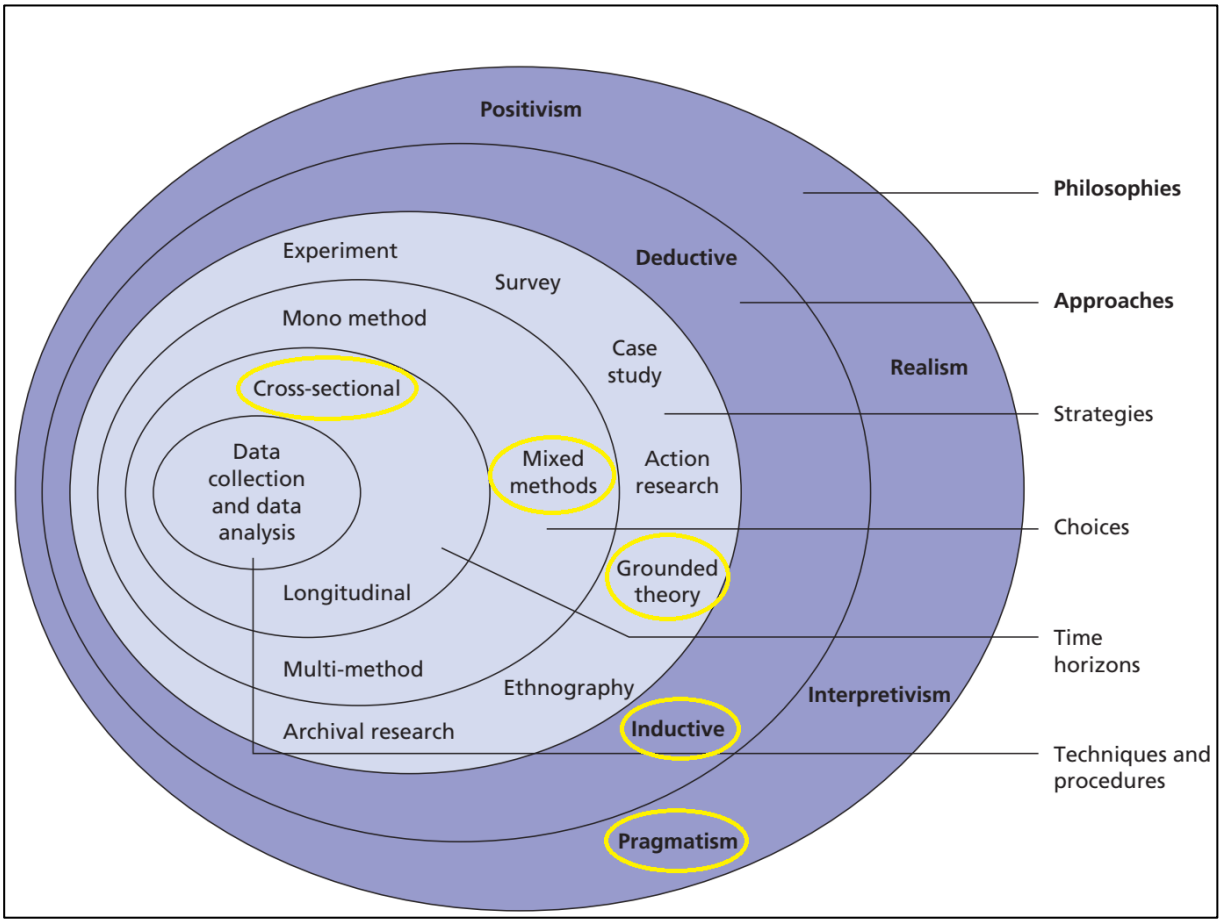

Figure 10: The research onion[29]

In the research onion, the research philosophy is based on pragmatism focusing on practical issues assuming the knowledge as temporary (Creswell 2013). In terms of approaches, it is Inductive while it starts from research questions, and the strategy point of view is grounded theory since it is working with open coding and linking concepts. Data sampling is used in grounded theory, in which the researcher seeks exploratory answers to research questions.

Concerning the time horizons, the research is a cross-sectional study. From the data collection point of view and considering Figure 11, a single data collection technique

[29] In conformity with Saunders et al. 2009.

with a mix of qualitative and quantitative methods is used. Therefore, it is a Multiple methods research, and since the researcher quantifies the qualitative data and converts them into numerical codes, the research is Mixed-model research.

Data collection is the last layer of the research onion, in which the researcher has used one of the common approaches in data collection, which is called snowball sampling. This type of sampling is a non-random method suitable when the members of a group or community are not easily identifiable. In other words, the researcher first identifies a minimum number of experts, and after collecting data, they are asked to introduce other experts. This method is also used to identify experts in a particular field.

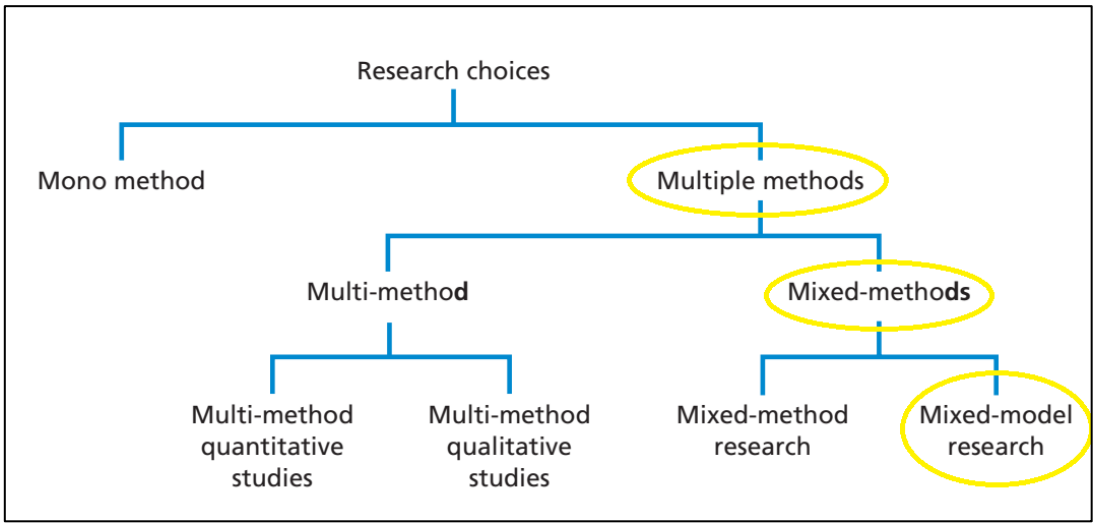

Figure 11: Data collection research choices[30]

Questionnaires are one of the most regularly utilized data gathering procedures. Because each individual is given to answer the identical set of questions, it is an efficient technique to collect responses from a large group of people before doing quantitative analysis. (Saunders et al. 2009)

The respondents usually complete Self-administered questionnaires by themselves. Such questionnaires are administered electronically using the Internet (Internet-mediated questionnaires) or posted to respondents who return them by post after completion (postal or mail questionnaires). (Saunders et al. 2009)

[30] In conformity with Saunders et al. 2009.

The research is based on the Delphi method. The Delphi method arose in a series of studies that the RAND[31] Corporation carried out in the 1950s. The aim was to develop a technique for obtaining the most reliable consensus of a group of experts.

“Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem. To accomplish this ‘structured communication’ there is provided: some feedback of individual contributions of information and knowledge; some assessment of the group judgment or view; some opportunity for individuals to revise views; and some degree of anonymity for the individual responses.”[32]

The Delphi steps are as follows (Project Smart 2021)*:*

Step 1: Identify the Experts and Define the Problem

The Delphi technique is based on a panel of experts. An expert is an individual with relevant knowledge and experience of a particular topic. The problem or issue that is being examined must also be defined.

Step 2: First Round Questions

General questions are asked to obtain a broad understanding of the expert's opinion on the issue. The questions may be in the form of a questionnaire or survey.

Step 3: Second Round Questions

Based on the answers to the first set of questions, the following questions should delve deeper into clarifying specific issues. The questions may be in the form of a questionnaire or interview (Brough 2018).

Step 4: Third Round Questions

The final questionnaire intends to derive the final results, upon which the experts are all agreed.

Step 5: Act on the Findings

In this section, the final results are prepared and adjusted.

[31] The RAND project stands for "Research and Development", and RAND Corporation is an American nonprofit global policy think tank founded in 1948 by Douglas Aircraft Company to provide research and analysis to the US Armed Forces.
[32] Okoli and Pawlowski 2004.

3.4. The Steps of the Research

As described in the first chapter, the research subject is the Application of BIM in Renovation Projects in Europe. The most important methods of data collection in this research are as follows:

3.4.1. Literature Study and Library Studies

In order to collect information about the previous works on the subject, library resources such as books, articles, journals, and the internet have been widely used.

3.4.2. Field Research

Questionnaires and interviews are used to collect information from the experts. The first questionnaire is as online form, created by online software tools (SurveyMonkey.com™). It contained checkboxes that list the choices available to the respondent, allowing them to 'check' or 'tick' one or more of them, and drop-down list boxes that restrict the respondent to selecting only one of the answers specified or text boxes where the respondent enters information. The first questionnaire comprised of two parts:

General questions:

In general questions, an attempt has been made to collect general and demographic information about the respondents.

Specialized questions:

Number of questions driven from the research questions are included in this part.

The second questionnaire has six exact and specific questions about the subject. A five-point Likert scale[33] has been used to design this questionnaire, which is one of the most common measurement tools (Figure 12). The questionnaires are attached in the Annex A.

[33] A Likert scale is a type of psychometric scale widely used in research to reflect people's opinions and attitudes toward a specific topic.

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
(1)	(2)	(3)	(4)	(5)

Figure 12: 5-Point Likert Scale[34]

Validity and reliability of the questionnaires

To check the reliability of the questionnaires, Cronbach's alpha method is used to determine the reliability of the test. This method is used to calculate the internal consistency of the questionnaires. Equation 1 shows the formula (Cronbach 1951).

Equation 1 the internal consistency of the questionnaires

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} \sigma^2_{Y_i}}{\sigma^2_X}\right)$$

Where α is the Cronbach's alpha coefficient, k is the number of questions, $\sigma^2 Y_i$ is the sum of the variance of scores of each respondent, $\sigma^2 X$ is the variance of the scores of question number i.

Validity of the interview

Interview validity refers to the degree to that the method can measure the study purpose. Validity in a qualitative study is the extent to which the researcher's observation can reflect the understudied phenomenon or its related variables. Guba *et al.* have proposed credibility, dependability, confirmability, transferability, and assurance to be considered in a qualitative study (Denzin and Lincoln 2018) where the same has been observed in the research. Cresswell and Miller (Creswell and Miller 2000) believe that writing about validity in qualitative inquiry is challenging on many levels. He has proposed spending prolonged time on the issue, detailed and accurate notetaking of the sessions, accurate voice recording, and external auditor consultation during the interview. Therefore, the researcher, consulting with two experts in BIM, spent enough time revising the interview process's topics, getting approval of the interview process to ensure the validity of the interview.

[34] Reference: own tabulation

Reliability of the interview

When it is said that a data collection tool such as an interview should have a reliable feature, it means that if we use it at several different times for a population, we will not see much difference in the result. Heale believes that "reliability relates to the consistency of a measure. A participant completing an instrument meant to measure motivation should have approximately the same responses each time the test is completed. Although it is not possible to give an exact calculation of reliability, an estimate of reliability can be achieved through different measures."[35] So to calculate the reliability by Test-retest, several interviews are selected and re-coded over a short period. The extracted codes are compared at different times. In interviews, similar codes, identified as "agreement," and codes that were not similar were marked as "disagreement".

The Research community

A Research Statistical community is a set of individuals who share at least one attribute, and the researcher wants to investigate. In this research, the statistical community is the experts of BIM, preferably with renovation experience, especially those with long working experience. Snowball sampling is used, which is a Non-random sampling method, where research participants recruit other participants for the study. It is used where potential participants are hard to find. It is called snowball sampling because the participants are introduced by each other, the same as rolling a ball on snow results in more snow sticking to the ball. The more ball is moving, the more snow is picking and enlarging the size. In this method, the selection of the sample population continues in a chain. Moreover, the researcher can preferably select samples that are different in terms of experience, education, etc.

According to Goodman, an s stage k name Snowball sampling technique is characterized as follows:

A finite population is used to choose a random sample of people. Each person in the sample is asked to name k different people from the population, where k is a fixed integer (Goodman 1961). Figure 13 shows the Snowball selection pattern.

[35] Heale and Twycross 2015.

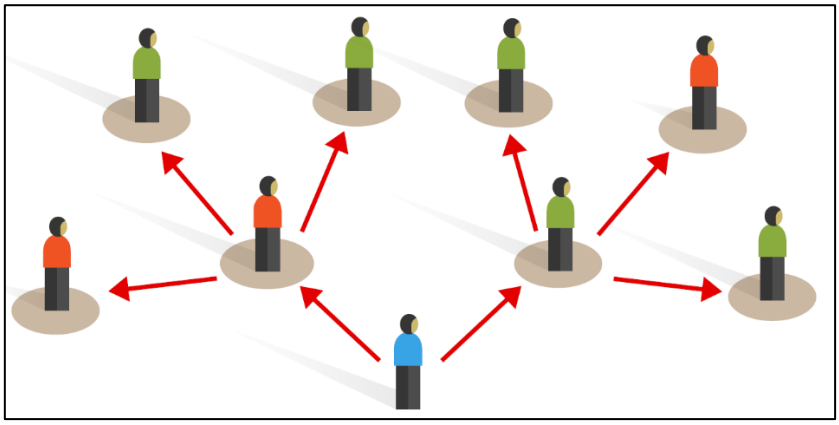

Figure 13: snowball sampling[36]

Therefore, snowball sampling has been used to find the research's statistical community for the initial questionnaire and the interview. The interview's statistical community is used for the final questionnaire.

