University of Agder

Building Occupants' Comfort Levels Identified with POE and Visualized by BIM

The main factors that contribute to discomfort for building occupants, and how can they be identified, visualized, and communicated using a combination of Post-Occupancy Evaluation (POE) surveys, dynamo and Revit add-ins.

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Preface

This master thesis has been prepared at the Department of Engineering Science as part of the master's program for Civil and Structural Engineering at the University of Agder (UiA). The master's thesis is the final task in the subject BYG508 and was executed in the fourth and final semester of the master program. The thesis has been written for, and in collaboration with, the University of Agder.

The aim of the master thesis is to research the level of satisfaction related to the indoor climate of the office spaces among employees at UiAs department of engineering science. The main goal is to demonstrate a possibility to visualize the employees' level of comfort using building information modeling (BIM).

I would like to take this opportunity to thank my supervisor at the University of Agder, Haidar Hosamo for his commitment, the follow-up, and his professional insight throughout the process. I would also like to thank the University of Agder for the possibility to write this master-thesis.

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Abstract

Creating and maintaining a comfortable indoor environment is crucial for energy-efficient building operation. However, there is often a disparity between defined comfort conditions and occupants' perceived comfort. To address this, collecting occupants' feedback and evaluating building performance through post-occupancy evaluation (POE) surveys are essential. Building Information Modeling (BIM) can enhance the visualization of survey results by providing a digital representation of the building.

This study aimed to utilize POE surveys, Dynamo, and Revit add-ins to identify, visualize, and communicate factors contributing to discomfort for building occupants. A POE survey was conducted with 51 respondents, assessing aspects such as temperature comfort, indoor air quality, visual comfort, acoustic comfort, and space adequacy. Results indicated that occupants were most dissatisfied with indoor air quality in summer and most satisfied with space adequacy.

Dynamo, a visual programming tool, was employed to create a script that imported the survey results into each room, colorizing them based on the survey aspects. Additionally, Revit add-ins were developed using Microsoft Visual Studio and the C# programming language to import and present data from Excel files within the Revit model. This facilitated the visualization of sensor data in the same BIM environment.

By conducting the POE survey, comfort levels were identified, and Dynamo scripts colorized the rooms in Revit to represent the comfort levels. The Revit add-ins further enhanced BIM's role as a unified and digital database, allowing the import and reading of sensor data.

In summary, this research aimed to use POE surveys, Dynamo, and Revit add-ins to identify, visualize, and communicate factors contributing to discomfort for building occupants. The combination of these tools provided valuable insights into comfort levels and facilitated efficient visualization and communication of survey results within the digital building model.

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Abbreviations

Below in table 0-1 is a listing of the most common used abbreviations in the text and the explanation for each one of them.

Table 0-1: Explanation of Abbreviations

Abbreviations	**Explanation**
POE	Post-occupancy evaluation
ZEB	Zero-Energy Buildings
BIM	Building Information Modeling
FM	Facility Manager
API	Application Programming Interface
IEQ	Indoor Environmental Quality
SDG	Sustainable Development Goals
AEC	Architecture, Engineering, and Construction
GUID	Globally Unique Identifier
XML	Extensible Markup Language
HVAC	Heating, Ventilation, and Air conditioning
NSD	Norwegian Center for Research Data
BN	Bayesian Network

1. Introduction

Creating and maintaining a comfortable indoor environment is a significant factor contributing to the energy consumption associated with building usage [1]. It is crucial to address this issue and achieve a comfortable living environment while implementing smart building management during the operation and maintenance phase, which accounts for approximately 80% of the overall life-cycle cost [2].

The satisfaction of occupants with the indoor environment quality (IEQ) plays a vital role in their overall productivity [1]. However, there have been instances where sustainability efforts have been prioritized at the expense of human comfort. The perception of thermal comfort in green buildings varies among users, with some perceiving them as less comfortable while others hold the opposite view. Personal factors such as gender, age, and culture contribute to the subjective nature of individuals' perception of the thermal environment [1].

Standards based on indoor IEQ have been established to define acceptable comfort ranges [3]. However, due to individual variation in sensation levels, there exists a disparity between the comfort conditions defined in the standards and those perceived by occupants [3]. Therefore, collecting occupants' feedback and evaluating building performance becomes essential in enhancing their comfort and productivity [3]. Various studies have developed methods and tools to assess building performance from the users' perspective, with post-occupancy evaluation (POE) surveys being a common technique employed [4]. These surveys focus on evaluating occupants' comfort and productivity [4].

Additionally, Building Information Modeling (BIM) can offer valuable insights by visualizing survey results in the digital representation of the building [3]. By utilizing BIM, the time and effort spent on manual data input by facility management teams can be significantly reduced [4]. BIM, serving as a digital representation of a building or infrastructure asset, can serve as a unified and digital database, facilitating the exchange of information [2]. BIM can be a valuable source of information during the operation and maintenance phase, supporting diverse activities in existing buildings and infrastructure. Although BIM has been successfully adopted in design and construction phases, its utilization during the operation and maintenance phase remains limited. However, the field is rapidly growing, with ongoing research focused on BIM-enabled asset management and its potential for improved collaboration, efficiency, and integration [2].

1.2 The Structure of The Thesis

The structure of the report is based on the template given by the administrators of the master's program for Civil and Structural Engineering. The structure is divided in the following twelve chapters: 1. Introduction, 2. Societal Perspective, 3. Knowledge Background, 4. Research Question, 5. Case/Materials, 6. Method, 7. Results, 8. Discussion, 9. Conclusion, 10. Recommendations, 11. References, and 12. Appendix.

Chapter 1`s main goal is to put the thesis` topic in context, explains its relevance and capture the reader's interest. Chapter 2`s main goal is to place the thesis in a larger context, usually the context is environmental among others as the themes must be linked to The UN's Sustainable Development Goals. Chapter 3`s goal is to present clarified, relevant, and sufficient knowledge background to shed light on the problem area. Chapter 4`s goal is to formulate the Research question with its relevant sub questions. Chapter 5`s goal is to elaborate on the materials and the case of the thesis. Chapter 6`s goal is to explain the methods used to solve the task thoroughly, and in such a detail that is possible to verify. Chapter 7`s goal is to objectively explain and present the result. Chapter 8`s goal is to show understanding of the results. The presented findings in chapter 7 Results must be discussed against findings from previous research which have been presented in the introduction, societal perspective, case, knowledge background and result. Chapter 9`s goal is to come with a conclusion based on the research question in chapter 4. Chapter 10`s goal is to present recommendations in relation to further work. The references used throughout the text can be found in chapter 11, and chapter 12 shows an overview of the appendixes.

2. Societal Perspective

In this chapter, the thesis is placed in a larger context, where the context and themes are linked to The UN's Sustainable Development Goals. Data and statistics that describe the current worldwide situation is presented, along with two Sustainable Development Goals thar covers this area.

2.1 Sustainable Development Goal 3

Air pollution is a critical environmental health issue in Europe, causing premature deaths and diseases such as lung cancer, stroke and heart disease [5]. According to the European Environment Agency, air pollution poses the most significant environmental health risk in Europe [6]. The latest available estimates suggest that 5.5 million premature deaths worldwide in 2013, or about one in every ten total deaths, were caused by air pollution [7]. Sustainable Development Goal 3 (SDG 3), pictured below in Figure 2-1, is focused on ensuring healthy lives and promoting well-being for all at all ages [8]. When discussing air quality, The SDG target 3.9.1 becomes relevant, which calls for a substantial reduction in deaths and illnesses from air pollution [9].

While buildings are supposed to provide shelter and protect us from outdoor pollutants, indoor environments can be twice as polluted as outdoor environments, according to the European Commission's studies on indoor air pollution [10]. The presence of hundreds of volatile components indoors has led to asthma in 20 percent of Europeans [10]. As humans spend a significant amount of time indoors, the indoor environment plays a critical role in achieving SDG 3. The European Research Commission reports that we spend approximately 85-90% of our time indoors, whether at home, school, work, or during leisure activities [10].

Furthermore, a significant number of workers and residents in commercial and residential buildings currently express dissatisfaction with the indoor air quality, which is directly linked to health issues at work [11]. As such, prioritizing indoor environmental quality (IEQ) in building design and operation is vital to ensuring the health and comfort of occupants. A study on the influence of IEQ on human health and productivity showed significant health and financial benefits of implementing IEQ in the built environment [11]. One way of doing this is through BIM-based design strategies and utilizing POE surveys.

BIM can play a crucial role in designing buildings that prioritize IEQ. BIM allows for the modeling of a building's systems and components to optimize their performance, reduce energy consumption, and optimize environmental comfort [12]. Utilizing POE surveys can also help identify areas that require improvement in terms of IEQ [13]. By addressing these areas, building owners and managers can improve indoor air quality and, consequently, the health and comfort of occupants.

Figure 2-1: SDG number 3: Good Health and Well-Being, image collected from [8]

2.2 Sustainable Development Goal 7

Optimizing building performance and reducing energy consumption is crucial now more than ever, as the buildings sector is responsible for one-fifth of the total delivered energy worldwide [14, p. 4]. From 2012 to 2040, global building energy consumption is expected to increase by 1.5% per year according to the International Energy Outlook 2016 [14, p. 11]. Buildings in Norway account for 40% of the overall energy consumption [15]. Without implementing measures to enhance energy efficiency in the building sector, there is a projected 50% increase in energy demand by 2050 [16].

Sustainable Development Goal 7 (SDG 7), pictured below in Figure 2-2, aims to ensure access to affordable, reliable, sustainable, and modern energy for all [17] Given that buildings are among the largest consumers of energy, achieving SDG 7 is closely linked to optimizing their energy performance, including their HVAC (heating, ventilation, and air conditioning) systems.

Figure 2-2: SDG number 7: Affordable and Clean Energy, image collected from [17]

HVAC systems are a significant contributor to a building's energy consumption and carbon emissions [18]. Older, oversized, or poorly maintained systems may use more energy than necessary, leading to higher costs of operation. Therefore, new management approaches are required to optimize the energy performance of HVAC systems in non-residential buildings [18]. By doing so, we can significantly reduce energy consumption and contribute to the achievement of SDG 7.

It is crucial to consider a building's thermal comfort and well-being when assessing its energy efficiency, especially in educational and office buildings where productivity is affected by the indoor climate [19]. Improving the energy performance of non-residential buildings towards ZEB while maintaining thermal comfort becomes considerably more challenging [19].

The basic principle of building energy efficiency is to use less energy without compromising the health and comfort of its occupants [20]. Improving the energy efficiency of functional buildings is an important step in minimizing their environmental effects [20]. It is possible to improve building sustainability and operational plans by implementing predictive, preventive, and corrective maintenance procedures based on occupant comfort evaluations [21]. In particular, there is a growing trend to use natural cooling and lighting methods rather than artificial ones in building design and operation [20].

BIM enables more accurate performance analysis and optimization of HVAC systems, allowing for energy savings by identifying inefficiencies and implementing targeted measures [22].
POE surveys can also be useful in assessing the actual performance of HVAC systems and identifying areas for improvement [23]. Building occupants can provide feedback on their thermal comfort and indoor air quality, which can be used to adjust HVAC settings or implement targeted improvements.

In conclusion, optimizing building energy performance, particularly in HVAC systems, is necessary to achieve SDG 7. This optimization must consider occupants' comfort and well-being, which can be achieved through predictive, preventive, and corrective maintenance procedures. Implementing BIM and POE can be effective ways to optimize the energy performance of HVAC systems in buildings [24].

3. Knowledge Background

This chapter introduces the most important theoretical background for this thesis. That includes the concept behind indoor environment quality and its many aspects, the post-occupancy evaluation, building information modeling, Dynamo, visual programming, Visual studio, and programming in C#.

3.1 Indoor Environmental Quality

Considering people spend most of their time indoors [10], it is important to understand how indoor environmental quality (IEQ) is influenced by various factors whose interdependencies, complexity, and dynamic nature are linked to health and productivity [11] IEQ refers to the quality of the indoor environment in terms of air quality, thermal comfort, lighting, acoustics, and ergonomics [25]. These factors play a crucial role in creating a comfortable and healthy indoor environment [26]. Research has shown that various factors related to the building's characteristics can have an impact on comfort and health, resulting in increased attention in both academic and professional literature regarding occupant health and building design [26]. Some studies have even suggested that minor discomfort symptoms stemming from the indoor environment can lead to a considerable decline in occupant work performance [26]. This chapter introduces the theory behind the different types of aspects of IEQ including indoor air quality, thermal comfort, visual comfort, acoustic comfort, and space adequacy comfort.