3.4.3. Statistical Method of Data Analysis

Since in this research, mixed or qualitative and quantitative methods have been used, in this section, methods of analyzing the collected data are briefly explained. “In fact, it is clear that quantitative and qualitative approaches are very different in terms of underlying epistemologies, data collection procedures, nature of data collected, and data analysis techniques.” [37]

Qualitative section

One of the important approaches in the field of qualitative data analysis is the Theme analysis approach. In the qualitative section, the theme analysis approach analyzes the data collected from the interviews. First, the theme and theme analysis is defined: "A Theme captures something important about the data **in** relation to the research question and represents some level of patterned response or meaning within the data set" (Braun and Clarke 2006). Thematic analysis is a qualitative data analysis approach that involves searching through data collection to find, evaluate, and report recurrent patterns (Braun and Clarke 2006). In fact, this method organizes the data and describes it in detail. By creating themes, this method can interpret different aspects of

[36] Harrison 2020.
[37] Peng et al. 2011.

the research topic. Qualitative approaches are diverse, complex, and delicate, and Theme analysis should be considered a fundamental qualitative analysis method.

Kiger and Vartpio (Kiger and Varpio 2020) described Braun and Clarke (Braun and Clarke 2006) theme analysis steps as follows:

Step 1: Become familiar with the data

This stage includes reading over the data repeatedly and actively, which offers a practical orientation to the raw data and is the foundation for all following phases. The data set may contain interviews, focus groups, recorded observations, field notes, diary entries, or other media such as pictures or videos, depending on the project.

Step 2: Generate initial codes

Coding, as the first genuinely analytic stage in the process, aids in the organization of data at a granular, particular level. Following the familiarization process in step one, researchers can start taking notes on prospective data items of interest, queries, relationships between data items, and other early ideas. This stage is the start of the coding process in phase two, which creates codes rather than themes.

Step 3: Search for themes

The third stage includes reviewing the coded and compiled data extracts to look for potential themes of more general relevance. If the analysis is considered a building, individual codes are the bricks and tile, and themes are the walls and roof. The process of theme identification (constructing those walls and roofs) is basically an active and interpretative one.

Step 4: Review themes

Step four is defined as a two-level analytical procedure. The researcher looks at coded data inside each topic to check the correct fit.

Step 5: Define themes

Step five involves the researcher developing a definition and narrative explanation of each theme, explaining why it is significant to the study question.

Step 6: Write-up

This final stage entails writing up the final analysis and findings description. The writing process has already started in previous phases of collecting notes, identifying themes, and selecting sample data extracts.

Quantitative section

The analysis of this section is performed by The Fuzzy Delphi method. The fuzzy Delphi method is very similar to the classical Delphi method and the only difference is the fuzzification of the scores, which causes the variables to be defined qualitatively. This is the advantage of the fuzzy method over the classical method. In the fuzzy method, qualitative variables are usually defined as triangular or trapezoidal fuzzy numbers.

Considering an apple, when it is half-eaten, it is still an apple until it is entirely eaten and turns to nothing. Therefore, half of the apple is a fuzzy apple, Spectrum between black and white. Fuzzy logic is also a multi-value logic in which there are infinite shades of gray instead of right or wrong, zero or one, black or white.

TFN[38] is a type of fuzzy number represented by three real numbers as F = (l, m, u). These types of fuzzy numbers are very common due to their very high computational efficiency. In addition, calculations with this type of number are very simple and understandable. Fuzzy logic was introduced by discovering fuzzy sets and fuzzy numbers. Moreover, TFN has played an important role in the development of fuzzy computing. In fact, the three real numbers (F= (l, m, u)) is a very good way to scale the qualitative research. The upper bound denoted by u is maximum values of fuzzy number F. The lower bound denoted by l is the minimum value of fuzzy number F. m is the most probable value of a fuzzy number(Habibi et al. 2015).

3.5. Summary

In this chapter, the research methodology and all related issues are discussed. The purpose of the research is an exploratory study. Concerning the philosophy, the research is pragmatism as it is focusing on current practical issues. In terms of approaches, deductive, and from the strategy point of view, is grounded theory. From the data collection point of view, it uses mixed or qualitative and quantitative methods. Therefore, the research enjoys Multiple-methods, and the research is Mixed-model

[38] Triangular Fuzzy Number

research. From the time horizons, the research is a cross-sectional study. For data collection, snowball sampling is used. The overall research method is based on the Delphi method, and the data analysis is performed by the Fuzzy Delphi method. Cronbach's alpha has calculated the reliability of the questionnaires, and for the reliability of the interview, a test-retest method is used. All the analysis and the calculations are done using MS Excel and a self-created conversion script to convert the scores to the TFN. Figure 14 shows the overall research schema.

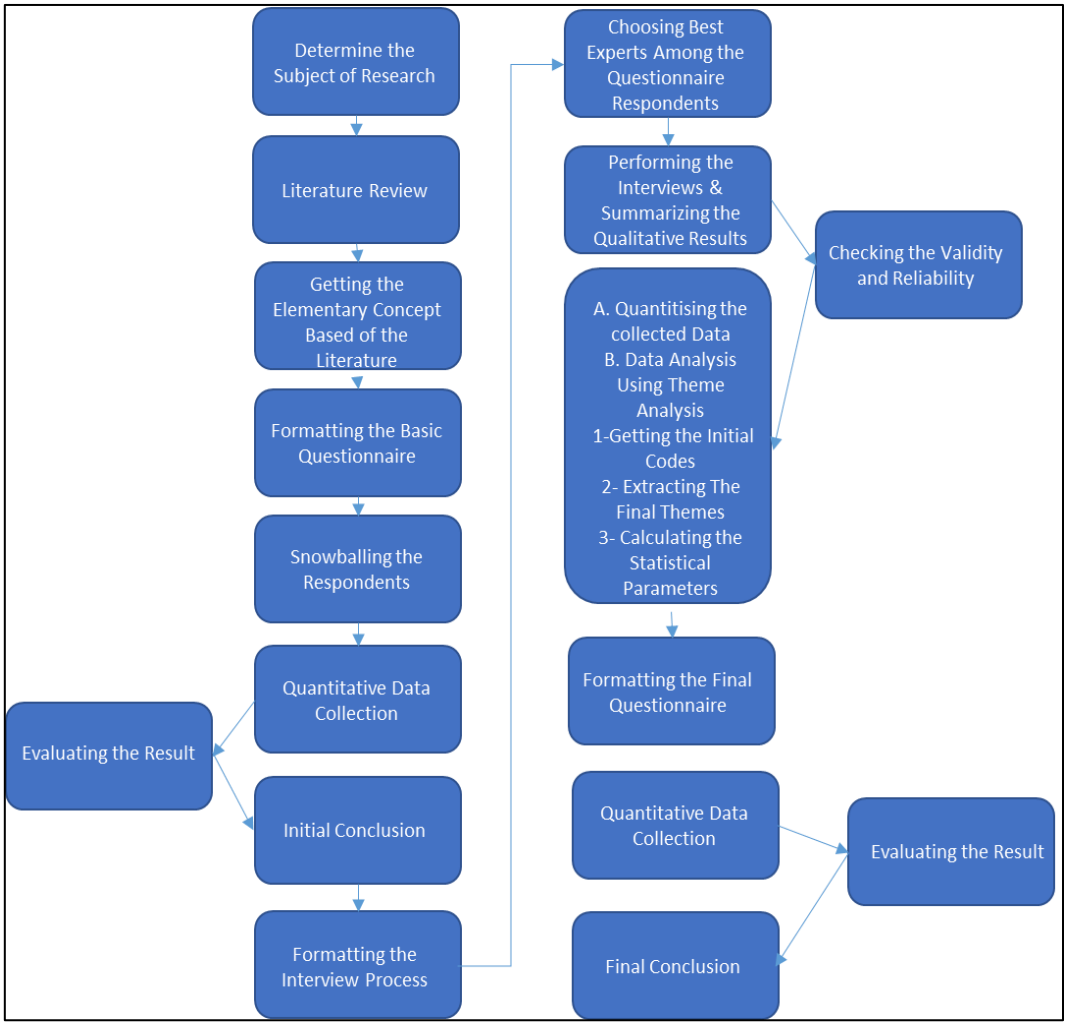

Figure 14: The Overall Research Schema

4. Analysis of the result

In this chapter, the collected data are extracted from the scientific analyzing process. By utilizing descriptive and inferential analysis methods, information is classified into numbers and figures. It is decorated and analyzed in unique tables with the integration of statistical and mathematical techniques and tools.

One of the most important parts of research that deal with data is data analysis, which is the extraction of scientific research results in data analysis. After collecting data from questionnaires and interviews, information is extracted, processed, and classified in the form of digits. There are several methods for analyzing research data, which can be classified as descriptive analysis methods and inferential analysis methods.

In the descriptive-analytical research method, the existing conditions are described. The generalization of the outcomes is restricted to specific individuals who are observed and studied. Despite, in inferential analysis, the results can be generalized to the larger community to which the sample belongs. However, the processing stage has a more complex process where with the aid of statistical and mathematical techniques and tools, the obtained information is placed in tables and finally analyzed. At this stage, the researcher uses statistical methods and techniques to get the answers to the questions. Accordingly, the analysis of statistical information and research findings are presented.

4.1. Data analysis method and observations

As part of this study, the Fuzzy Delphi Method has been chosen as the best method to review experts' opinions and represent the main novelty of the work.

4.1.1. Identifying the Experts and Defining the Problem

The targeted experts are those with experience with BIM or Renovation; therefore, the snowball sampling is chosen to select participants. A small pool of initial participants is selected from LinkedIn[39] profile. Later by snowballing with them, two hundred eight experts are chosen carefully.

[39] LinkedIn is an employment-oriented online platform used for professional networking.

As it is mentioned in the previous chapters, the problem or the main questions of the research are:

- What is the situation with the use of BIM software in renovation projects?
- What are the factors affecting BIM implementation in renovation projects?
- How does company profile (size and type of company) affect the use of BIM in renovation projects?
- How is the company's level of engagement (being a general contractor or sub-contractor) in renovation phases affecting the feasibility of BIM implementation in the project?

4.2. The first questionnaire

The first questionnaire is designed and conducted through the online software tool SurveyMonkey™. The scope of research is limited to northern and western Europe. The questions are in accordance with the checklist of questions for designing a survey method by Cresswell (Creswell 2014).

The survey was open for one month, and two hundred eight experts are invited to participate in the study by a text message on LinkedIn. The selection criteria are having experience with BIM or Renovation. Figure 15 shows the BIM software that participants use in their projects.

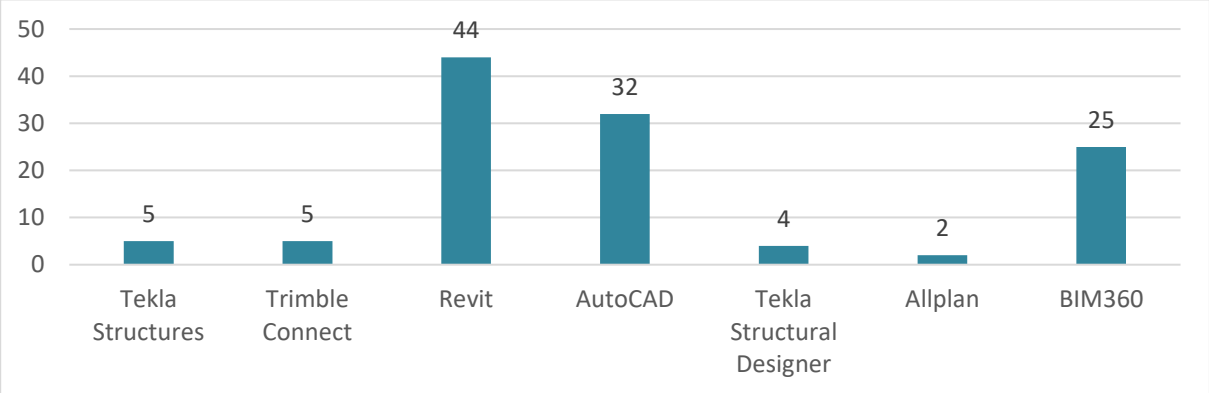

Figure 15: BIM related software used in the projects[40]

[40] Reference: own tabulation

The variety in the choice of countries is observed in snowballing, and the invitations were sent accordingly. Figure 16 shows the percentage of participation in different countries.

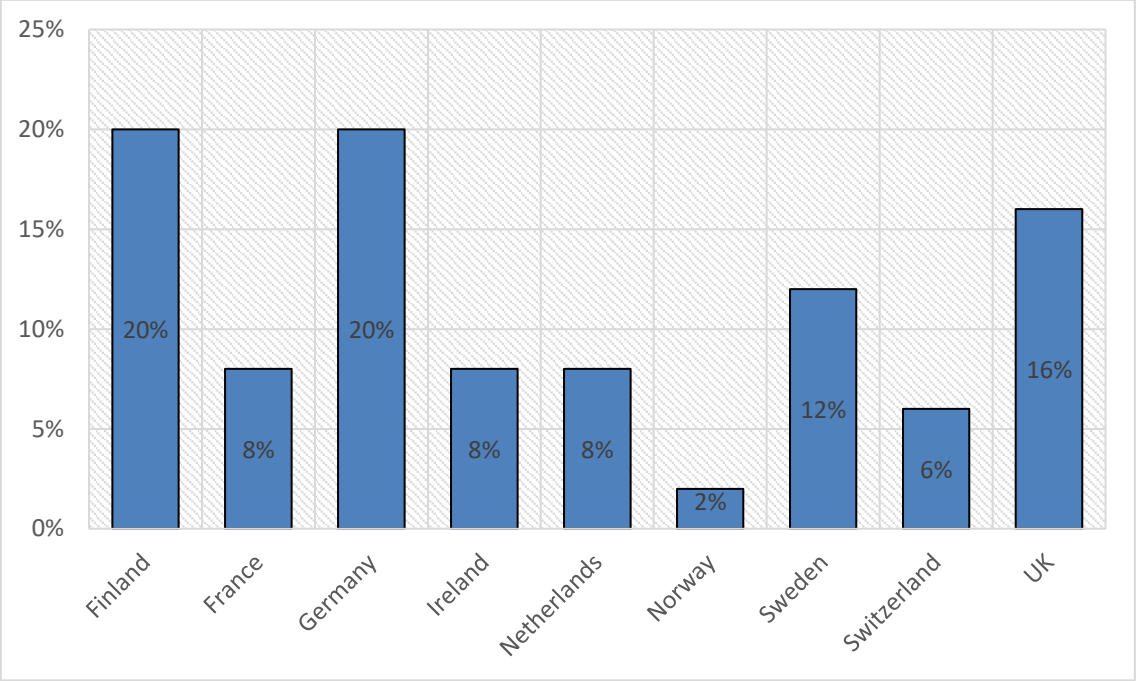

Figure 16: The country where the participants work.[41]

The survey covers the experts' attitudes towards implementing BIM in renovation projects and their view of the benefits and obstacles in this regard. Additionally, it is trying to find a link between company profile, project profile, and use of BIM in renovation projects.

Altogether, ninety responses are collected. Seventeen of them are removed because they were out of the scope of this research. As shown in Figure 17, the participants included BIM experts, Architects, structural engineers, construction managers, CEOs, department managers, project engineers, technical office engineers, modeling engineers, planning engineers, procurement, etc. More than 90% of them mentioned in the questionnaire that they prefer to use BIM in their projects.

[41] Reference: own tabulation

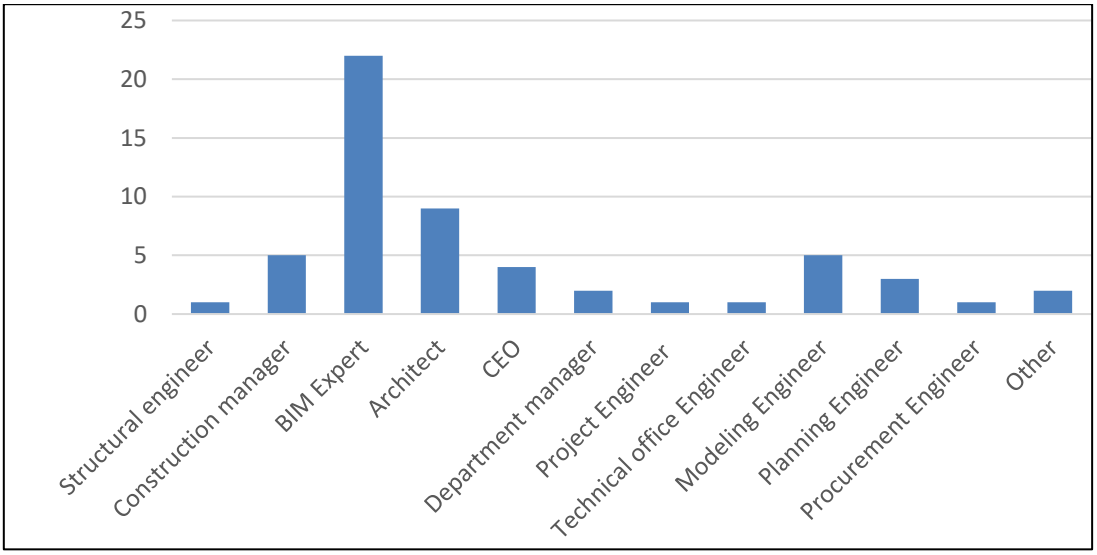

Figure 17: Participant's role in the company[42]

The responses are collected and summarized anonymously in this thesis. The typical time spent by each participant to complete the first questionnaire is around 5 minutes, and the average completion rate is 81%. The full text of the survey is provided in appendix 1.

4.2.1. The result of the first questionnaire

The main outcome of the first questionnaire is both descriptive and explanatory. The descriptive part will identify the situation with BIM in the renovation projects. The explanatory part examines and explains the relationship between the company and project profile and BIM in renovation projects.

Consequently, the survey questions contain a mix of opinion, behavior, and attribute variables. These variables respectively gather data about how respondents think about using BIM in the renovation, how it is working in their company in this regard and some general information about respondents' characteristics that may affect their point of view.

One of the findings of the first questionnaire is the situation of BIM in renovation projects. This topic is divided into three categories: usage, barriers, and benefits, shown in Figure 18.

[42] Reference: own tabulation

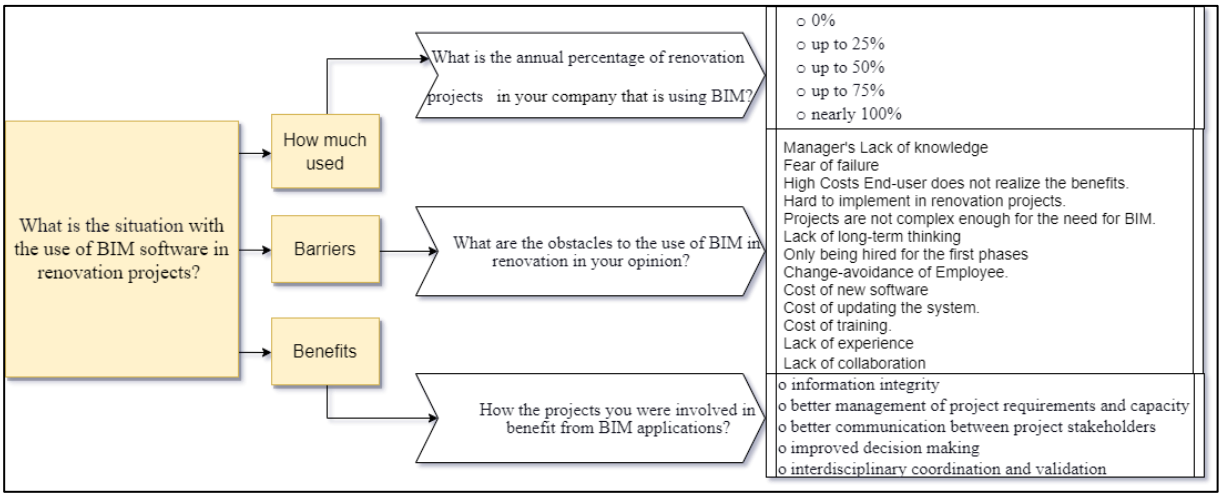

Figure 18: How situation of BIM is mentioned in the first questionnaire[43]

The first question is asking the participant about the annual percentage of renovation is their company that is using BIM. As shown in Figure 19 and considering that none of the participants were from the same company, 21 companies were using BIM in up to 25 percent of renovation projects, 18 companies between 26 and 50 percent, 17 companies between 51 and 75 percent, and 13 percent between 76 and 100 percent. This graph is showing that fewer renovation companies are fully incorporating BIM in their projects.

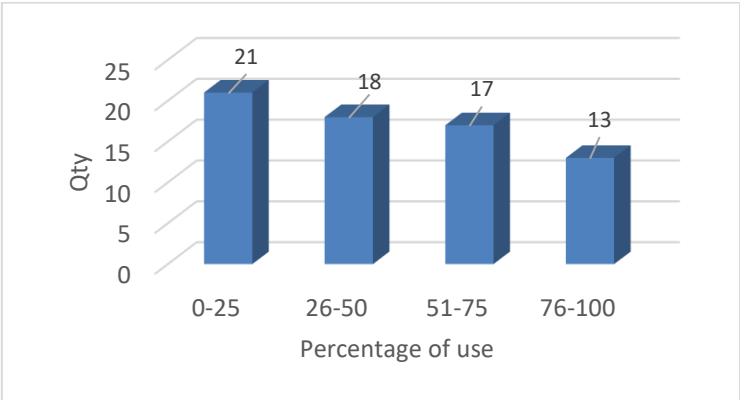

Figure 19: The annual BIM usage in renovation projects in the participant's company[44]

[43] Reference: own tabulation
[44] Reference: own tabulation

Another question focused on the obstacles to using BIM in renovation projects. The data gathered is analyzed to rank the considered factors in terms of significance. The Likert-style rating scale is used in research and asking the respondent to state the level of significance based on their experience. The 5-point Likert scale from "strongly agree" to "strongly disagree" is used (1 = strongly disagree, 2 = disagree, 3 = Neutral, 4 = agree and 5 = strongly agree). Figure 20 shows the result according to the participant's answers.

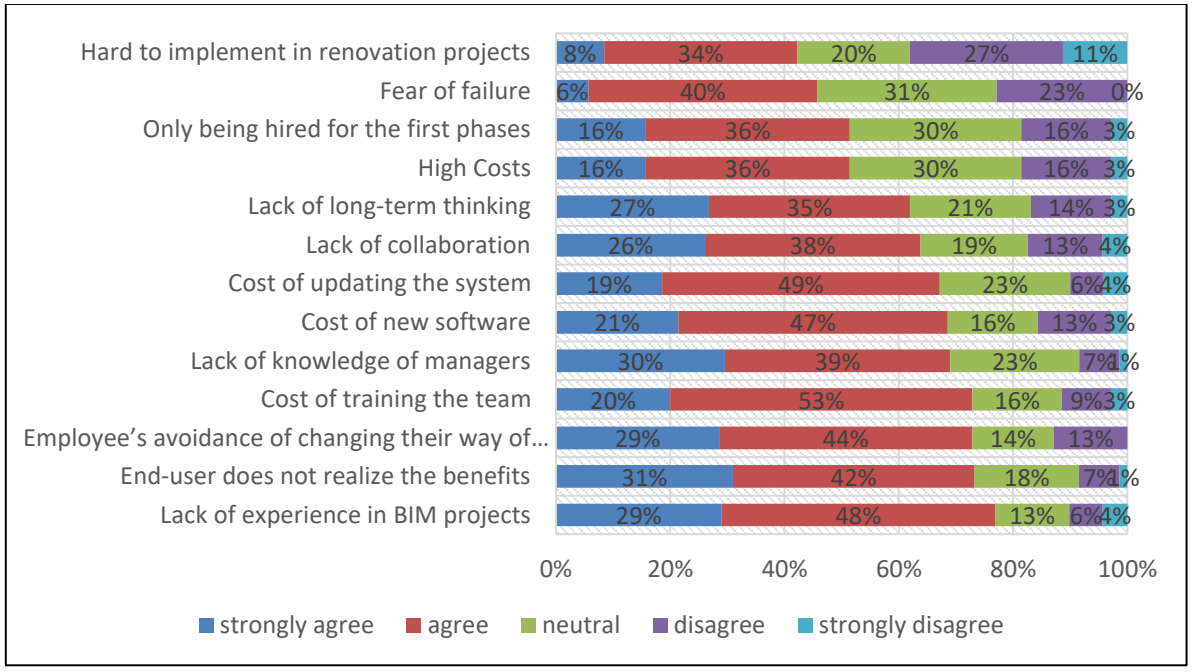

Figure 20: the obstacles to the use of BIM in the renovation[45]

As shown in Figure 20, the lack of knowledge of managers and end-user about the benefits and employee's avoidance of changing their way of thinking is the main obstacle. Furthermore, fear of failure and difficulty of implementation seems to be minor obstacles. This result explains that the majority of experts think that the reason why BIM is not used in renovation projects as much as it is expected is more about awareness and appreciation rather than software inadequacy or technical issues.

Following is the "benefits of using BIM programs in participants' projects", which is shown in Figure 21.

[45] Reference: own tabulation

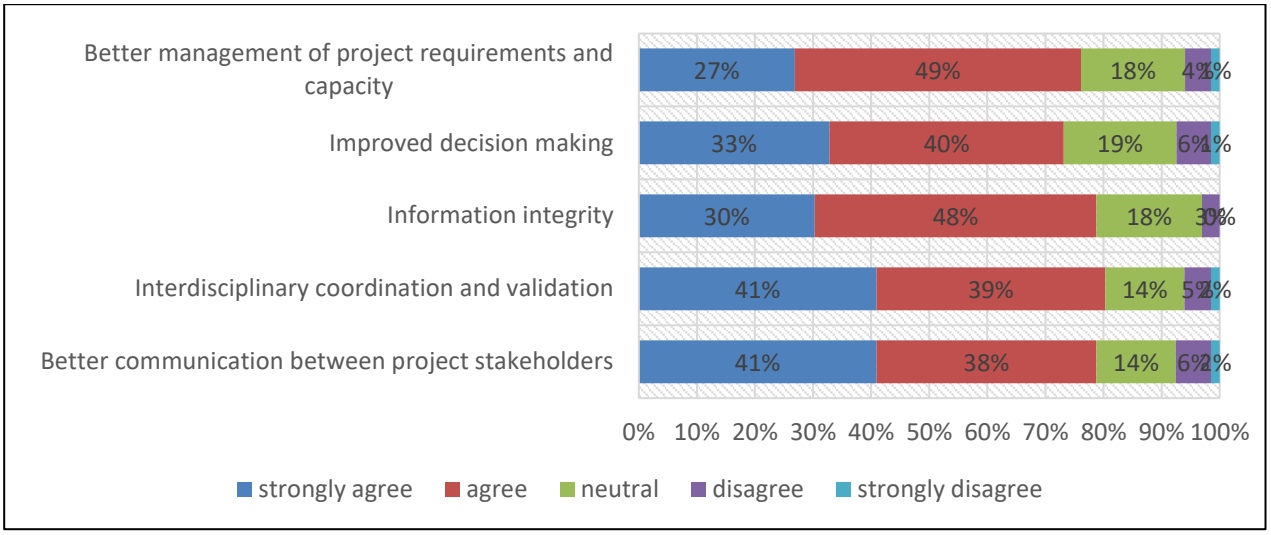

Figure 21: benefits of using BIM programs in participants' projects[46]

In this stacked bar, percentages are distributed in a way that it is challenging to decide on which item participants more agreed. Therefore, we can consider weighted average to understand the rankings better. Figure 22 shows the weighted average for each statement.