3.1.1 Indoor Air Quality

Air quality is a significant aspect of IEQ [25], as poor air quality can lead to respiratory issues and allergies [10]. Factors such as pollutants, humidity levels, and ventilation systems greatly impact the air quality indoors [26]. Adequate ventilation and air filtration are essential to maintain a healthy indoor environment. The development of occupant’s satisfaction surveys has been prompted by missing research on how the occupants react to the indoor air quality [26].

3.1.2 Thermal Comfort

Thermal comfort is another vital component of IEQ [25]. In order for individuals to maximize their productivity, it is crucial that their work environment provides them with optimal thermal comfort. Thermal comfort is affected by six factors, with four falling into the category of environmental parameters. These include air temperature, mean radiant temperature, air relative humidity, and air velocity. The remaining two factors are considered personal factors and encompass human metabolic rates and the insulation provided by clothing [25].

Furthermore, it is important to understand that acceptable temperature ranges are determined based on guidelines for IEQ [27]. However, it is worth noting that these guidelines may not align with what individuals personally find comfortable [7]. This is because people have different levels of sensitivity to temperature and other factors. Therefore, to truly enhance the comfort and productivity of occupants, it is crucial to involve them in the process by gathering their feedback and evaluating how well the building meets their needs. [27]

3.1.3 Visual Comfort

Visual Comfort (Lighting) is another important factor influencing IEQ, and therefore very important for the wellbeing and productivity for the occupants [26]. Visual comfort defines lighting conditions and Insufficient light, especially daylight or glare reduces the ability to see objects or details clearly. Sufficient natural and artificial lighting can enhance occupant well-being and productivity. Not only does visual comfort impact work but after work as well, with studies indicating that the quality of visual comfort impacts sleep quality of the occupants [26].

Lighting is crucial for creating a satisfying indoor environment and ensuring comfortable visual performance [28]. Inappropriate lighting can have noticeable effects on occupants, causing discomfort, eyestrain, and fatigue, which are commonly associated with sick building syndrome (SBS). It is important to provide suitable lighting conditions to prevent these negative consequences and promote the well-being of individuals in indoor spaces [28].

3.1.4 Acoustic Comfort

Acoustics also contribute to IEQ [25]. There is a direct link between unwanted noise, reduced concentration, and productivity [26] Although acoustic comfort is widely acknowledged as an important parameter, research indicates that it is often not given high priority in building design [26]. The acoustic element of designing commercial office buildings is of great significance [29]. Noise, which is often the primary cause of irritation in office environments, can lead to increased stress levels among occupants. However, acoustics are frequently not given the same level of design focus as thermal comfort, ventilation, and other architectural and engineering aspects [29].

3.1.5 Space Adequacy Comfort

Space adequacy refers to the level of comfort and functional quality provided by the work environment, which plays a crucial role in facilitating individual work and collaborative teams [30]. While physical comfort in the workspace is well-regulated, functional comfort, which supports people's tasks, lacks established standards and practices. Nonetheless, research indicates that an environment that effectively supports individuals' tasks enhances their overall productivity [30].

Functional comfort is instrumental in enabling workers to interact efficiently with their surroundings [4]. Occupant satisfaction in terms of space adequacy is influenced by various factors, including the size of the space, its aesthetic appearance, the furniture present, and its cleanliness. Incorporating ergonomic furniture and designated enclosed rooms for meetings and collaborative work are examples of measures that contribute to users' functional comfort in the workplace [4].

3.1.6 Sick Building Syndrome

Sick Building Syndrome (SBS) is a condition recognized by the World Health Organization [28]. It refers to a range of complaints that people experience when they occupy certain modern buildings. The symptoms of SBS are not specific and can include feelings of discomfort, such as eye, nose, or throat irritation, as well as skin problems and more [28].

SBS can have serious consequences, including reduced productivity [28]. According to the article [28] , many people suffering from SBS have reported a decrease in productivity of up to 20%. The main causes of SBS are often related to poor air quality and ventilation systems in the building. Other factors that can contribute to SBS include noise, artificial lighting, occupant control, workplace cleanliness, stress, and psychological effects. Noise in the building can also impact SBS, but its effects vary from person to person. Factors such as psychological and physiological differences determine whether noise is disturbing or annoying to an individual [28].

3.1.7 Comfort of Occupants and Building Performance

The comfort and well-being of building occupants can sometimes clash with the performance objectives of the building [26]. For instance, improving energy efficiency often involves sealing the building envelope tightly and reducing ventilation rates [26]. While this positively impacts the building's energy efficiency, it can compromise the well-being of occupants. Adequate ventilation rates are necessary to maintain a healthy indoor environment. Unfortunately, this conflict is often resolved in favor of building efficiency rather than occupant well-being [26].

However, it's crucial to consider that personnel costs, including salaries and benefits, typically exceed the operating costs of an office building [30]. Strategies that prioritize employees' health and productivity can yield significant returns on investment in the long run. In this context, IEQ goals aim to provide occupants with stimulating and comfortable environments while minimizing the risk of building-related health issues [31] To ensure that the needs and preferences of building occupants are effectively addressed, it is important to gather their opinions and feedback.

3.1.8 The Effect of Control

The satisfaction of building occupants with the indoor climate is closely linked to their level of control over it and their perception of the impact their actions have [32]. Studies have found a strong association between occupant satisfaction with thermal conditions and their ability to intervene and adjust the indoor climate. Seasonal variations further contribute to occupant satisfaction with room temperature. In particular, the potential for successful interventions tends to be higher during winter when there is a greater temperature difference between the indoor and outdoor environments. As a result, occupant satisfaction with room temperature tends to be lower in summer surveys, where the temperature differential is smaller [32]

Occupants who have the ability to adjust their thermal settings often report feeling more comfortable [30]. However, it is noteworthy that only a small number of buildings or workstations allow occupants to control lighting, temperature, ventilation rates, or noise levels. Despite the availability of such technologies, personal comfort systems have not gained popularity in the market. Nonetheless, research demonstrates that providing occupants with personal control over their environment leads to significant increases in comfort and work performance [30].

The presence of control, whether it involves physical environmental factors or aspects of job-related decision-making, is associated with higher levels of job satisfaction and psychological comfort [30]. Studies support the notion that allowing workers some degree of personal control over ambient physical conditions, such as temperature, lighting, and noise, contributes to their comfort, happiness, and overall productivity [30].

3.1.8 Facility Management

Facility Management (FM) is a critical component of ensuring the efficient operation of buildings [33]. It is estimated that FM accounts for more than 85% of the life-cycle cost of a typical facility, and the life-cycle costs can be significantly higher than the initial investment costs. In essence, FM is a profession that integrates various disciplines to ensure the functionality of the built environment by considering people, place, process, and technology [33].

Smart facility management recognizes the importance of considering occupants' perceptions and experiences alongside physical building performance [33]. This forward-thinking approach involves implementing real-time, context-aware POE and BIM systems. By incorporating these innovative technologies, a holistic FM system can be developed to meet the evolving needs of building management and help in planning for the future [33]. Facility managers can use POE to provide input during the planning and design phases, gather feedback from occupants, identify performance problems, improve future facilities based on feedback, and document data for legal purposes [34].

3.2 Post-Occupancy Evaluation

Currently, the assessment of indoor environmental quality (IEQ) in buildings involves two strategies: post-occupancy evaluation (POE) and measurement using instruments [11]. User surveys, combined with in-situ measurements, are the most common sources of information for POEs [35].
This thesis primarily focuses on POE surveys as a means of evaluating IEQ. In the following subchapter, the theoretical framework underlying this methodology will be presented.

Extensive research has been dedicated to analyzing indoor environments and determining the factors that contribute to a comfortable setting [27]. This research has resulted in the development of various methodologies and tools for evaluating the performance of buildings [27]. POE is a general approach to obtaining feedback about the building's performance during its use, including energy efficiency, IEQ, occupant satisfaction, productivity, and others [36]. Buildings undergo assessment after occupancy to determine how well they fulfill occupants' needs, including aspects such as visual comfort, acoustic comfort, thermal comfort, indoor air quality, and room size adequacy [27].

Traditionally, POE has primarily concentrated on assessing technical aspects of building performance, such as heating, ventilation, and air conditioning systems, as well as physical indoor conditions [33]. However, it is crucial for POE to extend its scope to encompass the impact of technical building performance on occupant health and comfort. The purpose of the evaluation is to identify disparities between performance criteria and the actual performance of the building. By doing so, it offers valuable insights into the implications of past design decisions. This knowledge serves as a solid foundation for improving future building projects, influencing the development of codes, standards, and design choices [33].

POE has the potential to bring about several benefits if conducted effectively [37]. It can support occupant satisfaction and productivity by validating their actual needs, ensuring that services are tailored to their preferences. Additionally, it can contribute to increased organizational efficiency by reducing ownership and operational expenses, as well as minimizing waste in terms of space and energy usage. However, despite the potential advantages, there is often a gap between the rhetoric surrounding POE and its practical implementation. Designers rarely assess the outcomes of their design decisions, and POE is typically not included in the standard planning process [37].

To address this issue, it is crucial to start evaluating buildings immediately upon occupation [37]. By conducting evaluations from the outset, the quality of user experiences within the building can be significantly enhanced. Such evaluations also provide an opportunity for all parties involved to learn from past mistakes or deficiencies, promoting continuous improvement in future building projects. It is through this continuous learning process that performance improvement can be achieved, benefiting both occupants and building stakeholders [37].

3.2.1 SurveyXact

Software plays a crucial role in the process of creating, distributing, and analyzing POE surveys. One such software that fulfills these requirements is SurveyXact, developed by Rambøll [38]. Rambøll is a globally recognized engineering, architecture, and consulting company that originated in Denmark in 1945 [39].

SurveyXact is a self-proclaimed leading tool in Scandinavia for creating questionnaire-based surveys [38]. Apart from its survey creation capabilities, SurveyXact offers functionalities for survey distribution, data monitoring, and report generation, all within the program itself. The software provides extensive customization options, allowing users to tailor various aspects of the survey to their specific needs. Furthermore, SurveyXact adheres to Google's standards for intuitive and user-friendly design, ensuring a seamless and accessible user experience [38].

3.3 Building Information Modeling

Building Information Modeling (BIM) is a digital representation of a facility that captures its physical and functional characteristics [40]. It serves as a shared knowledge resource, providing reliable information for decision-making throughout the facility's life cycle, from conception to demolition. The essence of BIM is collaboration among stakeholders at different stages of the facility's life cycle, allowing them to insert, extract, update, or modify information to support their respective roles [40].

The introduction of BIM technology has significantly transformed the design and construction process [41]. By creating a centralized database based on an information model, BIM facilitates seamless interaction among project participants, reducing collisions and the need for corrections and adjustments. This has led to increased efficiency in the construction industry [41].

Continual improvements are being made to BIM programs by developers to meet evolving user needs [41]. New tools are constantly being developed and updated to enhance productivity and streamline workflows. Automation features, such as add-ins that automate repetitive tasks, are being introduced to save time and improve efficiency [41].

However, the use of automation tools in BIM requires specific skills, particularly programming skills, which are often lacking among designers in the construction field [41]. This presents challenges in mastering the technology and leveraging automation tools. To address this, software developers have integrated visual programming languages and scripting capabilities into BIM programs, making them more accessible and user-friendly [41].

Despite BIM's widespread adoption in the architectural, engineering, and construction industry, its use in FM by owners has been slow to progress [33]. The limited adoption of BIM in FM suggests a lack of awareness among owners and FM personnel regarding the requirements for BIM use. Additionally, the absence of demonstrative case studies has contributed to the slower adoption rate. To fully realize the benefits of BIM in FM, increased awareness, education, and the provision of practical examples are crucial for encouraging wider adoption and integration of BIM in FM practices [33].

3.3.1 Autodesk Revit

Revit is a BIM software developed by Autodesk, a software development company [42]. The software was originally developed in 1997 by Charles River and acquitted by Autodesk in 2002 [42]. Revit is, according to Autodesk, "a BIM software helps architecture, engineering, and construction (AEC) teams create buildings and infrastructure and can unite multidisciplinary project teams for higher efficiency and collaboration. [43]. The software is primarily used for 3D modeling and renderings of building designs. Revit supports add-ins such as Dynamo and makes for a powerful tool across different disciplines [42].

Revit is a commonly used program that implements BIM technology and has an application programming interface (API) that allows to integrate add-ins created in any programming language that supports the NET. Platform, such as C# [41]. In addition to this, Revit has Dynamo, a visual programming module that allows you to work with the model in real time, with a community of users and developers that constantly creates new tool packages and shares them [41].