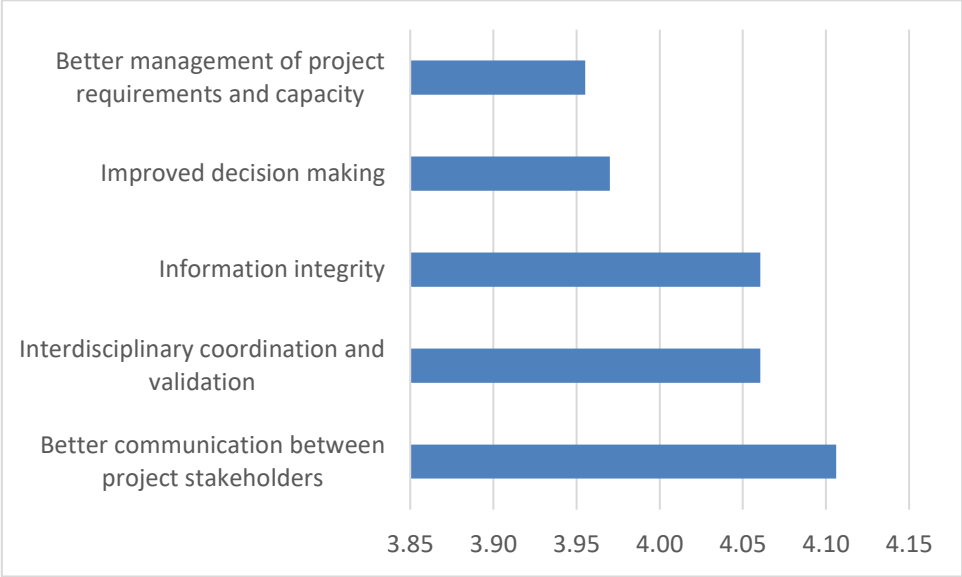

Figure 22: weighted average for benefits of BIM in participants' projects[47]

[46] Reference: own tabulation
[47] Reference: own tabulation

The bar chart suggests that "Better communication between project stakeholders", "Information integrity"," and "Interdisciplinary coordination and validation," respectively, are the most important benefit from the participants' point of view.

The second section of the questionnaire contains questions concerning the Project profile. As illustrated in Figure 23, it comprises three questions regarding the type of projects, size of projects, and type of clients.

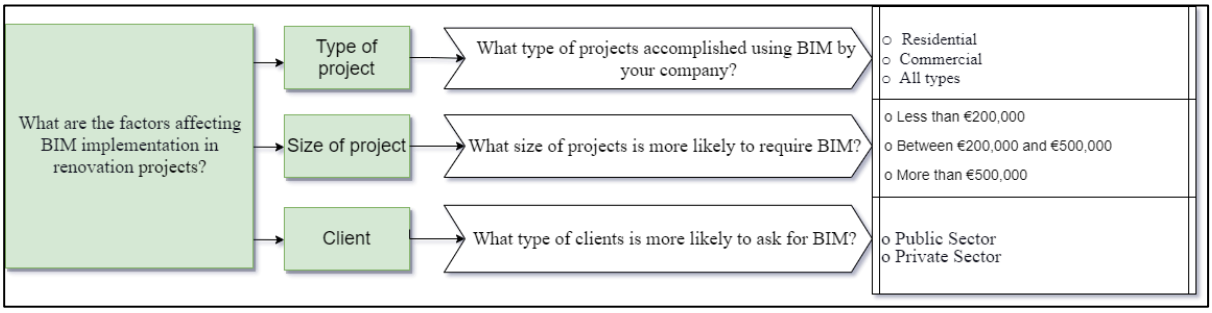

Figure 23: Project profile[48]

In this part, participants were asked to mention the share of residential and commercial BIM-based projects in their company. Figure 24 illustrates the distribution of responses to this question. The figures suggest that in most companies, 50% to 100% of commercial projects are BIM-based. However, in residential projects, the figures are somehow balanced, showing that some companies use BIM in 100% of their residential projects while it is never used in some others.

[48] Reference: own tabulation

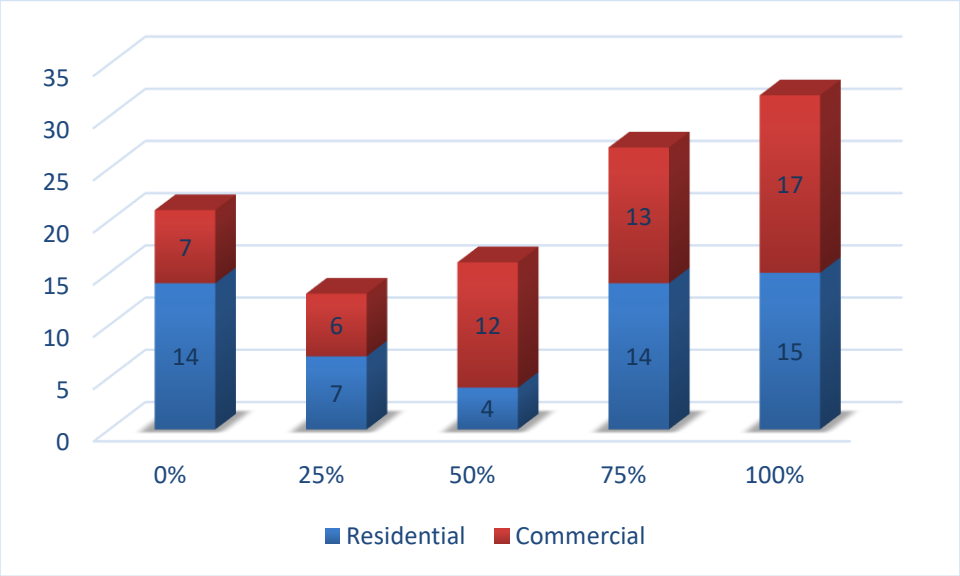

Figure 24: Type of projects[49]

The impact of project scale is the next, illustrated in Figure 25, showing that BIM plays a significant role in large-scale projects. The bigger is the project size, the more likely it is to use BIM.

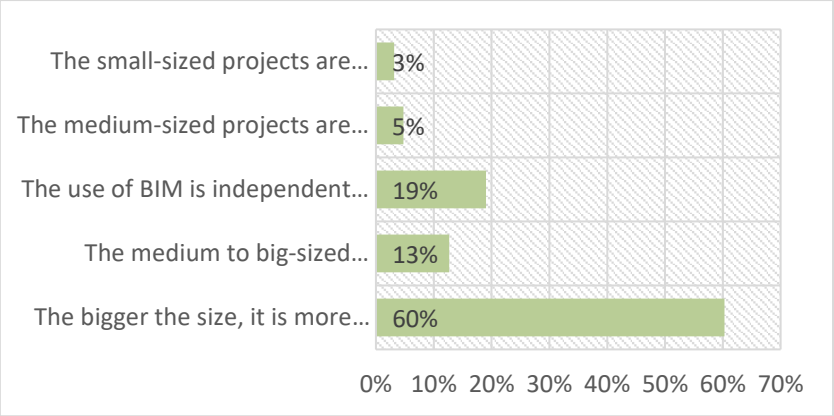

Figure 25: the relationship between the project size of and the acquisition of BIM[50]

The next question concerns the impact of the client on BIM usage, where most of the participants believe public projects are more likely to use BIM, as shown in Figure 26.

[49] Reference: own tabulation
[50] Reference: own tabulation

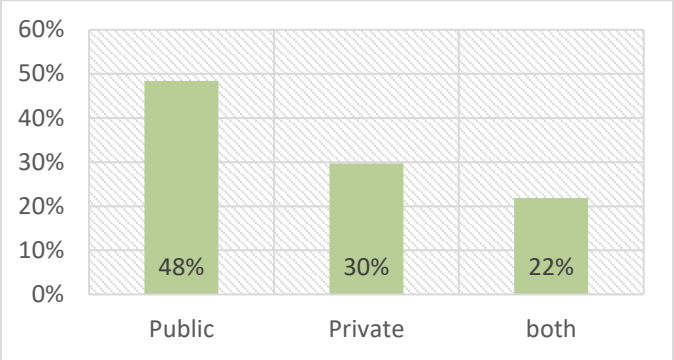

Figure 26: the impact of the type of the client on BIM usage[51]

The last section of the first questionnaire explores the impact of the company profile on the choice of using BIM in projects. This part comprises three questions: the company's size, type, and the stage of involvement in the projects. Figure 27 illustrates how the questionnaire is linked to the research question. In this set of questions, there is a shift toward the indirect question.

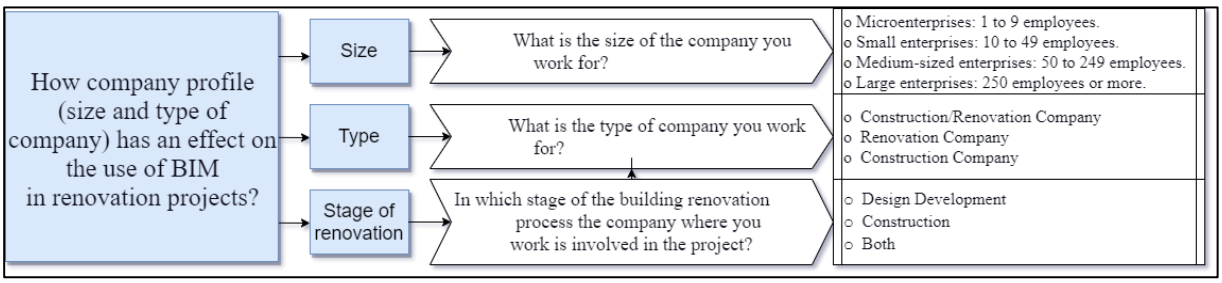

Figure 27: Company profile questions[52]

The first part aims to find a link between participants' company size and the annual percentage of BIM-based renovation projects in their company which is the subject of the first question of this questionnaire.

Figure 28 shows the data regarding the participants' company scale, which in the next step, it is combined with the answers to the first question according to the respondent ID.

[51] Reference: own tabulation
[52] Reference: own tabulation

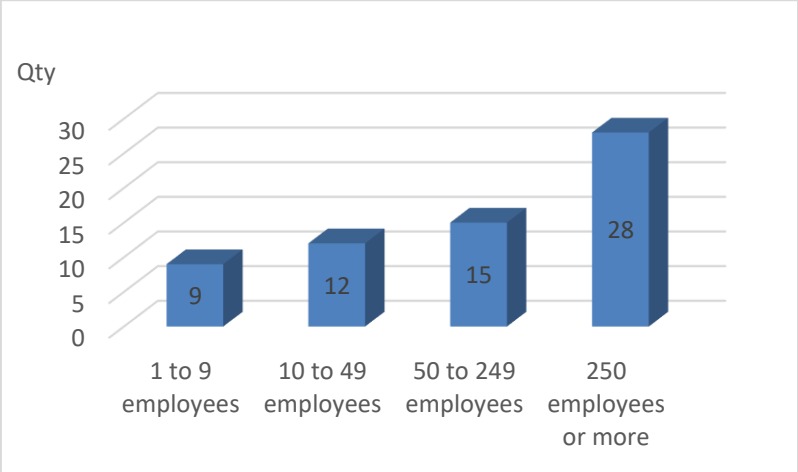

Figure 28: Participants company scale[53]

Figure 29 displays the data obtained after data combining. As shown in the chart, the distribution of integrated answers is in such a pattern that no apparent relationship can be concluded at this stage.

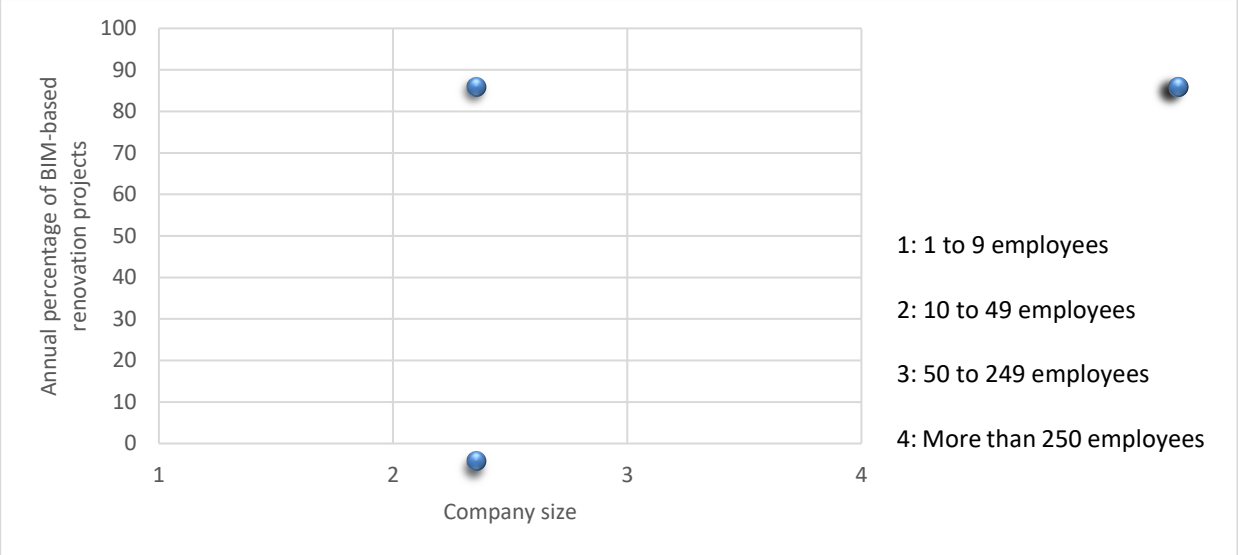

Figure 29: Participants' company size and the annual percentage of BIM-based renovation projects[54]

The following two questions ask about the type of company in which participants work. And the aim is to find a link between the annual rate of BIM-based renovation projects and the type of company. The former asks whether the participants work in a renovation, construction, or mixed company (to sort the answers better later). The latter asks

[53] Reference: own tabulation
[54] Reference: own tabulation

about the type of company. Figure 30 and Figure 31 show the answers these questions.

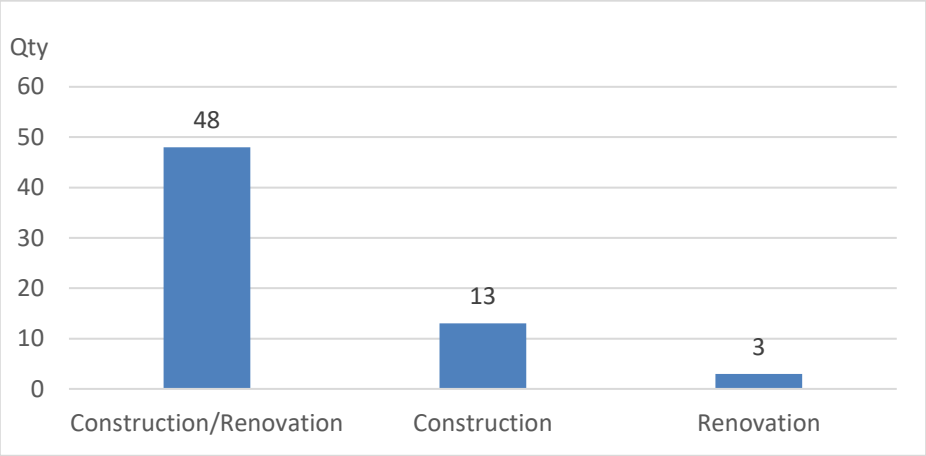

Figure 30: How effective is the type of the working company on BIM usage[55]

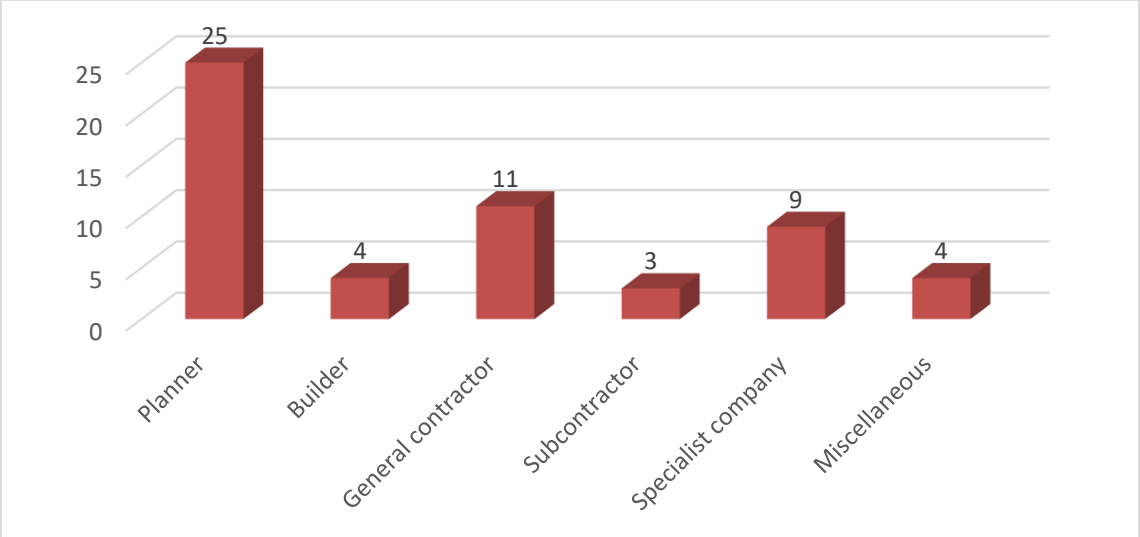

Figure 31: the role of own company in the BIM related project[56]

As displayed in two previous charts for this specific question concerning the company type, there is no balance in the sampling population that leads us to a reliable conclusion, i.e., the percentage of projects in a similar number of companies of each type are worthy of comparison. For instance, the number of planner companies participating is approximately six times bigger than Builders or subcontractors.

[55] Reference: own tabulation
[56] Reference: own tabulation

The last question concerns the company's level of involvement in projects and how it influences the decision-making toward a BIM-based renovation project. Figure 32 shows that most participants are mainly involved in the entire project or only design development.

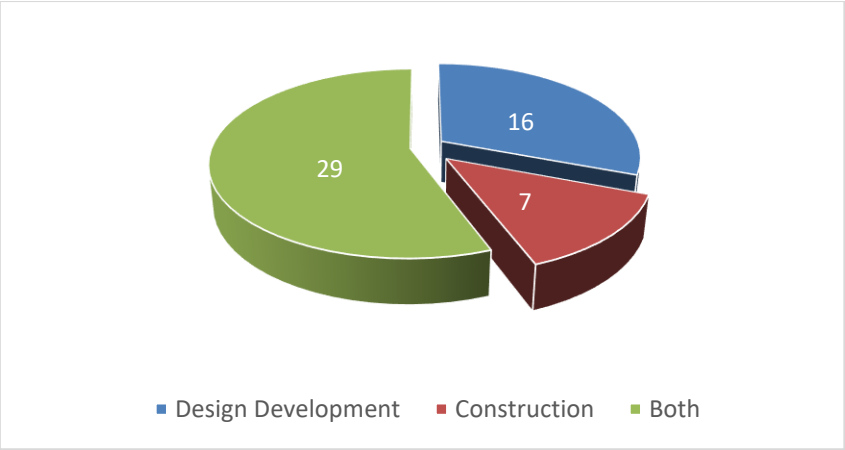

Figure 32: stage of involvement[57]

Figure 33 shows the percentage of annual BIM-based renovation projects in participants' company dividing them into three groups according to their level of involvement in the project.

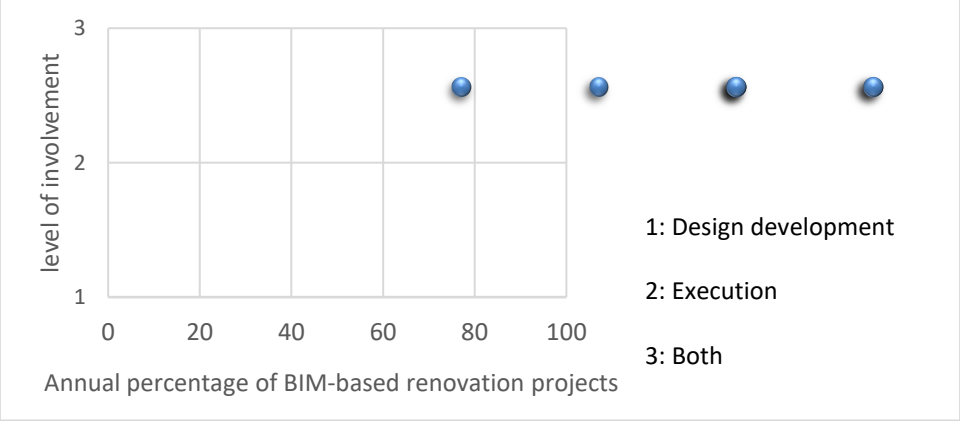

Figure 33: level of involvement in the project and using BIM in the projects[58]

As mentioned above, the data collected to answer the third research question cannot lead us to any conclusion. Since the nature of this question is different from other

[57] Reference: own tabulation
[58] Reference: own tabulation

research questions in this thesis, therefore, requires another methodology, and it can be the subject of another individual research. For this reason, the third research question has been excluded from this research.

4.2.2. The questionnaire's reliability

As the questionnaires had two different general and BIM-related sections, the reliability of the second part is calculated using Cronbach's alpha formula shown in Equation 2, and 0.87 is the result. According to Table 5, since the computed alpha value is between 0.8 and 0.9, the internal consistency of the questionnaires is good.

Equation 2 Cronbach's alpha formula

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} \sigma^2_{Y_i}}{\sigma^2_X}\right)$$

Table 5: Acceptable Cronbach's Alpha Test of Reliability Range[59]

Cronbach's alpha coefficients	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

4.3. The Interview

After analyzing the first questionnaire and as a qualitative part of the research, according to the derived data, interviews are performed with 18 experts selected according to their relevant education/experience among the questionnaire's initial respondents. The interview is conducted to understand the expert's knowledge and experiences.

The interview findings were classified and open coded using theme analysis suggested by Strauss and Corbin (Corbin 2014) for Grounded Theory research. Open coding is an analytical procedure through which concepts are identified and their properties and

[59] In conformity with Cronbach 1951.

dimensions are discovered. At this stage, Grounded Theory forms the primary categories of information about the phenomenon under study by segmenting the information. The researcher then classifies the collected data based on their categories. The collected data can be interviews, questionnaires, observations, and so on. The classified data forms the themes. As mentioned before, theme analysis is a flexible, relatively easy, and fast way to identify, analyze and extract patterns within data. The researcher considers meaningful patterns and topics related to the research. This analysis involves a continuous flow between data sets and chosen patterns, and finally, related patterns are extracted and coded. The researcher, using theme analyses, extracted 34 basic open codes (first level) out of interviews along with their frequencies at interviews, which are mentioned in Table 6.

Table 6: Basic concepts and open codes of interviews[60]

Open Code	Basic Concepts	Frequency at Interview
A1	Lack of knowledge of managers	9
A2	Management support	8
A3	High cost of software	5
A4	Insufficient understanding of the benefits	6
A5	Use of traditional method	5
A6	Complexity	7
A7	Not being demanded by the clients	9
A8	Management Attitude	7
A9	ICT Implementation problem	6
A10	Most of staffs are old and not willing to use systems	3
A11	Lack of expertise	4
A12	High Costs	8
A13	Fear of failure	5
A14	Projects are too small to use BIM	3
A15	High cost of implementation	7
A16	Lack of relevant software	5
A17	Decision makers don’t provide full support	3
A18	Legal barriers exit	2
A19	Unavailability of proper training on BIM	6
A20	Lack of long-term thinking	8
A21	Resistance to change	8
A22	End-user does not realize the benefits	8

[60] Reference: own tabulation

A23	Lack of guidelines and standards	3
A24	Hard to implement in renovation projects	5
A25	Only being hired for the first phases	4
A26	Employee's avoidance of changing their way of working	8
A27	Cost of new software	7
A28	Cost of updating the system	7
A29	Cost of training the team	7
A30	Lack of experience in BIM projects	9
A31	Lack of collaboration	8
A32	BIM licensing	5
A33	Maintenance costs	4
A34	Lack of BIM risk insurances	3

Next step, the researcher identifies potential themes to be aggregated. In other words, it must be decided which first-level code has a proper semantic relationship with others to be placed in a category or theme. Table 7 shows the extracted main and sub themes.

Table 7: Extracted main and sub themes[61]

Code	Themes	Basic Concepts	Open code	Freq at Interview	Total Freq	Rank
B1	Management support	Lack of knowledge of managers	A1	9	43	1
		Management support	A2	10		
		Management Attitude	A8	8		
		Decision makers don't provide full support	A17	8		
		Lack of long-term thinking	A20	8		
B2	High Cost	High cost of software	A3	3	27	4
		High Costs	A12	2		
		High cost of implementation	A15	3		
		Cost of new software	A27	3		
		Cost of updating the system	A28	4		
		Cost of training the team	A29	3		
		BIM licensing	A32	3		
		Lack of relevant software	A16	3		
		Maintenance costs	A33	3		
B3	Client not willing	Not being demanded by the clients	A7	9	28	3
		End-user does not realize the benefits	A22	10		
		Insufficient understanding of the benefits	A4	9		
B4		Use of traditional method	A5	9	42	2

[61] Reference: own tabulation

	Staff re-sistance	Most of staffs are old and not willing to use systems	A10	9		
		Resistance to change	A21	8		
		Employee's avoidance of changing their way of working	A26	8		
		Lack of collaboration	A31	8		
B5	Hard to im-plement	Complexity	A6	4	26	5
		ICT Implementation problem	A9	6		
		Lack of expertise	A11	4		
		Unavailability of proper training on BIM	A19	3		
		Lack of experience in BIM projects	A30	4		
		Hard to implement in renovation projects	A24	5		
B6	ELSE	Fear of failure	A13	5	20	6
		Projects are too small to use BIM	A14	3		
		Legal barriers exit	A18	2		
		Lack of guidelines and standards	A23	3		
		Only being hired for the first phases	A25	4		
		Lack of BIM risk insurances	A34	3		

As shown in the table, management support, high cost, client not willing, staff resistance, hard to implement, and else are the main extracted themes. Ranked data in this table shows that "Management support" is of the highest importance, while "Implementation difficulty" and "Else" are of the lowest importance.

4.3.1. The Interview Validity

Interview validity refers to the degree that the method can measure the study purpose. Validity in a qualitative study is the extent to which the researcher's observation can reflect the research's phenomenon or its related variables. In evaluating the validity, criteria such as admissibility, transferability, acceptability, credibility, and assurance are considered. Cresswell (Creswell and Miller 2000) believes that validity in qualitative inquiry is challenging on many levels. He has proposed spending prolonged time on the issue, detailed and accurate notetaking of the sessions, accurate voice recording, and external auditor consultation during the interview. Therefore, by consulting with two BIM experts, the researcher spent enough time revising the interview process and getting approval of the interview process to ensure the validity of the interview.

4.3.2. The Interview Reliability

Reliability in data collection tools, such as interviews, means that the results will not differ much if it is repeated several times on a population. Heale (Heale and Twycross 2015) believes that “reliability relates to the consistency of a measure. A participant completing an instrument meant to measure motivation should have approximately the same responses each time the test is completed. Although it is not possible to give an exact calculation of reliability, an estimate of reliability can be achieved through different measures.”