3.4 Dynamo

3.4.1 General Information

Dynamo is a powerful tool developed by Autodesk that works together with Revit to streamline AEC workflows [44]. Released in 2011 [45], it was designed to provide an accessible way for users to script without the need for extensive programming knowledge [44]. While Revit alone creates a robust project-based database, it can be challenging for average users to access the information outside the constraints of the interface. However, Revit's host application program interface (API) allows for the creation of custom tools by third-party developers. Despite this, text-based scripting isn't easily approachable by everyone, and this is where Dynamo comes in [44].

Dynamo's node-based graphical programming language uses a combination of text input/output and visual representation to build complex algorithms and processes [44]. One of the advantages with using Dynamo is that the user does not have to be fluent in more complex coding languages, such as Python or C# [46]. The platform, can amongst other things, automate tedious workflows while enabling design explorations [44]. One of the most helpful aspects of Dynamo is the “watch” and “watch3D” nodes, which can be placed in the script to inspect the output of a specific node or a branch of nodes [47].

Being an open-source programming tool [44], anyone can access the original source code and create third-party toolsets called "packages" to extend Dynamo's core functionality [48]. This makes it a versatile tool that can adapt to a wide range of needs. By leveraging these packages, users can automate even more workflows and create custom solutions for their specific needs [48]. Moreover, Dynamo's visual programming interface allows for collaboration amongst users [46]. By sharing scripts and packages, users can build upon each other's work and create a shared library of tools. Dynamo's open-source nature also means that it is constantly evolving. The community of users and developers actively contributes to the development of the platform, creating new nodes, packages, and workflows. This could promote a sense of community and innovation within the AEC industry [46].

3.4.2 Visual Programming

Visual programming languages utilize graphical elements, such as blocks and wires, to create software programs [49]. Instead of typing code into a text editor, like C# and other popular programming languages, visual programming languages rely on flow diagrams as the program itself. This approach differs significantly from text-based programming languages commonly used in other disciplines. Examples of visual programming languages include Grasshopper and Dynamo. Dynamo, in particular, holds great promise as a constructive tool that complements BIM, 3D modeling, and analysis programs. It offers parametric geometries and seamlessly integrates with Revit, a leading BIM software [49]

In a study focused on teaching computer programming to adult learners, it was found that 20% of beginners preferred using real language to understand programming, 40% favored flowcharts, and another 40% preferred pseudo code [50]. Notably, all participants expressed a desire to see a sample of the program's result in executable (EXE) form, enabling them to visualize the program's appearance and functionality. These findings affirm the notion that starting with visual programming is more advantageous than diving straight into coding [50]

3.3 Visual Studio

3.3.1 General Information

Visual Studio is a integrated development environment (IDE) developed by Microsoft [51]. Released initially in 1997, Visual Studio has evolved over the years with Visual Studio 2022 released on February 15 2022 [51].

3.3.3 Plug-ins vs Add-ins

Plug-ins and add-ins refer to software extensions that enhance the functionality of a program [52]. These extensions can be created by the software maker or by third-party developers. While the terms plug-in and add-in are often used interchangeably, plug-ins are typically associated with third-party software that interacts with a specific program, while add-ins are designed to modify the interface of a particular program. Most add-ins are merely pieces of code that allow you to customize the interface and are not full-fledged programs. Although there is some overlap between plug-ins and add-ins, they are generally created to perform specific functions that cater to the user's preferences. One reason why these codes are not included in the program from the outset is that they may not be essential, and some users may find them unnecessary. These tools can also motivate members of a software community to contribute to the development and improvement of the program [52]. In the context of this thesis a Revit Add-In is a tool using a coding language, for example C#, and is created using a manifest file (.addin) and one or more DLLs [53].

3.3.4 Add-in Manifest

An add-in manifest is an Extensible Markup Language (XML) file located in specific location on the hard disk. It can be applied to either a specific user or all users [54]. For both an external application and an external command, certain required tags must be specified, including "Assembly", "FullClassName", and "ClientId". In the case of an external command, the Text and Description tags are also utilized [54]. The initial line of a basic manifest declares the XML version and encoding used in the file [55].

The manifest contains an assembly, which represents the full path to the add-in assembly file [56]. It also includes a FullClassName, which denotes the name of the class in the assembly file that implements the IExternalCommand interface. Another component of the manifest is the AddInId, which is a GUID representing the ID of the application. Although not always mandatory, it is common to include a "Name," "Text," and "Description" in the manifest. The "Name" refers to the application's name, the "Text" represents the name of the button, and the "Description" provides a brief explanation of the command. The "VisibilityMode" allows for specifying the documents in which the command will be visible, with the option to set multiple values. Additionally, there may be a "VendorId" and "VendorDescription" present. The "VendorId" serves as a unique identifier for the vendor, potentially used in certain Revit operations. The VendorId must be distinct, and the "VendorDescription" provides a description of the "VendorId," although it is often an optional component [56].

3.2 Application Program Interface

An add-in doesn't work with every program, it needs an API [57]. This means that the program needs a sort of docking point that you can dock into from the outside and exchange data. In Revit`s instance, it has a Revit core software but also an API that makes it possible to exchange data between the core software and new code/programs [57]. API stands for application program interface, and this interface allows for the creation of custom tools by third-party developers in Revit [44] These often involve text-based programming languages such as C#. An add-in is typically produced in C# and Visual Studio using Revit API [58]. Revit APIs run on the .NET framework [59] which is a software development framework for building and running applications on Windows [60].

3.4 Programming in C#

C# is a programming language created by Microsoft and is a simple and versatile language that belongs to the C family [51]. C# was designed by Anders Hejlsberg in 2000 [51] and the latest version is C# 11.0, released in 2022 [61]. It runs on the .NET Framework and is used to build different types of applications like desktop apps, web apps, mobile apps, and games [51]. C# has gained a lot of popularity in recent years and has become one of the most widely used programming languages [51]. This chapter explores important aspects of coding with C# in the context of developing Revit add-ins in Visual Studio.

3.4.1 Namespace

In C# projects, it is common to use the "using" keyword at the beginning of the code [62]. This is because different libraries may have classes with the same name, which can lead to confusion and conflicts. To address this, .NET introduces namespaces, which organize classes logically and make it easier to identify the specific class you want to use. The "using" keyword acts as a directive, instructing the C# compiler to make the contents of a particular namespace available for use in the current code file [62].

3.4.2 Classes

A class in C# is a sort of a description of a representation of a thing or an individual object [62]. A public class is a class that is accessible from other classes in the add-in as well as other Visual Studio projects that reference the add-in. Classes define the properties and actions that an object of that type can have, providing a structured way to represent data and behavior [62].

3.4.3 External Commands and Applications

To extend and interact with Revit using the Revit API, developers need to implement specific interfaces in their add-ins [63]. These interfaces include IExternalCommand. The IExternalCommand interface is provided by the Revit API to enable developers to extend Revit through external commands. When Revit is not executing any command, loading a command through the Add-in Manager triggers the associated program within Revit, activating the IExternalCommand. Once activated, the Execute function is executed, which should return "Autodesk.Revit.UI.Result.Succeeded" to indicate successful execution. If the execution is not successful, all operations and modifications made by the program are revoked [63].

To create an external command, an object must be created that implements the IExternalCommand interface [64]. This interface includes one abstract method called Execute, which serves as the main method for external commands. The ExternalCommandData object contains references to the Application and View, which are necessary for the external command. All Revit data is retrieved directly or indirectly from this parameter within the external command [64].

3.4.4 Methods

In object-oriented programming, a method refers to a block of code within a class that performs a specific task or [62]. In the context of Revit add-ins, the Execute method is of particular importance. The Execute() method is the main method for external commands and requires three parameters: commandData, message, and elementSet [62]. Let's examine each of these parameters in more detail:

1. The commandData parameter, of type ExternalCommandData, grants API access to the Revit application [62]. By utilizing the application object, it can retrieve information about the command, such as the application and document objects. The document object provides access to the active document in the user interface and its corresponding database. Essentially, all Revit data, including that of the model, can be accessed through this commandData parameter [62].
2. The message parameter is a string parameter that includes the ref keyword, allowing for modification within the method implementation [62]. This parameter is used to display a message to the user. In the case of a failed or canceled command, the external command can set this message. When the Execute() method returns a failure or cancellation result, Revit displays an error dialog containing the specified message [62].
3. The elements parameter, of type ElementSet, enables the selection of elements to be highlighted on the screen in the event of a failed or canceled external command [62]. This parameter provides the flexibility to choose specific elements for highlighting purposes [62].

By utilizing the Execute() method and its parameters effectively, it is possible to interact with the Revit application, display informative messages, and manipulate elements within the project.
[62].

3.4.5 Results

In the context of Revit add-in development, the Execute() method is expected to return a Result object, specifically an Autodesk.Revit.UI.Result, instead of being declared as void (not returning anything) [62]. The Result returned from the Execute() method provides information to Revit about the execution status of the command, indicating whether it succeeded, failed, or was canceled [62].

3.4.6 Globally Unique Identifier

A Globally Unique Identifier (GUID) is a 128-bit number that is used to uniquely identify an object or entity in a computer system [65]. It is a string of hexadecimal digits that is generated according to certain rules and is intended to be unique across all devices and systems. A GUID can be used for many items, and the term is often used in software created by Microsoft [65]. In the context of Revit and Visual Studio, a GUID is often used to identify add-ins and other extensions [66]. When you create a new add-in project in Visual Studio, a GUID is automatically generated for the project and is used as the unique identifier for the add-in. This GUID is then registered with Revit when the add-in is loaded, allowing Revit to identify and execute the add-in when necessary [66]. The GUID represents the id of the particular application [67]. Because the AddInId must be unique for a given session of Revit, Autodesk recommends you generate a unique GUID for each registered application or command [67].

3.5 Dynamo vs Revit Add-in

In this chapter the pros and cons with using Dynamo and Revit Add-ins are described and compared.

Dynamo, as a visual programming tool, offers the advantage of not requiring a coding background, making it accessible to users with various skill levels [53]. An easy learning curve allows for fast development and utilization. Furthermore, being open source, Dynamo benefits from a wealth of available content. However, the use of connection lacing between nodes in Dynamo can sometimes result in disorganized-looking scripts that are challenging to read. Additionally, Dynamo may not be the most efficient computing language [53]. Performing complex algorithms with a high number of nodes in Dynamo, especially when accessing external files, can be more time-consuming and demanding for both the computer and the Revit software compared to using an add-in with program code [41]. This drawback becomes apparent when there is a continuous exchange of data, such as when working with sensor data [41]. Maintenance is also required for Dynamo scripts when updating the program, as nodes can become outdated, and error feedback is not always descriptive [53]. Furthermore, script reuse may be limited due to its project-specific nature [53].

On the other hand, Revit add-ins offer the ability to utilize Revit API Events, enabling actions to be triggered while Revit is running [53]. The use of a smart code editor, such as Visual Studio, ensures efficient tools and faster computing times. Revit add-ins provide complete control over the code logic, which, in certain cases, can be more efficient than using packages and nodes in Dynamo. They also offer robust error handling and clear messages for debugging purposes. However, learning a coding programming language like C# can be time-consuming, requiring a deeper understanding of the Revit API and posing a challenge for beginners. Writing code for Revit add-ins can also be more time-consuming than connecting nodes in Dynamo in certain situations. Another drawback is that any logic changes made in the code of a Revit add-in necessitate restarting Revit, whereas in Dynamo, rapid logic changes can be made without restarting the program. Additionally, digital signing of the Revit add-in is required to avoid warning messages appearing each time Revit is launched [53]. However, an advantage of add-ins is that the results are compiled into a program, protecting the work from unauthorized access [58]. This feature allows programmers to sell their add-ins to others [58].

In conclusion, both Dynamo and Revit add-ins offer distinct advantages and drawbacks in their use for BIM.

4. Research Question

In this chapter, the research question in this master's thesis is presented with related sub questions and limitations. The research question is based on the problem area introduced chapters 1 and 2.

4.1 Research Question

The main research question of this thesis is formulated as follows:
What are the main factors that contribute to discomfort for building occupants, and how can they be identified, visualized, and communicated using a combination of Post-Occupancy Evaluation surveys, Dynamo and Revit-add-ins?

4.1.1 Sub-Questions

The sub-research questions presented below serve as a means to address the main research question while also expanding the scope of the investigation.

A. What are the predominant factors contributing to occupant discomfort in buildings?

B. How can post-occupancy evaluation be effectively employed to assess the comfort levels of building occupants and identify the root causes of their discomfort?

C. How can BIM and Dynamo be utilized to effectively visualize and communicate the outcomes of post-occupancy evaluation surveys?

D. How can sensor data information be displayed within BIM using Revit add-ins?

E. What are the advantages and disadvantages of utilizing Dynamo, and Revit add-ins for data visualization?

4.1.2 Limitations

To establish the boundaries of the work and thesis, the following limitations have been imposed:

- The analysis of the POE and the BIM model does not include information about the building envelope, materials, and technical aspects of HVAC systems.
- Personal information of occupants, such as gender and age, is limited and not analyzed to respect privacy concerns.
- The examination of comfort criteria is primarily focused on workplace environments, particularly office spaces.
- Although various tools are available for data visualization in BIM, this thesis specifically concentrates on Dynamo with visual programming and Visual Studio for creating a Revit add-in using C# language.

5. Case and Materials

Chapter 5, "Case and Materials" is divided in two sections. Section one describes the case used for this thesis, and section two describes the materials needed to execute the method. The materials consist of software programs needed to execute the POE survey, and the BIM visualization.

5.1 Case

The occupants that are being surveyed in this thesis are employees of the Department of Engineering Science inhabiting office spaces in the C, D and H building at the University of Agder (UiA), campus Grimstad. UiA has two campuses, campus Kristiansand and campus Grimstad. Figure 5-1 depicts the structure of the organization UiA [68]. On these two campuses there are 6 facilities plus the teacher education unit, 23 departments and about 14.096 students [69]. The "Faculty for Engineering and Science" has 4 departments, where one of them, the department of Engineering science has 161 employees according to UiA's webpages [70], but how many of them that are currently inhabiting office spaces are unknown.

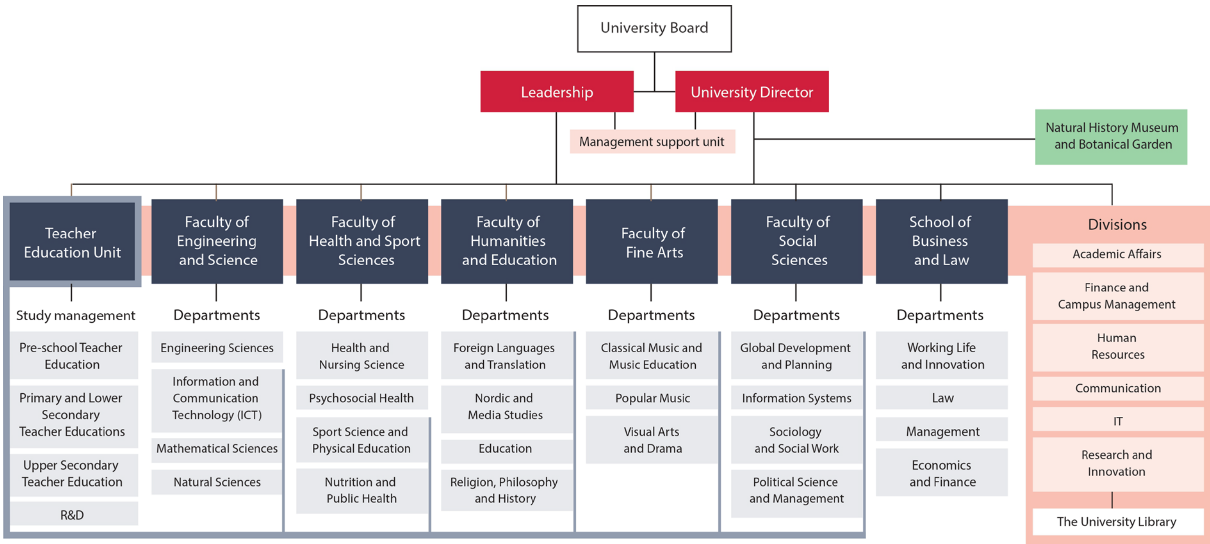

Figure 5-1: The organization structure of UiA [68].

Campus Grimstad has about 3500 students and 350 employees [71]. The campus originally consisted of a building mass of 27,000 square meters, where several new buildings and facilities has been built after the opening in 2010 [72]. The campus is dived into sections raging from A to P [73]. Figure 5-2 below shows the campus divided into sections, a figure that is retrieved from the FM of the campus. According to UiA department webpages, most of the employees of the Engineering science department has office spaces in building C, D and H [70].

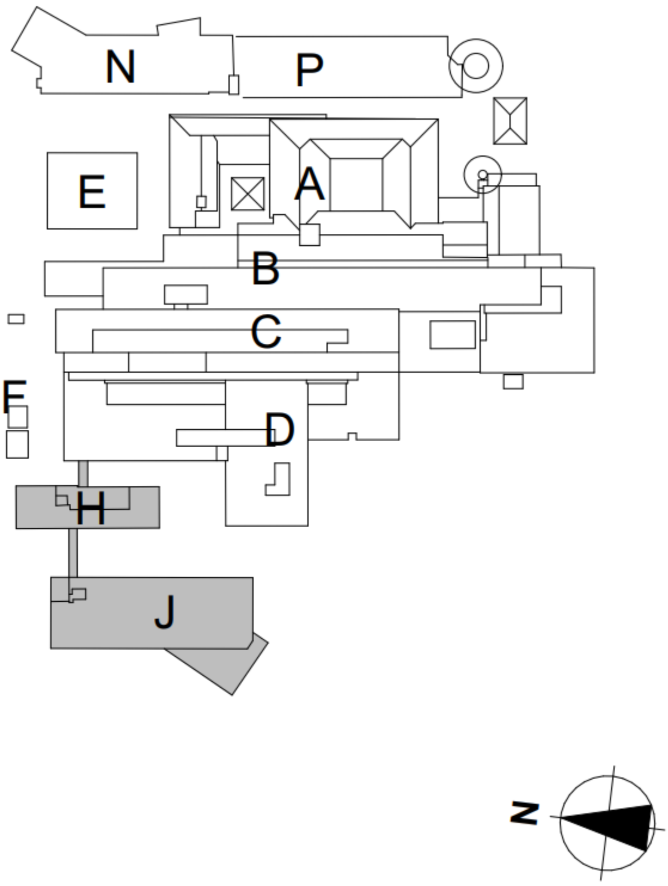

Figure 5-2: Campus Grimstad divided into sections, received from the FM.

The department of engineering science mainly have offices in building C floor 4 and 5, building D floor 2 and 3 and building H floor 4 and 5 [70]. It is the occupants inhabiting the offices in these sections that is the case for the POE survey and BIM visualization.

5.2 Materials

To be able to create a POE Survey and visualize it through a BIM model, certain software is needed. These materials are described in this subchapter.

5.2.1 SurveyXact

Software is needed to create the POE survey, distribute it, and analyze the results. SurveyXact is a software that can be used for this. Students and employees at UiA can utilize SurveyXact free of charge because a data processing agreement exists between UiA and Rambøll Management in accordance with the Personal Data Act and the Personal Data Regulations [74].

5.2.2 Excel

Microsoft Office 2016 Excel is used to store data from the POE survey. Excel is a part of the free office package for UiA students.

5.2.3 Autodesk Revit

To create a model a BIM software is needed. Autodesk Revit is used in this thesis, and Revit 2022 Is free when using a student license [75].

5.2.4 Dynamo

Dynamo 2022 is visual programming software used to import and color rooms in Revit in this thesis. Dynamo is already a part of Revit, which means that there are no additional licenses needed other than the Revit one.

5.2.5 Visual Studio

Another programming software was used to import sensor data to the Revit model. Visual Studio 2022 was used for this purpose, and can be downloaded on Microsoft's pages for free when using the community version and student license [76]

6. Method

The methodology in this thesis is described in this chapter, along with the tools and resources needed. The main methodologies used in the thesis to answer the research question is a literature study, a POE survey, visual programming, and some C# programming together with building a model in Revit. The method chapter is divided in subchapters depicting the process from start to finish in appropriate themes. These subchapters include the initial actions and planning, but also how the guidance was organized, the literature study, the POE survey and the use of BIM and its programming tools, and the compiling of the thesis report. Knowledge needed to understand and execute the method is found under chapter 3 Knowledge Background.

6.1 Progress Plan

A progress plan was established early to properly organize the necessary task to complete the thesis. The plan also needed to include estimated workload per task. It was deemed practical to divide the plan into weeks since the total timeframe is only a few months. A tool called Microsoft Project was used to create the progress plan, and the finished plan was delivered to the master course administrator some time after the start of the project. The progress plan file can be found in appendix 12.5 Progress Plan.

6.2 Guidance

There have been guidance meetings with the project's advisor from UiA throughout the process. The guidance meetings consist of physical meetings at the university's location in Grimstad, where the objective is to update the advisor on progress and discuss aspects of the thesis. Simple questions that arise between the meetings where either saved for the next meeting or communicated over email. Meeting minutes was written during and after the meetings and a copy was sent to all participants. It was initially planned to have a guidance meeting every two weeks, unless the participants felt a longer time in between was necessary.

6.3 Literature Study

The scope and focus of the master thesis were determined in collaboration with the thesis supervisor. To gain a comprehensive understanding of the topic and identify key areas of focus, an initial Google search was conducted. Broad keywords such as "post-occupancy evaluation," "BIM Visualizations," and "Comfort criteria" were used to gather an overview of the subject and pinpoint important aspects for further exploration.

To ensure timely survey responses, existing literature on POE surveys was reviewed. This involved examining how others have utilized these surveys on platforms like Google Scholar and Science Direct. This literature review facilitated the quick design and distribution of the survey, ensuring an adequate number of responses for the data analysis.

As knowledge increased, the search terms became more specific and targeted. Terms like "Sources of discomfort office building occupants," "Revit, BIM, POE," "Revit, add-in, display data" and "Revit, dynamo, display data" "Dynamo, color, BIM, POE" were used to explore relevant literature on Google Scholar and Science Direct. Additionally, YouTube tutorials were consulted to gain practical insights and a basic understanding of tools such as Dynamo and Visual Studio.

The literature research focused on finding previous studies on specific topics: 1) Sources of Discomfort for Building Occupants, 2) Using POE to Find Sources of Discomfort for Building Occupants, and 3) Using BIM Tools to Visualize POE Data. Google Scholar and Science Direct were relied upon to locate relevant articles. Three initial articles suggested by the supervisor served as a starting point: "A probabilistic-based approach to support the comfort performance assessment of existing buildings" [4], "Digital Twin framework for automated fault source detection and prediction for comfort performance evaluation of existing non-residential Norwegian buildings" [27], and "Enhancing occupants' comfort through BIM-based probabilistic approach" [3]. The resources cited in the suitable articles were explored to expand the research.

In the knowledge background chapter, a responsive literature study was conducted whenever new topics requiring explanation emerged. Sources from Google Scholar and Science Direct were consulted to provide scholarly insights. For certain subjects, particularly coding-related aspects, Google was utilized as a helpful resource when scientific journals did not comprehensively cover every detail.

No strict limitations were imposed on the literature search regarding publication dates, years, or geographical boundaries. The focus was on selecting relatively new articles from credible and peer-reviewed sources. This approach reduced the risk of overlooking important information. Although the process of gathering and analyzing literature was extensive and time-consuming, it significantly reduced the likelihood of omitting research and literature that could have influenced the project's findings and conclusions.

By following these research methods, utilizing various platforms, and applying source criticism, a comprehensive understanding of the relevant literature was achieved. This approach laid a strong foundation and facilitated an in-depth exploration of the selected topics.

6.4 Post-Occupancy Evaluation

A questionnaire survey consisting of three sections was developed to collect occupants' feedback. This chapter describes the method behind the POE survey, including the decision process, the NDA, the creation of the survey, the structure of the survey, the methods of distribution, the data analyzing and the results interpretation and presentation.

6.4.1 Decision Process

To identify the primary sources of discomfort for the building occupants in the Department of Engineering Science, a Post-Occupancy Evaluation (POE) survey was conducted to gather input directly from the occupants. Considering ease of implementation, an online survey format was chosen as the preferred method. The survey primarily aimed to assess the comfort levels reported by the occupants in their office spaces and understand the reasons behind their discomfort, based on a predefined list of potential factors. Although the survey did not specifically address aspects such as productivity, its main emphasis was on gathering occupants' self-assessment of comfort levels and identifying the reasons for their discomfort.

SurveyXact was used to create the survey, analyze the result, and make charts and tables from the result. All this was possible within the same software. By implementing the POE survey through SurveyXact it was possible to gain a direct input hear from the occupants themselves about what was making them uncomfortable in their office spaces based on IEQ. The online survey allowed occupants to conveniently access and complete it at their preferred time, potentially resulting in a higher response rate and more comprehensive data collection.

6.4.2 The Norwegian Center for Research Data

In order to investigate the sources of discomfort for building occupants, it was necessary to apply to the Norwegian Center for Research Data (NSD) to ensure the protection of respondents' privacy. The NSD is actively involved in national and international projects aimed at coordinating and developing services related to data handling, archiving, and sharing of research data [77]

Fortunately, the thesis supervisor had previously conducted a similar POE study and obtained permission to carry out research between August 1, 2020, and July 30, 2023. Based on this prior approval, the supervisor recommended using the same survey and utilizing the existing research permission from the NSD. This decision proved to be a significant time-saver for the current project, as the application process for such permissions can be lengthy and time-consuming.