Test-retest Reliability Calculation

Several interviews are selected and re-coded over a short period to calculate the reliability by Test-retest. The extracted codes are compared at different times. In interviews. Similar codes were identified as "agreement," and codes that were not similar were marked as "disagreement". Figure 34

#	Interview	No of Codes	Agree-ment	Disagree-ment	Acceptable
1	Fourth	12	8	4	66.67%
2	Seventh	10	7	3	70.00%
3	Thirteenth	11	8	3	72.73%
4	Seventeenth	9	6	3	66.67%
Total		42	29	13	69.05%

Figure 34: Test-retest Reliability Result[62]

4.4. The Final Questionnaire

To finalize the research finding, the final themes, which are the results of the interviews, are used to create the final questionnaire (Figure 35) having a Five-Point Likert Scale based on Delphi's approach. The ranges of the answers were from "strongly agree" to "strongly disagree," illustrated in Table 8. Output of the final questionnaire is summarized in Figure 36.

[62] Reference: own tabulation

Table 8: Five-Point Likert Scale[63]

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
(1)	(2)	(3)	(4)	(5)

#	Questions	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
1	Management support is effective on BIM usage	☐	☐	☐	☐	☐
2	High Cost of software and implementation is a barrier to use BIM	☐	☐	☐	☐	☐
3	How Client willingness effects on BIM incorporation	☐	☐	☐	☐	☐
4	Staff resistance has great impact on BIM usage	☐	☐	☐	☐	☐
5	Difficulty of implementation is a barrier to use BIM	☐	☐	☐	☐	☐
6	Other reason	☐	☐	☐	☐	☐

Figure 35: The final questionnaire[64]

[63] In conformity with Cronbach 1951.
[64] Reference: own tabulation

Experts	Management support is effective on BIM usage	High Cost of software and implementation is a barrier to use BIM	How Client willingness effects on BIM incorporation	Staff resistance has great impact on BIM usage	Difficulty of implementation is a barrier to use BIM	Other reason	Total
Expert1	4	3	3	5	3	1	19
Expert2	5	5	4	3	1	1	19
Expert3	3	4	4	4	2	2	19
Expert4	5	2	3	4	4	2	20
Expert5	4	3	4	5	2	3	21
Expert6	5	3	4	3	3	2	20
Expert7	2	4	5	4	2	2	19
Expert8	4	2	2	5	4	3	20
Expert9	3	5	4	5	3	2	22
Expert10	2	4	3	4	3	4	20
Expert11	5	2	4	4	2	3	20
Expert12	5	3	4	3	4	3	22
Expert13	5	4	5	4	3	4	25
Expert14	4	3	5	4	3	4	23
Expert15	3	4	4	1	2	3	17
Expert16	4	3	2	4	4	2	19
Expert17	4	5	2	3	4	2	20
Expert18	4	2	3	5	3	2	19

Figure 36: Output of the final questionnaire

4.4.1. Reliability of the final questionnaire

A criterion is used to assess the reliability of questionnaire answers called "Cronbach's alpha[65]". Cronbach's alpha is broadly used to measure reliability or internal consistency used explicitly for Likert questions in questionnaires that form a scale. Equation 3 shows the formula (Cronbach 1951).

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} \sigma^2_{Y_i}}{\sigma^2_X}\right)$$

Equation 3 Cronbach's alpha Formula

[65] Cronbach's alpha (Cronbach's α) index, also known as the alpha coefficient, was introduced by Lee Cronbach, a psychologist, and educational scientist, in 1951.

Where α is the Cronbach's alpha coefficient, k is the number of questions, $\sigma^2 Y_i$ is the sum of the variances of each respondent's scores, $\sigma^2 X$ is the variance of the scores of question number i.

The Cronbach's alpha coefficients of the final questionnaire is 0.981, which according to Table 5, confirms that the questionnaire has a relatively high internal consistency.

In the next step, as shown in Figure 37, the questionnaire is summarized by frequency, percentage, cumulative frequency, and each question's rank.

#	Questions	Frequency						Percentage						Cumulative frequency						Effect	
		Strongly Agree	Agree	Nuetral	Disagree	Strongly disagree	Total	Strongly Agree	Agree	Nuetral	Disagree	Strongly disagree	Total	Strongly Agree	Agree	Nuetral	Disagree	Strongly disagree	Total	%	Rank
1	Management support	6	7	3	2	0	18	33.3%	38.9%	16.7%	11.1%	0.0%	100%	30	28	9	4	0	71	19.51%	1
2	High Cost of software and implementation	3	5	6	4	0	18	16.7%	27.8%	33.3%	22.2%	0.0%	100%	15	20	18	8	0	61	16.76%	4
3	Client willingness	3	8	4	3	0	18	16.7%	44.4%	22.2%	16.7%	0.0%	100%	15	32	12	6	0	65	17.86%	3
4	Staff resistance	5	8	4	0	1	18	27.8%	44.4%	22.2%	0.0%	5.6%	100%	25	32	12	0	1	70	19.23%	2
5	Difficulty of implementation	0	5	7	5	1	18	0.0%	27.8%	38.9%	27.8%	5.6%	100%	0	20	21	10	1	52	14.29%	5
6	Other reason	0	3	5	8	2	18	0.0%	16.7%	27.8%	44.4%	11.1%	100%	0	12	15	16	2	45	12.36%	6

Figure 37: Frequency, Percentage and Cumulative frequency of the final questionnaire[66]

From the table, Figure 38 could be accordingly concluded, where management support has the highest portion (19.51%), staff resistance is in the second level (19.23%), and client willingness is in the third level (17.86%). The high cost of software and implementation is ranked in fourth place (16.76%), the fifth is the difficulty of implementation (14.29%), and the last one is "Other reason" (12.36%).

[66] Reference: own tabulation

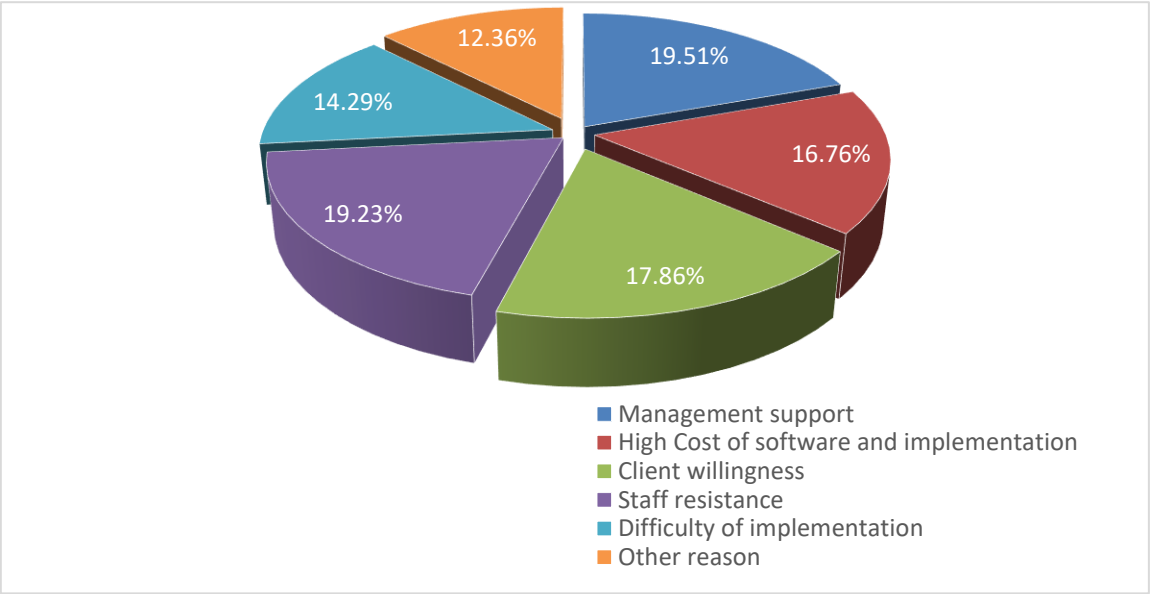

Figure 38 The primary result of the questionnaire[67]

4.4.2. Fuzzy Delphi method

As mentioned in chapter 3, the fuzzy Delphi method is similar to the classical Delphi method, and the only difference would be the fuzzification of respondents' responses. An advantage of the Fuzzy method over the classical approach is that the fuzzification allows the values to be defined qualitatively. In this method, values are usually represented as TFN[68]. Understanding the meaning of fuzzy logic is necessary to comprehend fuzzy numbers. A famous example of fuzzy logic is the following.

TFN is a type of fuzzy number represented by three real numbers as F = (l, m, u). These types of fuzzy numbers are prevalent due to their very high computational efficiency. In addition, calculation with this type of numbers is very simple and understandable. Fuzzy logic was introduced by discovering fuzzy sets and fuzzy numbers. Moreover, TFN has played an essential role in the development of fuzzy computing. Indeed, the three real numbers (F= (l, m, u)) are an excellent way to scale qualitative research. The upper bound denoted by "u" is the maximum value of the fuzzy number "F". The lower bound denoted by "l" is the minimum value of fuzzy number "F". "m" is the most probable value of a fuzzy number (Habibi et al. 2015). Figure 39 is a TFN shape and can be defined as a triplet (l, m, u).

[67] Reference: own tabulation
[68] Triangular Fuzzy Numbers

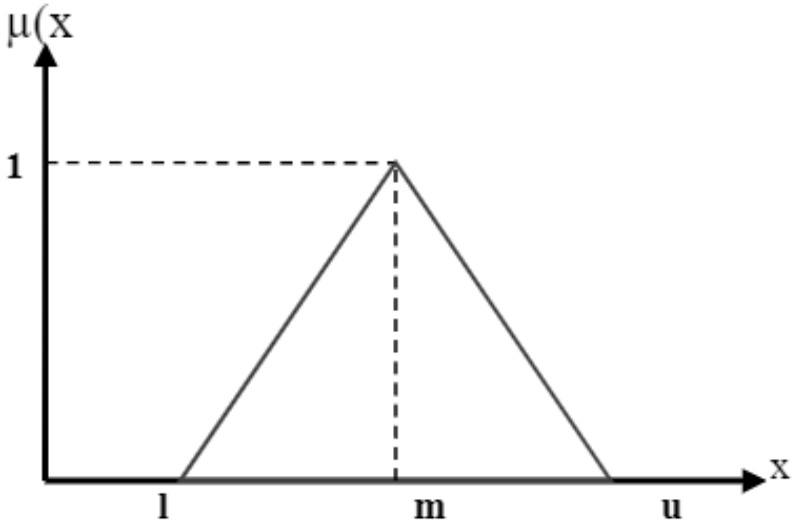

Figure 39: Triangular fuzzy number[69]

The conversion of five-point Likert Scale to Triangular fuzzy numbers (Cheng 2004) are summarized in Table 9.

Table 9: Triangular fuzzy numbers for five-point scale[70]

Likert Scale					
Linguistic Terms	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Linguistic Value	1	2	3	4	5
TFN	0.0, 0.0, 0.2	0.0, 0.2, 0.4	0.20, 0.4, 0.60	0.4, 0.6, 0.8	0.60, 0.8, 1.00

The associated membership function is calculated by Equation 4 (Shahyamal and Pal 2007), in which $l \leq m \leq u$ and where l, m and u are real numbers. Therefore, TFN number w_{ij} is TFN of expert *i* for question *j*.

[69] Habibi et al. 2015.
[70] Reference: own tabulation

$$\mu_{\tilde{N}}(x)=\begin{cases}0, & x<l\\ \dfrac{(x-l)}{(m-l)}, & l\le x\le m,\\ \dfrac{(u-x)}{(u-m)}, & m\le x\le u,\\ 0, & x>u,\end{cases}$$

Equation 4: The membership function μ

Fuzzification

Expressing views and opinions about any phenomenon is a subject with a qualitative state and includes a range of feelings of the person towards the issue. In recording this opinion and feeling, the person tries to include his opinion in one of the available formats. The same is true for interviews, and it is often challenging for the interviewer to adapt the issues mentioned in the interviews to existing patterns. The traditional process of quantifying people's perspectives does not fully reflect the human thinking style. Therefore, it is better to use fuzzy sets (fuzzy numbers) to understand the qualitative issues better. In other words, the use of fuzzy sets is more compatible with linguistic and sometimes ambiguous human explanations.

Triangular fuzzy numbers or trapezoidal fuzzy numbers are usually used for this purpose. A suitable fuzzy spectrum is also proposed for each technique.

Following is the result of the final questionnaire shown in Figure 40, which is grouped by the questions. In the fuzzification stage, this result is the input data to be converted to TFN.

#	Questions	Expert1	Expert2	Expert3	Expert4	Expert5	Expert6	Expert7	Expert8	Expert9	Expert10	Expert11	Expert12	Expert13	Expert14	Expert15	Expert16	Expert17	Expert18
1	Management support is effective on BIM usage	4	5	3	5	4	5	2	4	3	2	5	5	5	4	3	4	4	4
2	High Cost of software and implementation is a barrier to u	3	5	4	2	3	3	4	2	5	4	2	3	4	3	4	3	5	2
3	How Client willingness effects on BIM incorporation	3	4	4	3	4	4	5	2	4	3	4	4	5	5	4	2	2	3
4	Staff resistance has great impact on BIM usage	5	3	4	4	5	3	4	5	5	4	4	3	4	4	1	4	3	5
5	Difficulty of implementation is a barrier to use BIM	3	1	2	4	2	3	2	4	3	3	2	4	3	3	2	4	4	3
6	Other reason	1	1	2	2	3	2	2	3	2	4	3	3	4	4	3	2	2	2

Figure 40: Result of the final questionnaire grouped by the questions[71]

[71] Reference: own tabulation

At this stage, a script is developed to solve equation 3 for converting the results of the final questionnaire to TFN. The program is implemented as a function using VBA[72] integrated into Microsoft Excel.

```
Sub convert_to_fuzzy()
Dim score As Integer, r1 As Double, r2 As Double, r3 As Double
Dim i As Integer
For j = 1 To 18            '—Expert numbers
For i = 3 To 8
score = Range("C" & i).Value
Select Case score
   Case Is = 5
      r1 = 0.6
      r2 = 0.8
      r3 = 1
   Case Is = 4
      r1 = 0.4
      r2 = 0.6
      r3 = 0.8
   Case Is = 3
      r1 = 0.2
      r2 = 0.4
      r3 = 0.6
   Case Is = 2
      r1 = 0
      r2 = 0.2
      r3 = 0.4
   Case Else
      r1 = 0
      r2 = 0
      r3 = 0.2
End Select
Range("v" & i).Value = r1
Range("w" & i).Value = r2
Range("x" & i).Value = r3
Next i
Next j
```

Equation 5: Conversion Function to triangular fuzzy numbers[73]

After generating the Equation 5, the researcher used it to convert the results of the final questionnaire shown in Figure 40. Finally, the generated TFN is stored in a table. A sample of generated TFN for four experts is presented in Table 10.