For reference, the acceptance letter from the NSD, granting permission for the research, is provided in appendix 12.6 Letter from the Norwegian Center for Research Data. This document serves as validation of the obtained authorization and confirms the commitment to upholding ethical considerations and safeguarding data privacy regulations.

6.4.3 Creating the Survey

Supervisor Haidar Hosamo provided a template to the POE survey in relation to the paper "Digital Twin framework for automated fault source detection and prediction for comfort performance evaluation of existing non-residential Norwegian buildings" [27]. The structure and content of the survey are very similar to other POE surveys, like the one used in paper "A probabilistic-based approach to support the comfort performance assessment of existing buildings" [4] and paper " Enhancing occupants' comfort through BIM-based probabilistic approach" [3]. Having similar content and rating systems with the comfort criteria aspects makes it easier to compare data with other research on the same topic. It was therefore decided not to deviate much with the contents and structure of the provided POE survey except for some modifications needed to fit the purpose of the thesis.

6.4.3 The Structure of the Survey

This subchapter provides an overview of the contents on the POE survey the occupants received. The survey was divided into 3 sections where section one consisted of general questions about the occupant's workplace situation, section two consisted of questions regarding their level of satisfaction with the workplace, and section three are question regarding their level of satisfaction with the common spaces they spend the most time in. Before the sectioning starts the recipients of the survey are given information about the survey, the use of the data relating to it and contact information for further questions.

First up is section one which included the following questions:

- 1.2. Please write the room number where you work
- 1.3. Please specify the number of office space in the same room
- 1.4. Please specify the number of people working in the same room (with Corona)
- 1.5. Please specify the number of people working in the same room (without Corona)
- 1.6. How long have you been working in this building?
- 1.7. Which of the following do you personally adjust or control in your workspace? (Check all that apply)

Section two is called "Satisfaction with the workplace" and consist of question where the occupants are prompted to rate their level of satisfaction relating to different comfort criteria. The occupant can rate the aspect on a scale consisting of very dissatisfied, dissatisfied, neutral, satisfied, very satisfied, and not applicable. The question in section 2.1 is formulated as following "Indicate the degree of your satisfaction in relation to the different aspects of your workplace". The aspects are temperature comfort in summer, temperature comfort in winter, indoor air quality in summer, indoor air quality in winter, visual comfort (light level), acoustic comfort (noise level), and space adequacy (room size).

Section 2.2 are follow-up-questions for the occupants that are dissatisfied with the comfort criteria aspects. Section 2.2 is formulated as following "If you are dissatisfied, which of the following contribute to your discomfort regarding:". This is repeated for all the comfort criteria aspects with a suggested list of reasons for discomfort. In addition to the suggestions, the "other" option is available with a text box. For temperature comfort the following reasons for discomfort are suggested: always too hot, often too hot, occasionally too hot, occasionally too cold, often too cold, and always too cold. For temperature comfort the following reasons for discomfort are suggested: the air is stuffy, the air is dry, the air is humid, there are disturbing odors. For light level the following reasons for discomfort are suggested: glare of sunlight, lack of daylight, dark, impossibility to control light, low level of artificial light, high level of artificial light. For room size (room adequacy) the following reasons for discomfort are suggested: quantity of space (m^2), circulation space, privacy, ergonomics of chair and table, availability of equipment (furniture, printer, etc.), and lack of flexibility.

Section 3 regards the satisfaction with the common spaces. The survey prompts the occupant to specify which laboratory, conference room, and lunch facilities they spend most time in. It follows the same pattern as section 2, prompting the occupants to rating their satisfaction of comfort aspects with the common spaces. The survey ends with an open text box question asking the occupant to add any information they think have been missed in this survey.

6.4.2 Methods of Distribution

The survey was distributed using different methods. This included contacting the head of the different subdepartments within engineering science on e-mail, to get help distributing the survey to the right employees. The survey was also sent directly to the relevant employees by e-mail and by visiting the employees` office on site. The e-mails were obtained by UiA's webpages [70], and from contact information listed on the office doors.

6.4.3 Data Analyzing

This subchapter describes the data analyzing that was done in the aftermath of the POE survey, what data was included in the further research and why.

In order to analyze the data, the Norwegian version of the survey was translated and merged with the English version. However, it should be noted that there were respondents who did not complete the entire survey. Those who did not finish section 1 and 2 were excluded from the data analysis due to insufficient information. Additionally, some rooms had multiple respondents, which is understandable considering that certain office spaces accommodate more than one occupant. To ensure consistency and compatibility with the BIM visualization in Dynamo discussed in 6.6 Dynamo, only one response per office space was included in the results. This decision was made because the current script in Dynamo can only visualize data from a single occupant per room at a time. Properly representing shared office spaces would require a more complex survey approach and research methodology to accurately depict the overall state of the entire office. Moreover, modifying the Dynamo script would be necessary. Although this aspect is not addressed in the current thesis, it is recommended in Chapter 10 as an area for future research.

Furthermore, it is important to note that there is another aspect of data that was not included in the results, specifically section 3 of the survey. The survey was designed and distributed at an early stage in the thesis work, as it relied on gathering input from occupants for further research. This early distribution allowed occupants ample time to complete the survey, maximizing the participation rate. Initially, the thesis aimed to incorporate occupants' satisfaction levels with both office spaces and common areas. However, as the research progressed, the focus of the thesis was narrowed down to solely examining satisfaction levels in the office spaces.

6.4.4 Result Interpretation and Presentation

The interpretation and presentation of the POE survey results primarily focused on analyzing the patterns of data derived from respondents using the provided answer choices, rather than solely relying on the individual suggestions written by some occupants in the open text boxes.

Some information in the models and figures generated from SurveyXact was removed in the result presentation to protect the anonymity of the respondents. The results were presented in charts and tables as deemed fit using the SurveyXact tool. The results from the POE-survey can be found in chapter 7.2 The Post-Occupancy Evaluation Survey and the figures from SurveyXact can also be found in appendix 12.1 SurveyXact Report.

6.5 Creating the Revit Model

This chapter describes the method behind creating the model in Revit that serves as a base for the further modifications done in Dynamo and Visual Studios. As the occupants' feedback was reported based on the individual spaces, the rooms served as suitable hosts for the user satisfaction survey. Consequently, all aspects related to comfort in the user satisfaction survey, such as indoor air quality and visual comfort, were established, specified, and connected to the respective rooms in the BIM model to facilitate the collection of occupants' feedback. The initial step in this process involved creating the base for the Revit model.

6.5.1 Creating the Revit Project

The method Is largely inspired by [42]. When starting Revit, you have a few options. If you click New under Models, a new project is made. Here you chose imperial construction template under template file. Then you click OK. It is important to save the project right away, so you remember where you place it. The project was saved as master-thesis under an appropriate folder on the computer. Other related files, such as downloaded furniture, were also stored in this location. Within the Revit environment, the decision was made to design a total of six rooms, with two rooms selected from each building.

The floor plans of buildings H, C, and D, including the office spaces, were provided by the university's facility manager. Although some floor plans were available online through Mazemap, they lacked the desired level of detail. However, the floor plans obtained from the facility manager offered a complete layout and included office dimensions. Initially, the plan was to use these dimensions to ensure the accuracy of the visualization for the selected six offices. However, it was later decided not to use the specific office dimensions to maintain survey respondents' anonymity. Since the offices varied in size, utilizing their dimensions could potentially reveal their identities. Nevertheless, the floor plans provided a good overview of all the offices, and the most commonly observed office dimensions were noted. The area of 9 m^2 emerged as the most popular, and this dimension was therefore used in the BIM model.

To create the rooms in Revit, the wall function was utilized. Basic flooring, windows, doors, and basic furniture were assigned to each room to enhance the visualization of the office space. The furniture was obtained by downloading office-furniture from the website "bimobject.com" and accessing the components option under "Build" to load the family. In chapter 6.6.4 Step 2: Creating Room List and

Setting Parameters, the rooms are imported into Revit using Dynamo, and they can be placed within the walls by utilizing the rooms option under the architecture tab.

Data from SurveyXact played a crucial role in two operations. Firstly, the actual rooms were imported into the room function in Revit. Secondly, the answers per room were imported into the properties of each room, and the 3D objects were colored based on a predefined parameter. The detailed methodology behind these operations can be found in chapter 6.6 Dynamo.

6.6 Dynamo

In this subchapter the method used in Dynamo 2022 is described in detail. The goal is that the method will be replicable, even for users with no Dynamo or other coding experience. The Dynamo subchapter includes general information about the program and some important functions, the learning materials used to complete the script, and step-by-step explanation of the method used for scripting in Dynamo. The step-by-step explanation is divided into four steps: Import Excel Data and List Formatting, Creating Room List and Setting Parameters, Creating the 3D Room Geometry and Setting Parameters, and Coloring the 3D Rooms Based on Comfort Criteria. The nodes are grouped together were appropriate to better visualize the process. The group colors in Dynamo can have different meanings [78], in this thesis however, they are only there to easily separate and visualize the steps for the reader.

6.6.1 Learning Materials

The thesis supervisor, Haidar Hosamo advised to use Revit and Dynamo to visualize the results from the survey. As a civil engineering student, Revit is a BIM program that is somewhat familiar. Some repetition of its basic functions was needed, but Dynamo was something totally unfamiliar. Internet resources collected by using Google and YouTube was used to get a basic understanding of the program and how to use it. Hosamo has previously worked with Dynamo and suggested starting with the following YouTube tutorials:

- “Dynamo and Excel - Parsing Excel Data with Dynamo”, by channel “Proving Ground” [79]
- “Dynamo and Excel - Creating a Room List in Revit”, by channel “Proving Ground” [80]
- “3D Rooms & colorizing | Revit Tutorial | Dynamo”, by channel “Niko G.” [81]

Watching these YouTube tutorials, other relevant videos were “suggested” by YouTube, some of these became relevant to get a better understanding of Dynamo as a beginner. *“Learn Dynamo - Introduction: About the Series*”, by channel “Aussie BIM Guru” [82] is a video that started my learning of Dynamo basics. This video is the first in a total of 18 videos in the series “Learn Dynamo” by the same channel. These videos were very helpful in gaining a basic understanding of the program. Helpful topics the series cover include setting up Dynamo, basics of the general user interface, installing custom packages, arithmetic and logic, working with strings and other less used data types, working with lists, design scripting and code blocks, accessing and leveraging model element data from Revit, and many other topics with practical applications. Not all the videos ended up being directly relevant/used in the final Dynamo script but was important for gaining a general understanding along the way.

Through the trial-and-error process of scripting, the forum for Dynamo became very helpful. The dynamo forum [83] is an environment to ask questions and discuss topics with other Dynamo users. The forum provides help from both experts and novices but was helpful in gaining others perspective. This was especially helpful since some of the YouTube tutorials and other learning material online had become partly outdated due to updates in the software. Hosamo, the thesis supervisor, also came with input and suggestions for the script throughout the process.

6.6.2 Launching the Program

The following subchapters shows the method used in the Dynamo scripting in detail. First is launching the program. Dynamo is already a part of Revit 2022, under the tab “Manage”. The group is called “visual programming” and includes Dynamo and Dynamo Player. The background in Dynamo is a 3D visualization with the visual programming on top. This makes it possible to see the result of your programming in real time. It is recommended to change the run from automatic to manual down in the left corner of the screen. This allows you to determine when to run the script, which is useful with bigger scripts as the run process can take some time. Some packages are needed to follow the script in this method. Packages are downloaded under the “Packages” tab and “search for packages” options in Dynamo. The packages used are listed below.

Packages used in this method:

- “LunchBox”: LunchBox for Dynamo version 2018.7.7
- “Springs”: spring nodes version 210.1.1

6.6.3 Step 1: Import Excel Data and List Formatting

The first part of the Dynamo script method is to import excel data and format the lists, so they are ready for further use in the script. Before the excel file is imported to Dynamo, the excel table needs some formatting. This is because it is easier to work with a number scale throughout the script, especially in part 4 where the rooms are colored depending on how well the room scored on comfort criteria. The original scale “Very Dissatisfied”, “Dissatisfied”, “Neutral, “Satisfied” and “Very Satisfied” was converted to a scale from 1 to 5. In addition to this, Information that isn’t used in the script is removed from the excel table. An example of how parts of a table would look before and after is shown in Table 6-1 and Table 6-2 below. The values in the table-examples are fabricated and only for visualization’s sake.

Table 6-1: Excel table before formatting

Room type	Room number	Temperature comfort in summer	Temperature comfort in winter
Office	CX XXX	Very satisfied	Very satisfied
Office	DX XXX	Satisfied	Satisfied
Office	HX XXX	Dissatisfied	Neutral

Table 6-2: Excel table after formatting

Room type	Room number	Temperature comfort in summer	Temperature comfort in winter
Office	CX XXX	5	5
Office	DX XXX	4	4
Office	HX XXX	2	3

The beginning of the script closely follows the method used in YouTube tutorial “Dynamo and Excel - Parsing Excel Data with Dynamo” [79]. The total script for part 1 is pictured below in Figure 6-1, the script is also divided in two parts in Figure 6-2 and Figure 6-3 to make it more readable. It starts with the “File Path” node that allows you to select a file to get its filename, to get the actual file we need the “File From Path” node. To be able to import excel data we need the sheet name. If the sheet name is known beforehand, the name could be added as a string. Another method is to use the “Excel.GetExcelFileInfo” node which is a part of the package “Lunchbox”.

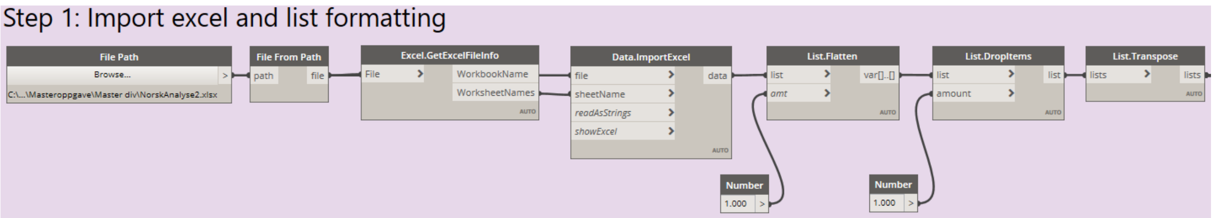

Figure 6-1: The total dynamo script for part 1: Import Excel Data and List Formatting.

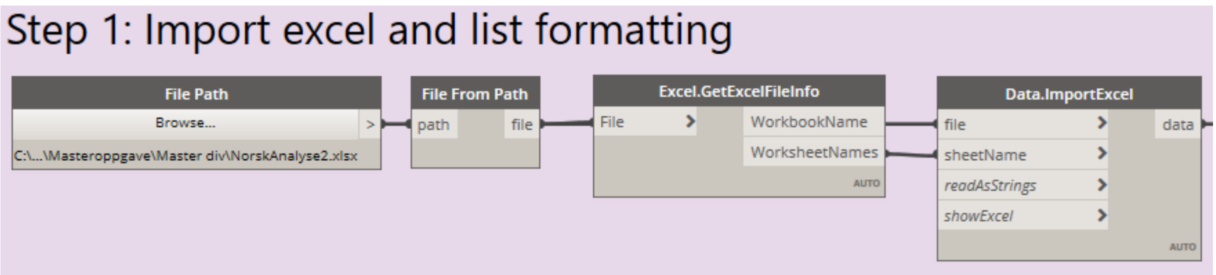

Figure 6-2: First few nodes in dynamo script part 1

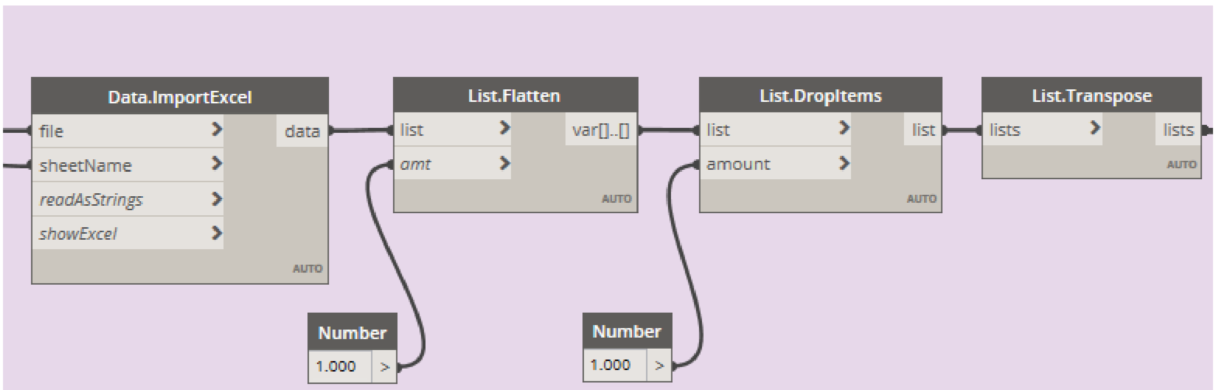

Figure 6-3: The last few nodes in dynamo script part 1

The "Data.ImportExcel" node reads data from an excel spreadsheet and the data is read by row and returned in a series of lists by row. The node needs the file and sheet name as input. The information is being organized by row where each of the sub lists contain a row of information from the excel table. Additionally, the header is included in the data imported. This information is not needed in this script; therefore, we need to drop this part of the data before we proceed. The "List flatten" and "List.DropItems" node cleans up the data by removing unnecessary sub lists categorizations and by dropping 1 amount and thereby dropping the headers. Lastly, the list needs to be transposed for the data to be correctly formatted for further use in the script. Using the "List.Transpose" node the column and rows are swapped. Down below in Figure 6-5 and Figure 6-4, the list formatting is visualized in before and after pictures.

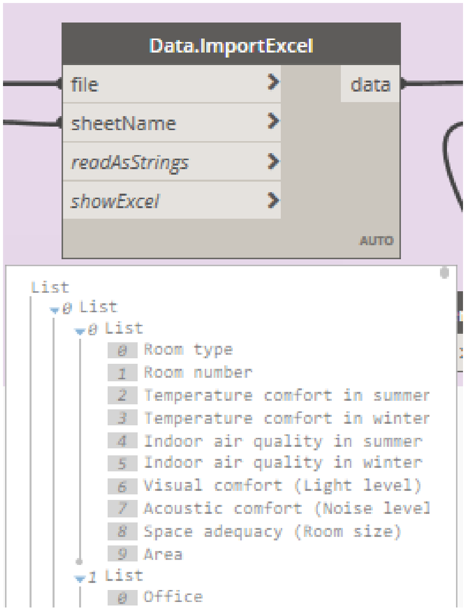

Figure 6-5: The data list before formatting

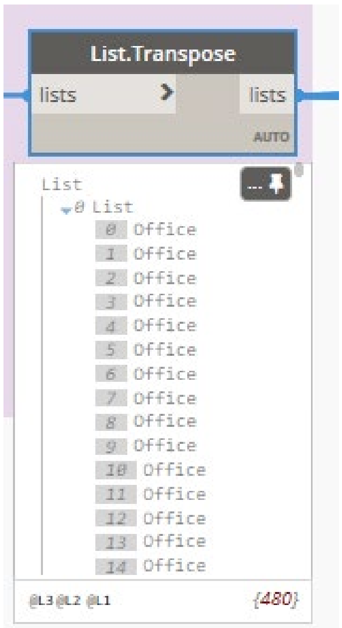

Figure 6-4: The data list after formatting

6.6.4 Step 2: Creating Room List and Setting Parameters

The second step of the Dynamo script method is to create a room list from the imported excel data from part 1 and set parameters for the 2D room objects. The concept for the script in part 2 is pictured below in Figure 6-6, the script is also divided in two parts in Figure 6-7 and Figure 6-8 to make it more readable. The YouTube tutorial "Dynamo and Excel - Parsing Excel Data with Dynamo" [79] and "Dynamo and Excel - Creating a Room List in Revit", by channel "Proving Ground" [80] was used for the method of creating the room list.

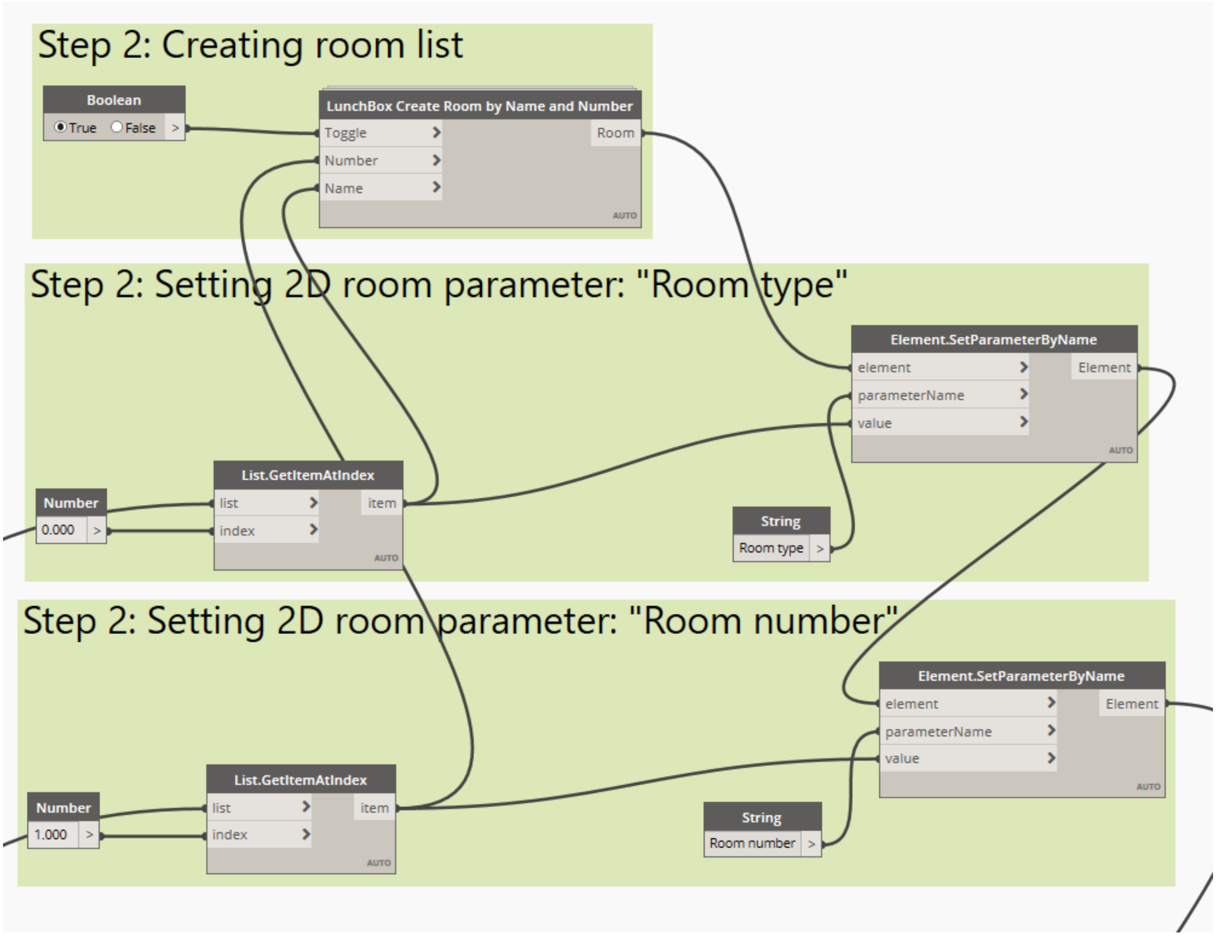

Figure 6-6: The method for Dynamo script for part 2: Creating Room List and Setting Parameters

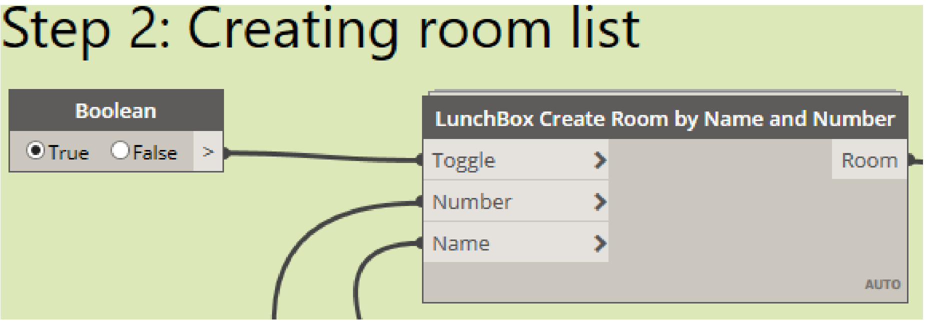

Figure 6-7: Creating room list for Dynamo script part 2.