[72] Visual Basic for Applications
[73] Created by the author

Table 10: Score of 4 experts Converted to TFN (as an example)[74]

Expert1			Expert2			Expert3			Expert4		
L	M	U	L	M	U	L	M	U	L	M	U
0.40	0.60	0.80	0.60	0.80	1.00	0.20	0.40	0.60	0.60	0.80	1.00
0.20	0.40	0.60	0.60	0.80	1.00	0.40	0.60	0.80	0.00	0.20	0.40
0.20	0.40	0.60	0.40	0.60	0.80	0.40	0.60	0.80	0.20	0.40	0.60
0.60	0.80	1.00	0.20	0.40	0.60	0.40	0.60	0.80	0.40	0.60	0.80
0.20	0.40	0.60	0.00	0.00	0.20	0.00	0.20	0.40	0.40	0.60	0.80
0.00	0.00	0.20	0.00	0.00	0.20	0.00	0.20	0.40	0.00	0.20	0.40

As it is shown in the table, there are three L, M, and U numbers for each answer of every expert.

Defuzzification

After fuzzification and experts' opinions aggregation, to get understandable numbers, the resulted values should be defuzzified. The defuzzifier receives the fuzzy input and converts it to the crisp output. There are several methods for defuzzification. The author selected the one mentioned in Equation 6, which is one of the suggested methods in qualitative research (Talon and Curt 2017). The defuzzified number of x_{ij} is calculated by $l_{ij} + 2m_{ij} + u_{ij}$ devided by four, as mentioned in Equation 6.

$$x_{ij}^{defuzzy} = \frac{\left(l_{ij} + 2m_{ij} + u_{ij}\right)}{4}$$

Equation 6: Defuzzification formula

The results of defuzzification using the defuzzifier is mentioned in Table 11.

[74] Reference: own tabulation

Table 11: Result of defuzzification (crisp scores)[75]

#	Questions	L	M	U	Fuzzy Average	Rank
1	Management support is effective on BIM usage	7	21	14	1.76	1
2	High Cost of software and implementation is a barrier to u	5	17	12	1.40	4
3	How Client willingness effects on BIM incorporation	6	19	13	1.55	3
4	Staff resistance has great impact on BIM usage	7	21	14	1.74	2
5	Difficulty of implementation is a barrier to use BIM	3	14	10	1.09	5
6	Other reason	2	11	9	0.85	6

As shown in the table, Management support has a 1.76 Fuzzy Average score and stands as the first rank. Staff resistance with 1.74 scores is the second barrier, Client willingness has a 1.55 score and stands as the third, and High Cost of software and implementation with 1.4 Fuzzy Average scores is the fourth barrier from the point of view of the experts. The fifth one in the table belongs to the Difficulty of implementation that has a 1.09 Fuzzy Average. Other reason is the last one with 0.85 Fuzzy Average scores.

The interesting point of the research is that the result of both Fuzzy Delphi and the classic one for the ranking of the barriers are the same, showing that the overall Credibility of the research is acceptable.

4.5. Summary of the Chapter

In this section, the author found the main barriers and factors affecting incorporating BIM in renovation projects. Using the Delphi method, a basic questionnaire is generated to collect general information about the research. It is filled by seventy-four experts whose education and works are related to BIM. The validity and reliability of the questionnaire are checked, and results are collected out of the questionnaire.

A primary conclusion is obtained from the first questionnaire, which shows that larger projects are more likely to use BIM in participants' opinions. It is also more probable for public projects to require BIM. The researcher did not find any apparent relationship between the company size and the number of BIM projects. Nevertheless, no balance in the sampling population leads us to a reliable conclusion about the effect of the

[75] Reference: own tabulation

company type. Also, the participants believe that better communication between project stakeholders, information integrity, and interdisciplinary coordination and validation, respectively, are the most important benefits of BIM. Moreover, the general opinions of the participants about the barriers are collected.

To get the precise results about the barriers, the researcher continued the research and chose eighteen experts among the first group to be interviewed. The interviews are analyzed by theme analysis method, and 34 open codes are extracted from them. Then aggregation of the open codes is done by combining those who had a proper semantic relationship with each other and placing them in categories or themes. At this stage, six themes are created.

In order to get the exact weight of the selected themes and according to the Delphi method, the final questionnaire was created from the extracted themes and sent to the same 18 experts. After filling and sending back the questionnaires by the experts, the author summarized the results by calculating the frequencies, percentages, and cumulative frequencies in which ranking of them was done.

Finally, the extracted scores are converted to the TFN using the Fuzzy Delphi method. This process enabled the author to get the exact impact of each barrier and better understand the qualitative data of linguistic ideas of experts. Then the obtained TFNs are defuzzificated, and the Fuzzy Average and Rank of each theme are calculated. From the results, it is concluded that management support, staff resistance, client unwillingness, high cost of software, the difficulty of implementation, and other reasons are the most critical barriers by sequence.

Since the nature of the third research question was different from the overall research, the collected data could not help find an answer to it. For this reason, the third research question has been excluded, and it can be a subject of another individual research.

5. Conclusion and recommendation

Nowadays, the construction industry, like other industries, has undergone many growths and transformations, which has caused it to be divided into various categories. From residential to commercial or industrial areas, all have experienced fundamental changes. Construction trends in recent years show that intelligence, productivity, and profitability are the main factors that are improved. Understanding the developments in the construction industry and recognizing solutions to overcome business barriers will help construction companies to scale their company effectively for the upcoming decades. One of the basic principles in the construction and renovation projects is to meet the increasing demands of the clients and contractors. Cost Estimation and optimization, preconstruction visualization, rapid implementation and better productivity by using prefabrication, preventing clash and full coordination, scheduling and sequencing improvement, reducing risk and increasing safety and Facility Management are some of the demands which all can be done by incorporating the Building Information Modeling or in short BIM. The exact time of starting the BIM is not clear, but we can refer to 60s, when the use of CAD and CAM concepts by computers in various industries started. During these years, a number of researchers proposed theories to achieve the best performance in the implementation of projects. The turning point of this issue is done by Charles Eastman, who proposed the theory of using a 3D model under a shared database on mid-1970s. At that time, the first steps for enjoying the BIM are taken.

Today, using BIM in construction projects are widespread, and is increasing, but usage of BIM in renovation projects is not as much as in new construction projects. Therefore, in this research situation with the use of BIM in renovation projects, and the factors or barriers affecting BIM implementation in renovation projects has been investigated.

In the first chapter, aims and objectives of the research along with the problem description and research questions are fully described. Chapter two begins with an overview of the subject to provide some background information. The past research relevant to the study's title is then evaluated to summarize what has been done in this subject before. Finally, the knowledge gap and the problem that this work aims to solve are described. In chapter three, the research methodology and all related issues are discussed. Overall method of the research is based on Delphi method and Fuzzy Delphi

method is one of the data analysis methods performed in this research. The reliability of the questionnaires is calculated by Cronbach's alpha and for the reliability of the interview, test retest is used. All the analysis and the calculations are done using MS Excel and self-created conversion script for converting of the scores to the triangular fuzzy numbers. In chapter four, the collected data are extracted from the scientific analyzing process. By utilization of descriptive and inferential analysis methods, information is classified into numbers and figures and is decorated and analyzed in the form of special tables with the integration of statistical and mathematical techniques and tools. The author found the main barriers of using of BIM in the construction renovation project. Using the Delphi method, a basic questionnaire is generated to collect some general information related to the research along with general BIM related questions. The first questionnaire is filled by 74 BIM experts whose education and/or job is related to BIM. The validity and reliability of the questionnaire are checked, and some general barriers are collected out of the questionnaire. Then 18 experts are chosen among the above-mentioned experts to be interviewed. The interviews are analyzed by theme analysis method and 34 open codes are extracted from them. Then aggregation of the open codes is done by combining those who had proper semantic relationship with each other and placing them in categories or themes. At this stage, six themes of management support, high cost, client not willing, staff resistance, hard to implement and else are created. In order to get the exact weight of the selected themes and according to the Delphi method, the final questionnaire is created from the extracted themes and sent to the same 18 experts. After filling and sending back the questionnaires by the experts, the author summarized the results by calculating the frequencies, percentages and cumulative frequencies by which ranking of them is done. So, the detected barriers are management support, staff resistance, client willingness, high cost of software and implementation, difficulty of implementation, and the last one is other reason respectively. Finally, the extracted scores are converted to the Triangular Fuzzy Numbers using the Fuzzy Delphi method. This enabled the author to get the exact impact of each barrier and better understand the qualitative data of linguistic ideas of experts. Then the obtained TFNs are defuzzificated and the Fuzzy Average and Rank of each theme are calculated. The management support is the first in ranking, staff resistance the second, client willingness the third, high cost of software the fourth, the fifth is difficulty of implementation and other reasons is the least effective element. The interesting point is the output of two calculations of classic and Fuzzy Delphi are identical.

5.1. Limitation

Researchers always face limitations in their research. One of the most critical aspects of research is access to statistics and information related to the field. In most cases, either the data is not updated or is not available. The present study was no exception to this rule, and the lack of updated statistics is felt in some parts of the research. Moreover, limited prior research studies are focusing specifically on the topic.

A wide range of researchers, students, and academics have been affected by the COVID-19 epidemic. Higher education institutions have reduced in-person operations, and research and training have been interrupted. Many graduate students have faced new barriers as a result. This research had the same problem in accessing people to interview and doing observations.

5.2. Recommendation

This study had an explorative approach, investigating factors or barriers affecting BIM implementation in renovation projects in Northern and Western Europe. It would be interesting to conduct the same research in other regions. Nevertheless, I find it challenging for a researcher to find out more about the correlation between company profile and the use of BIM.

The researcher also recommend that related organizations or governments adopt new rules and mandatory instructions to encourage using of BIM in all construction and renovation projects.

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, 07/28/2021

Location, Date

Signature of the student

Appendix

Appendix A

BIM

This questionnaire is conducted to analyze obstacles for BIM solutions to be incorporated in the renovation projects.
Your answer will be anonymous and the collected data will be used for educational purposes only.

1. Basic Questions

1. What is the annual percentage of renovation projects in your company that is implementing BIM?: 0

0 Percentage 100

2. Do you prefer BIM-based solutions over traditional methods?: 0

- Yes
- No

3. What are the obstacles to the use of BIM in the renovation, in your opinion? 0

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Lack of knowledge of managers					
Fear of failure					
High Costs					
End-user does not realize the benefits					
Hard to implement in renovation projects					
Lack of long-term thinking					
Only being hired for the first phases					
Employee's avoidance of changing their way of working					
Cost of new software					
Cost of updating the system					
Cost of training the team					
Lack of experience in BIM projects					
Lack of collaboration					

4. Which of the following items were benefits of using BIM programs in your projects? 0

	0%	25%	50%	75%	100%
Information integrity	○	○	○	○	○
Better management of project requirements and capacity	○	○	○	○	○
Better communication between project stakeholders	○	○	○	○	○
Improved decision making	○	○	○	○	○
Interdisciplinary coordination and validation	○	○	○	○	○

NEW QUESTION

or Copy and paste questions

NEXT

0 of 16 answered

BIM

This questionnaire is conducted to analyze obstacles for BIM solutions to be incorporated in the renovation projects.
Your answer will be anonymous and the collected data will be used for educational purposes only.

2. Main Questions

5. What type of projects in your company is using BIM? 0

	0%	25%	50%	75%	100%
Residential	○	○	○	○	○
Commercial	○	○	○	○	○
All types	○	○	○	○	○

6. What size of projects is more likely to require BIM? 0

	0%	25%	50%	75%	100%
Less than €200,000	○	○	○	○	○
Between €200,000 and €500,000	○	○	○	○	○
More than €500,000	○	○	○	○	○

7. What type of clients is more likely to ask for BIM? 0

	0%	25%	50%	75%	100%
Public Sector	○	○	○	○	○
Private Sector	○	○	○	○	○

8. What is the size of the company you work for? 0

- ○ 1 to 9 employees
- ○ 10 to 49 employees
- ○ 50 to 249 employees
- ○ 250 employees or more

9. What type of construction projects your company deals with? 0

- ○ Construction/Renovation
- ○ Construction
- ○ Renovation

13. What type of BIM tools are you using in your projects? 0

- [ ] Tekla Structures
- [ ] Trimble Connect
- [ ] Revit
- [ ] AutoCAD
- [ ] Archicad
- [ ] Solibri
- [ ] SketchUp
- [ ] Navisworks
- [ ] Civil 3D
- [ ] RAM Structural System
- [ ] Tekla Structural Designer
- [ ] ArCADia Architecture
- [ ] Tekla PowerFab
- [ ] Allplan
- [ ] BIM360
- [ ] Other (please specify)

14. In which country are you working? 0

15. Are you willing to have a voluntary interview regarding the topic? 0

- ( ) Yes
- ( ) No

Publication bibliography

Acampa, G.; Diana, L.; Marino, G.; Marmo, R. (2021): Assessing the Transformability of Public Housing through BIM. In *Sustainability* 13 (10), p. 5431. DOI: 10.3390/su13105431.

Birna Kjartansdóttir, I.; Mordue, S.; Nowak, P.; Philp, D.; Snæbjörnsson, J. T. (2017): Building Information Modelling BIM.

Brahmi, B. F.; Boudemagh, S. S.; Kitouni, I.; Kamari, A. (2020): Sustainable renovation of heritage buildings through IPDish and.