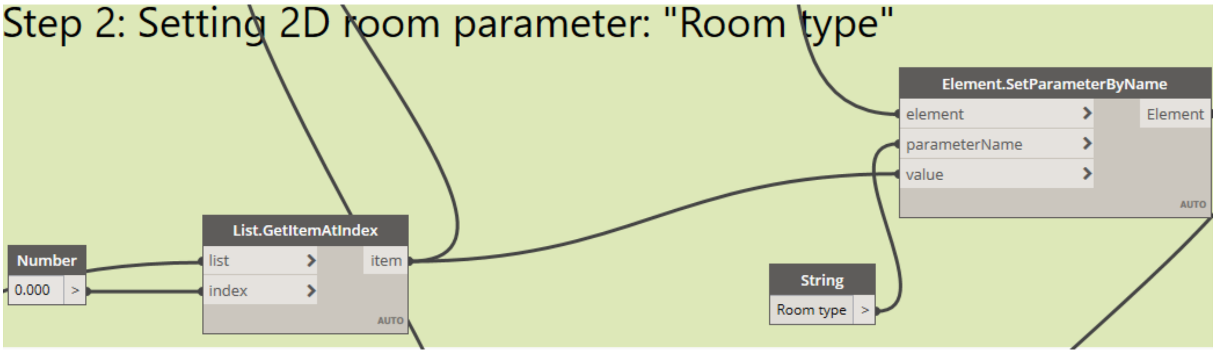

Figure 6-8: Example of setting 2D room parameter for Dynamo script part 2.

To create rooms in Revit we use the node from “Lunchbox Create Room By Name and Number” from the lunchbox package. This node creates an unplaced room element in Revit using a name and a number. The name is the room type and the number is the room number. All the rooms are offices, scripting this way opens for the possibility to add non-office rooms in the excel table at a later moment. To get this data from the excel for the name and number we use the “List.GetItemAtIndex” node. This node returns an item from the given list that’s located at the specified index. The input needed is therefore a number for index and the previously transposed list from part 1. “Room type” is the first item in the list, therefore the index is 0 because Dynamo start the numbering at 0 instead of 1. The same is done for Room number but with number 1. These inputs are attached to the lunchbox create room node in addition to a Boolean stating “True” as the toggle. The result is a list of rooms with attached ids. This room list will now appear in Revit under the room tool.

The next step is to assign parameters to each room according to the data in the excel file. The “Element.SetParameterByName” is used for this. For this to work it is necessary to have parameters that match the parameter name in Revit’s project parameters. Before continuing with the script, all the project parameters needed to be added in Revit. This can be done under the manage tab -> settings -> project parameters -> add in Revit 2022. Once the parameters are added, the “Element.SetParameterByName” can be used. The needed input for the node is the rooms from the lunchbox node as element, the parameter name, and the value. The parameter name input is a string with the corresponding name and the value is the item from the “List.GetItemAtIndex” node from previously. This process is repeated for all project parameter, including the rating of all the comfort criteria from the survey, look in appendix 12.2 Figures from Dynamo Script for more pictures of the repeating script. The result in Revit for this part of the script is shown in Figure 6-8. In the figure the property data for the chosen room shows data for room type, and other parameter stating the occupants comfort level on a scale from 1 to 5 on several comfort criteria. The room number has been edited to C1 to preserve the anonymity of the occupant.

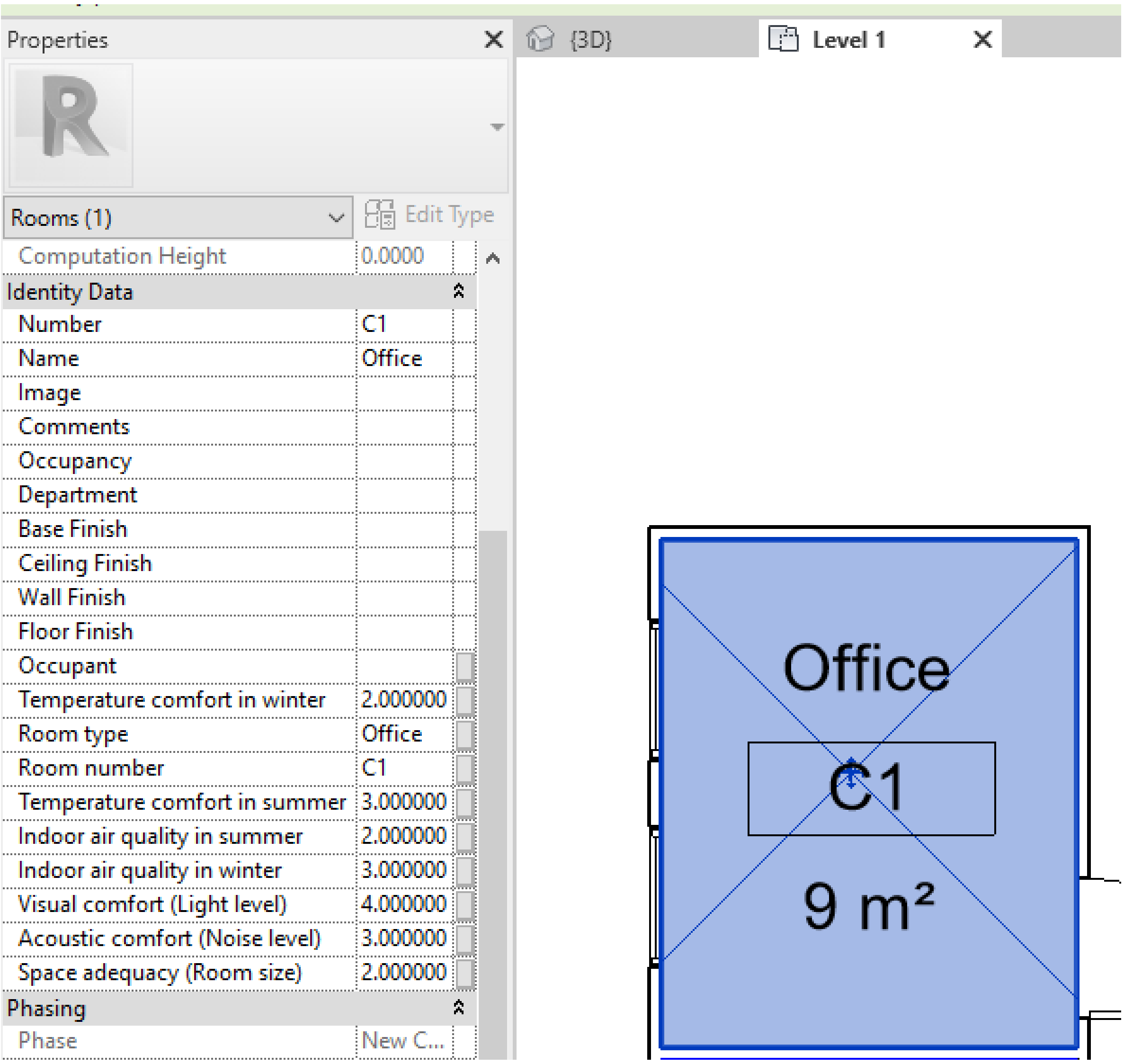

Figure 6-9: Screenshot showing the imported properties for a room in Revit.

6.6.5 Step 3: Creating the 3D Room Geometry and Setting Parameters

Step 3 is creating the room geometry in 3D and setting the parameters for the 3D room objects. The total script for the room geometry is picture below in Figure 6-10, the script is also divided in two parts in Figure 6-11 and Figure 6-12 to make it more readable. The YouTube tutorial “3D Rooms & colorizing | Revit Tutorial | Dynamo”, by channel “Niko G.” [81] was used to understand how geometric shapes was created from rooms. However, there ended up being a scaling issue between dynamo and Revit and the 3D object was placed as an imported object under family type in properties, making it impossible to set properties to the 3D room objects. Therefore, some modifications were done with the help of contributors on the Dynamo help forum [84]. The modifications involved using the “Element.Solids”, and “DirectShape.ByGeometry” nodes instead of using the “Room.FinishBoundary”, “PolyCurve.ByJoinedCurves”, “Surface.ByPatch”, and “Surface.Thicken” nodes.

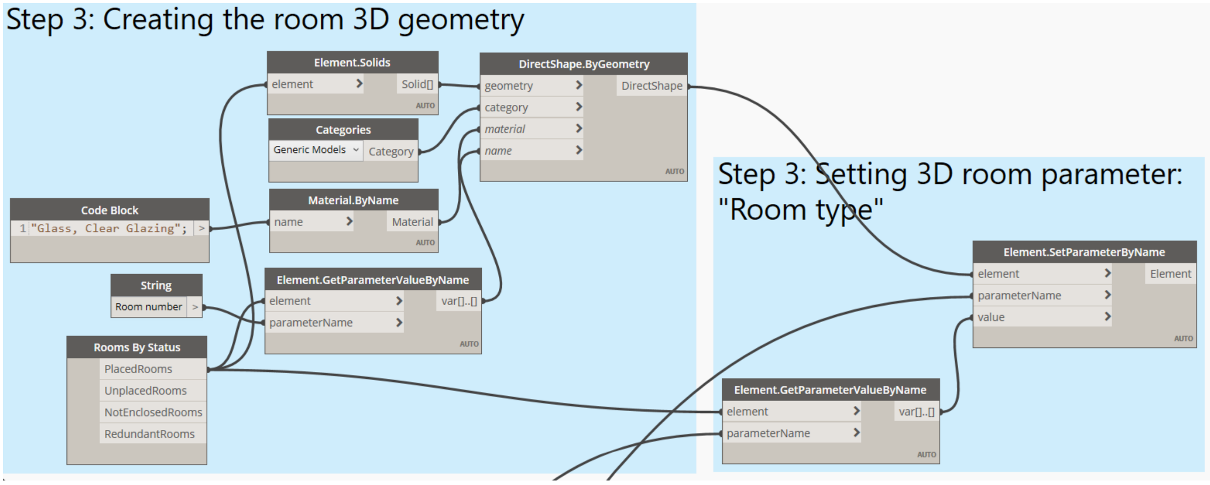

Figure 6-10: The dynamo script for part 3

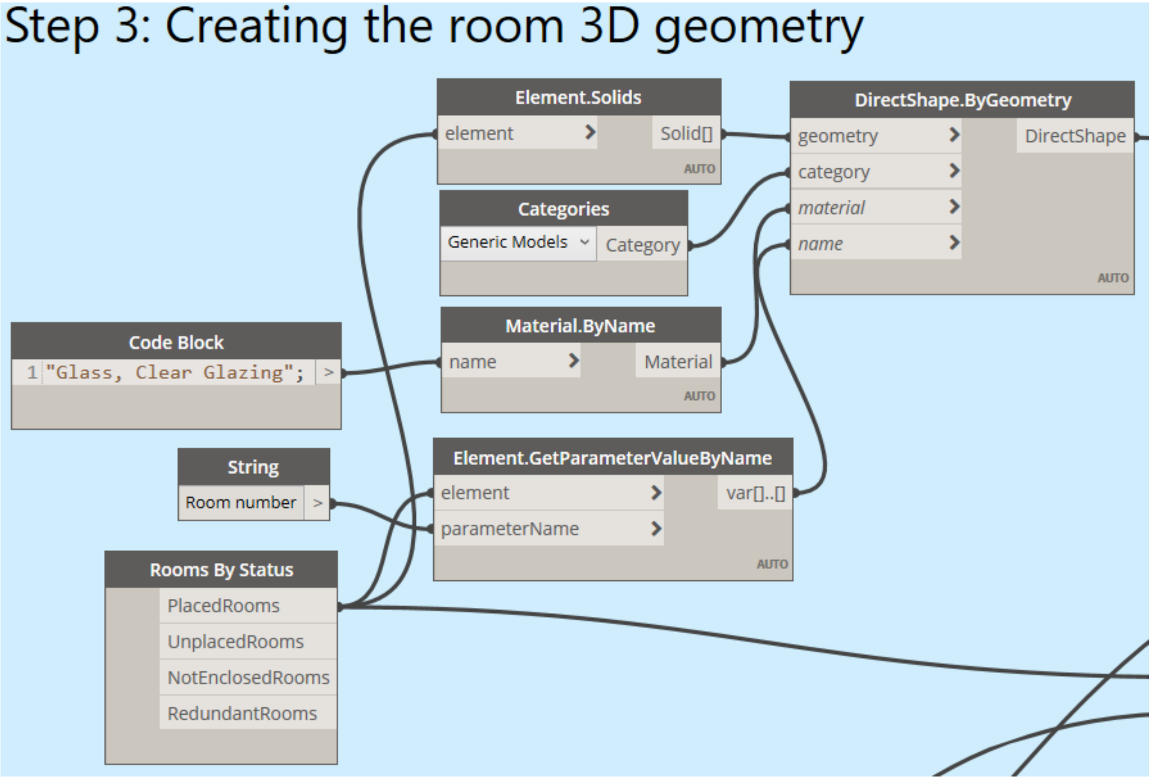

Figure 6-11: Creating the 3D room geometry for Dynamo part 3.