Braun, V.; Clarke, V. (2006): Using thematic analysis in psychology. In *Qualitative Research in Psychology* 3 (2), pp. 77–101. DOI: 10.1191/1478088706qp063oa.

Brough, P. (Ed.) (2018): Advanced Research Methods for Applied Psychology: Design, analysis and reporting. Abingdon Oxon, New York NY: Routledge.

Catenda (2021): BIM (Building information modeling) | Catenda. Available online at https://catenda.com/glossary/bim/, updated on 5/4/2021, checked on 7/25/2021.

Cheng, C. (2004): Group opinion aggregationbased on a grading process: A method for constructing triangular fuzzy numbers. In *Computers & Mathematics with Applications* 48 (10-11), pp. 1619–1632. DOI: 10.1016/j.camwa.2004.03.008.

Corbin, J. (2014): Basics of Qualitative Research. Techniques and Procedures for Developing Grounded Theory. 4th. New York: SAGE Publications.

Creswell, J. W. (2013): Qualitative inquiry and research design. Choosing among five approaches. third edition. Los Angeles, Calif., London, New Dehli, Singapore, Washington DC: SAGE.

Creswell, J. W. (2014): Research design. Qualitative, quantitative, and mixed methods approaches. 4th ed. Thousand Oaks: SAGE Publications.

Creswell, J. W.; Miller, D. L. (2000): Determining Validity in Qualitative Inquiry. In *Theory Into Practice* 39 (3), pp. 124–130. DOI: 10.1207/s15430421tip3903_2.

Cronbach, L. J. (1951): “Coefficient Alpha and the Internal Structure of Tests,” Psychometrika 16 (3), pp. 297-334.

Daniotti, B.; Bolognesi, C. M.; Lupica Spagnolo, S.; Pavan, A.; Signorini, M.; Ciuffreda, S. et al. (2021): An Interoperable BIM-Based Toolkit for Efficient Renovation in Buildings. In *Buildings* 11 (7), p. 271. DOI: 10.3390/buildings11070271.

Denzin, N. K.; Lincoln, Y. S. (2018): The SAGE Handbook of Qualitative Research. 5th. United States of America: SAGE Publications.

Di Mascio, D.; Wang, X. (2013): Building Information Modelling (BIM)-Supported Cooperative Design in Sustainable Renovation Projects. In David Hutchison, Takeo Kanade, Josef Kittler, Jon M. Kleinberg, Friedemann Mattern, John C. Mitchell et al. (Eds.): Cooperative Design, Visualization, and Engineering, vol. 8091. Berlin, Heidelberg: Springer Berlin Heidelberg (Lecture Notes in Computer Science), pp. 205–212.

DIN German Institute for Standardization: DIN SPEC 91400 Building Information Modeling (BIM) | CASE STUDY. With assistance of DIN German Institute for Standardization.

Ding, Z.; Liu, S.; Liao, L.; Zhang, L. (2019): A digital construction framework integrating building information modeling and reverse engineering technologies for renovation projects. In *Automation in Construction* 102, pp. 45–58. DOI: 10.1016/j.autcon.2019.02.012.

Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K. (2008): BIM for the Construction Industry. In C. Eastman, P. Teicholz, R. Sacks, K. Liston (Eds.): BIM Handbook. Hoboken, NJ, USA: John Wiley & Sons, Inc, pp. 207–242.

Economidou, M.; Atanasiu, B.; Despret, C.; Maio, J.; Nolte, I.; Rapf, O. et al. (2011): Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings. Netherlands. Available online at https://www.osti.gov/etdeweb/biblio/21514343.

Elagiry, M.; Dugue, A.; Costa, A.; Decorme, R. (2020): Digitalization Tools for Energy-Efficient Renovations. In *Proceedings* 65 (1), p. 9. DOI: 10.3390/proceedings2020065009.

Elagiry, M.; Marino, V.; Lasarte, N.; Elguezabal, P.; Messervey, T. (2019): BIM4Ren: Barriers to BIM Implementation in Renovation Processes in the Italian Market. In *Buildings* 9 (9), p. 200. DOI: 10.3390/buildings9090200.

Empler, T.; Caldarone, A.; Rossi, M. L. (2021): “BIM Survey”. Critical Reflections on the Built Heritage’s Survey. In C. Bolognesi, D. Villa (Eds.): From Building Information Modelling to Mixed Reality. Cham: Springer International Publishing (Springer Tracts in Civil Engineering), pp. 109–122.

Energy Performance of Buildings Directive (2021): Public consultation launched on revising the Energy Performance of Buildings Directive. Available online at https://ec.europa.eu/info/news/public-consultation-launched-revising-energy-performance-buildings-directive-2021-mar-30_en, updated on 3/30/2021, checked on 7/25/2021.

European Innovation Council and SMEs Executive Agency (2021): Calculating Costs and Benefits for the use of Building Information Modelling in Public tenders. Methodology Handbook.

Feng, H.; Liyanage, D. Rukmal; Karunathilake, H.; Sadiq, R.; Hewage, K. (2020): BIM-based life cycle environmental performance assessment of single-family houses: Renovation and reconstruction strategies for aging building stock in British Columbia. In *Journal of Cleaner Production* 250, p. 119543. DOI: 10.1016/j.jclepro.2019.119543.

Fernandez, T.; Diaz, C.; Stöffler, S. (Eds.) (2020): Smart Cities for Smarter Citizens: Participatory Planning in Housing Renovation using 3D BIM Tools: the Case of Eckart Vaartbroek: REAL CORP 2020.

Gamayunova, O.; Vatin, N. (2014): BIM-Technology in Architectural Design. In *AMR* 1065-1069, pp. 2611–2614. DOI: 10.4028/www.scientific.net/AMR.1065-1069.2611.

Gökgür, A. (2015): Current and future use of BIM in renovation projects.

Goodman, L. A. (1961): Snowball Sampling 32, pp. 148–170.

Habibi, Arash; Jahantigh, Farzad Firouzi; Sarafrazi, Azam (2015): Fuzzy Delphi Technique for Forecasting and Screening Items. In *Asia. Jour. Rese. Busi. Econ. and Manag.* 5 (2), p. 130. DOI: 10.5958/2249-7307.2015.00036.5.

Harrison, K. (2020): ‘Snowball sampling’. Available online at https://cuttingedgepr.com/find-mobilize-unofficial-opinion-leaders/, updated on 6/1/2020, checked on 7/29/2021.

Heale, Roberta; Twycross, Alison (2015): Validity and reliability in quantitative studies. In *Evidence-based nursing* 18 (3), pp. 66–67. DOI: 10.1136/eb-2015-102129.

Helander, David; Singh, Vishal (2016): BIM in building renovation projects: what is the useful minimum information requirement? In *IJPLM* 9 (1), p. 65. DOI: 10.1504/IJPLM.2016.078863.

Ilter, Deniz; Ergen, Esin (2015): BIM for building refurbishment and maintenance: current status and research directions. In *Structural Survey* 33 (3), pp. 228–256. DOI: 10.1108/SS-02-2015-0008.

Jensen, Per Anker; Maslesa, Esmir (2015): Value based building renovation – A tool for decision-making and evaluation. In *Building and Environment* 92, pp. 1–9. DOI: 10.1016/j.buildenv.2015.04.008.

Joblot, L.; Paviot, T.; Deneux, D.; Lamouri, S. (2017): Literature review of Building Information Modeling (BIM) intended for the purpose of renovation projects. In *IFAC-PapersOnLine* 50 (1), pp. 10518–10525. DOI: 10.1016/j.ifacol.2017.08.1298.

Karlapudi, J.; Menzel, K.; Törmä, S.; Hryshchenko, A.; Valluru, P. (2020): Enhancement of BIM Data Representation in Product-Process Modelling for Building Renovation. In F. Nyffenegger, J. Ríos, L. Rivest, A. Bouras (Eds.): Product Lifecycle Management Enabling Smart X, vol. 594. Cham: Springer International Publishing (IFIP Advances in Information and Communication Technology), pp. 738–752.

Kiger, M. E.; Varpio, L. (2020): Thematic analysis of qualitative data: AMEE Guide No. 131. In *Medical teacher* 42 (8), pp. 846–854. DOI: 10.1080/0142159X.2020.1755030.

Langston, C.; Wong, F. K.W.; Hui, E. C.M.; Shen, L. (2008): Strategic assessment of building adaptive reuse opportunities in Hong Kong. In *Building and Environment* 43 (10), pp. 1709–1718. DOI: 10.1016/j.buildenv.2007.10.017.

Leskovar, V. Ž.; Premrov, M. (2019): Integrative Approach to Comprehensive Building Renovations. Classification of Renovation Approaches.

Mekawy M. and Petzold F. (2018): Bim-Based Model Checking in the Early Design Phases of Precast Concrete Structures, pp. 71–80.

Mésároš, P.; Spišáková, M.; Mandičák, T.; Čabala, J.; Oravec, M. M. (2021): Adaptive Design of Formworks for Building Renovation Considering the Sustainability of

Construction in BIM Environment—Case Study. In *Sustainability* 13 (2), p. 799. DOI: 10.3390/su13020799.

NIBS; NBIMS Committee (2007): National Building Information Modeling Standard. Version 1 - Part 1: Overview, Principles, and Methodologies. Available online at https://buildinginformationmanagement.files.wordpress.com/2011/06/nbimsv1_p1.pdf.

Nielsen, A. N.; Jensen, R. L.; Larsen, T. S.; Nissen, S. B. (2016): Early stage decision support for sustainable building renovation – A review. In *Building and Environment* 103, pp. 165–181. DOI: 10.1016/j.buildenv.2016.04.009.

Okoli, C.; Pawlowski, S. D. (2004): The Delphi method as a research tool: an example, design considerations and applications. In *Information & Management* 42 (1), pp. 15–29. DOI: 10.1016/j.im.2003.11.002.

Ostermeyer, Y.; Camarasa, C.; Saraf, S.; Naegli, C.; Jakob, M.; Geibler, J. von et al. (2018): Building Market Brief Germany.

Peng, G. C.; Nunes, M. B.; Annansingh, F. (2011): Investigating information systems with mixed-methods research.

Project Smart (2021): Delphi Technique a Step-by-Step Guide. Available online at https://www.projectsmart.co.uk/delphi-technique-a-step-by-step-guide.php, updated on 7/28/2021, checked on 7/28/2021.

Reinhardt, J.; Associated General Contractors of America (2008): The Contractors' Guide to BIM. 1st ed.: Associated General Contractors of America (AGC publication). Available online at https://books.google.fi/books?id=svQSSQAACAAJ.

Sanei Sistani, N. (2017): An investigation on Success Factors for Scan to BIM Process.

Saunders, M. N. K.; Lewis, Philip; Thornhill, Adrian (2009): Research methods for business students. 5th ed. New York: Prentice Hall.

Schäfer, J.; Conzen, G. (Eds.) (2019): Praxishandbuch der Immobilien-Projektentwicklung. With assistance of Stefan Blümm, Ralf F. Bode, Klaus Dederichs, Jörg Eschweiler, Ralf Euling, Robin L. Fritz et al. Verlag C.H. Beck. 4. Auflage. München: C.H. Beck (Immobilienrecht).

Shahyamal, A. K.; Pal, M. (2007): Triangular Fuzzy Matrices. In *Iranian Journal of Fuzzy Systems* 4 (1), pp. 75–87.

Signorini, M.; Spagnolo, S. L.; Dejaco, M. C. (2021): A Digital Logbook as an Interactive Tool to Fulfil Service Companies' Needs and Requirements in Building Renovations. In *IOP Conf. Ser.: Mater. Sci. Eng.* 1044 (1), p. 12010. DOI: 10.1088/1757-899X/1044/1/012010.

Son, H.; Kim, C. (2016): Automatic segmentation and 3D modeling of pipelines into constituent parts from laser-scan data of the built environment. In *Automation in Construction* 68, pp. 203–211. DOI: 10.1016/j.autcon.2016.05.010.

Stegnar, G.; Cerovšek, T. (2019): Information needs for progressive BIM methodology supporting the holistic energy renovation of office buildings. In *Energy* 173, pp. 317–331. DOI: 10.1016/j.energy.2019.02.087.

Talon, A.; Curt, C. (2017): Selection of appropriate defuzzification methods: Application to the assessment of dam performance. In *Expert Systems with Applications* 70, pp. 160–174. DOI: 10.1016/j.eswa.2016.09.004.

the Committee on Industry, Research and Energy (ITRE) of the European Parliament (2016): Boosting Building Renovation:What potential and value for Europe?

Törmä, S.; Kiviniemi, M.; Lavikka, R.; Kousouris, S.; Tsatsakis, K. (2020): Towards BIM-Enhanced Renovation Management Tools with Support to Stakeholder Interaction. In *Proceedings* 65 (1), p. 15. DOI: 10.3390/proceedings2020065015.

Tzedaki, V.; Kamara, J. M. (2013): Capturing As-Built Information for a BIM Environment Using 3D Laser Scanner: A Process Model, pp. 486–495. DOI: 10.1061/9780784412909.047.

Volk, R.; Stengel, J.; Schultmann, F. (2014): Building Information Modeling (BIM) for existing buildings — Literature review and future needs. In *Automation in Construction* 38, pp. 109–127. DOI: 10.1016/j.autcon.2013.10.023.

Wang, C.; Cho, Y. K.; Kim, C. (2015): Automatic BIM component extraction from point clouds of existing buildings for sustainability applications. In *Automation in Construction* 56, pp. 1–13. DOI: 10.1016/j.autcon.2015.04.001.

Wang, W.; Gao, S.; Mi, L.; Xing, J.; Shang, K.; Qiao, Y. et al. (2021): Exploring the adoption of BIM amidst the COVID-19 crisis in China. In *Building Research & Information*, pp. 1–18. DOI: 10.1080/09613218.2021.1921565.

Yang, F.; Tepfer, S. (2018): Prescription for Healthier Building Materials: A Design and Implementation Protocol: AIA.