First, all the placed rooms in Revit needed to be collected using the “Rooms By Status” node. The output of “placed rooms” was connected to node “Element.Solids” to convert the element, which are the placed rooms, to solids. The “DirectShape.ByGeometry” node was used to create a direct shape given some geometry, a category, a material, and a name. This node is a part of the downloaded package “Springs”. The solid output from “Element.Solids” is the geometry, the category is Generic Models, and the material name is “Glass, Clear Glazing”. The “Glass, Clear Glazing” material was chosen for its transparent characteristics that will be useful for the colorization in part 4. The “Material.ByName” node is needed to retrieve the material from Revit based on the name. The name input is collected by using a “Element.GetParameterValueByName” node that gets the value of the given element parameter. The input needed in an element and a parameter name. In this case, the parameter name is Room number, and the element is the placed rooms from “Rooms by Status node”. The output from the “Element.GetParameterValueByName” node is connected to the name input on the “DirectShape.ByGeometry” node, and the result is 3D room objects in Revit, which is pictured in Figure 6-13.

Lastly The parameters for the 3D objects were set in the same way as the 2D room objects in part 2 using the ”Element.SetParameterByName” node. The input for element is the DirectShape from the “DirectShape.ByGeometry” node, parameter name is the string “Room type” from part 2 and the value is the output from a “Element.GetParameterValueByName” node. The input for this node is the Rooms By Status output PlacedRooms and the parameterName input is the string “Room type” Similar to the process in part 2, this is repeated for all the parameters.

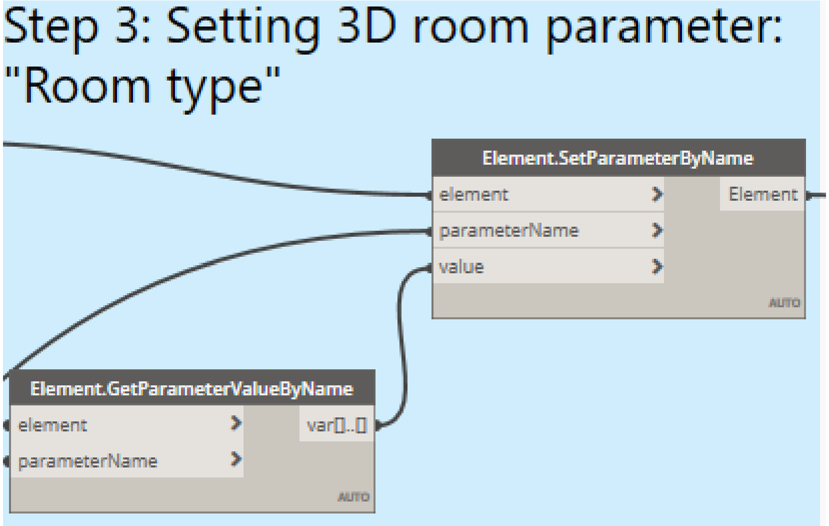

Figure 6-12: Setting the parameters for the rooms 3D objects.

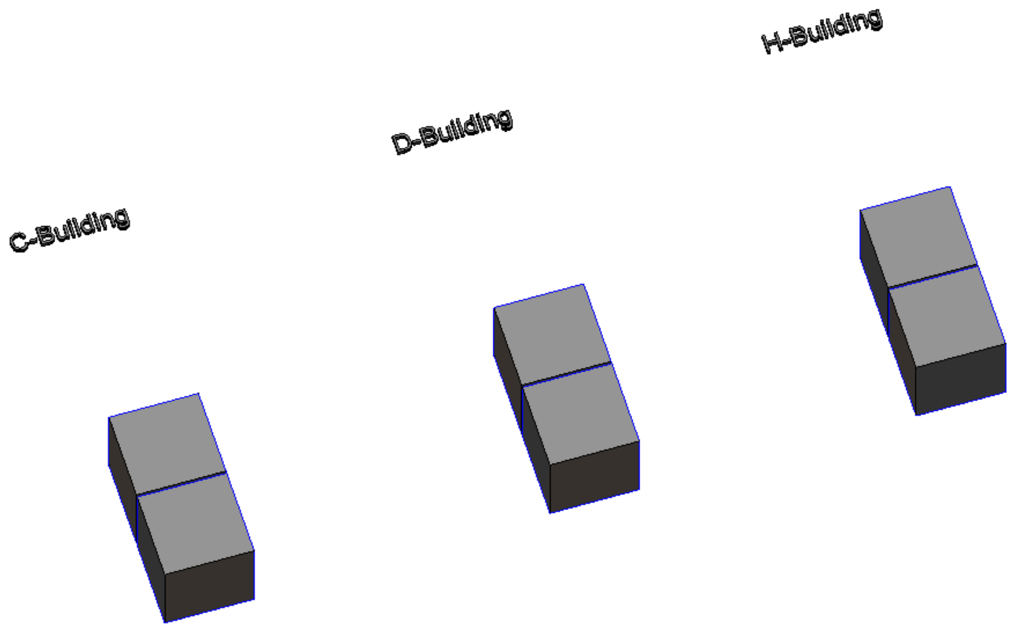

Figure 6-13: 3D view of the rooms in Revit after Dynamo step 3

6.6.7 Step 4: Coloring the 3D Rooms Based on Comfort Criteria

The last part of the Dynamo script is coloring the 3D room object based on a set criterion. The method used for this is inspired by YouTube tutorial “3D Rooms & colorizing | Revit Tutorial | Dynamo”, by channel “Niko G.” [81] but some modifications are done with the help contributors on the Dynamo help forum [84]. The concept for script part 4 is pictured in Figure 6-14x, the script is also divided in two parts in Figure 6-15 and Figure 6-16 to make it more readable.

Step 4 is colorization based on the comfort criteria. The first criteria scripted is “Temperature comfort in summer”. Using the “Element.GetParameterValueByName” node with the parameterName “Temperature comfort in summer” the room value from that criterion is collected by using the element “PlacedRooms” from part 3. The next step is to filter which of the placed rooms scored high, low, and neutral on the criteria. This is done using a “List.FilterByBoolMask” node. The needed input is a list and a mask. The list is the DirectShape output from the “DirectShape.ByGeometry” node from part 3. The mask input is created using a greater than node “>” and an equal to “==” node. It was decided that the rooms that scored higher than 3 would be colored green, the rooms scoring 3 would be colored yellow and the rooms scoring below 3 would be colored red. Neutral translates to 3 in the formatted score system. Therefore, the input Y for the “==” node is the number 3. The rooms being sorted as “in” on the “List.FilterByBoolMask” node gets colored yellow using a “Element.OverrideColorInView” node and the “Color Palette” node.

The rooms sorted as “out” on the “List.FilterByBoolMask” node will be further filtered based on if the room scored higher or lower than 3. This is done by getting the parameter values from the remaining rooms again by using the same “Element.GetParameterValueByName” method as before, but this time the element is the output of the “List.FilterByBoolMask” node. The list needs to be flatten using the “List.Flatten” node. Now the rooms are ready to be sorted again using the “>” with the x value being the output of the “List.Flatten” node and the y value being the number 3. The output is put through a “List.FilterByBoolMask” node again, and the rooms sorted as “in” gets colored green using a “Element.OverrideColorInView” node and the “Color Palette” node with color green. The remaining rooms is sorted as “out” and gets colored red using the same nodes.

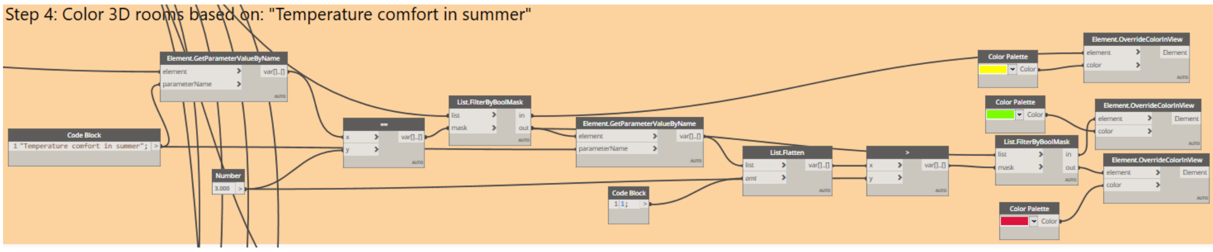

Figure 6-14: The concept of the dynamo script for step 4

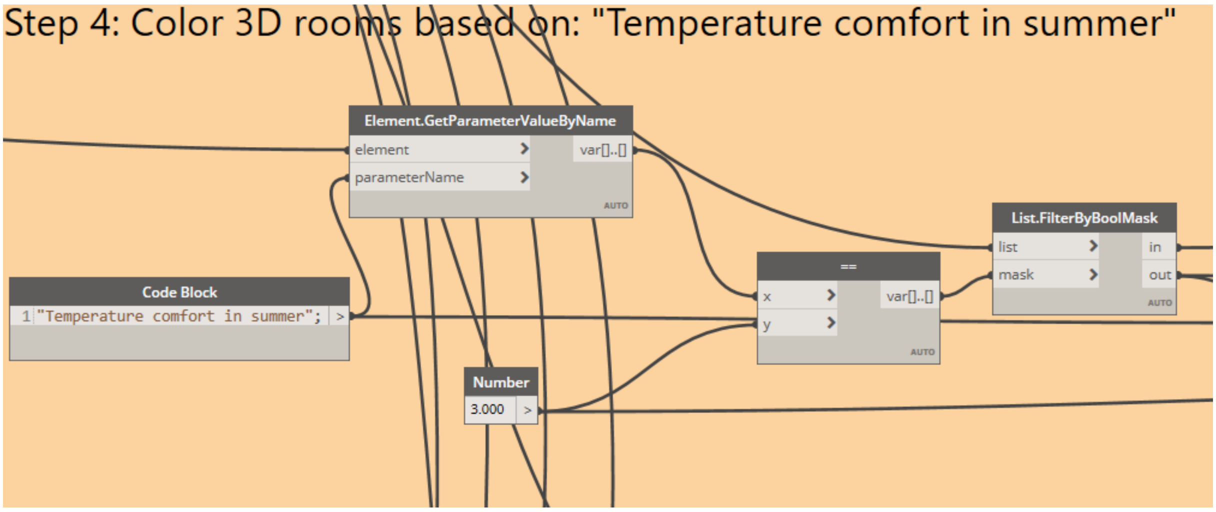

Figure 6-15: First few nodes of Dynamo script step 4

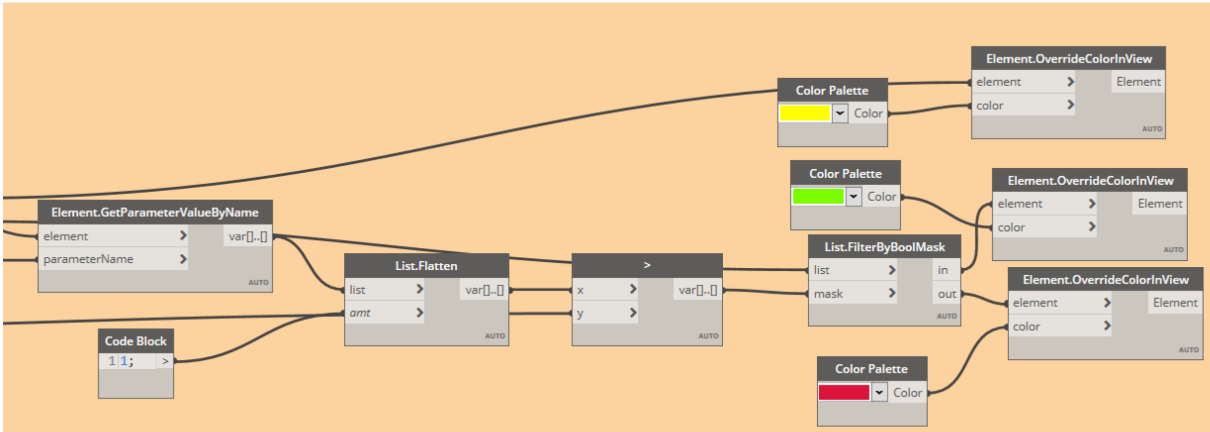

Figure 6-16: Last few nodes of Dynamo script step 4

The results in Revit from the whole Dynamo script is pictured in Figure 6-17, Figure 6-18 and Figure 6-19 below as well as in the chapter 7.3.2 Dynamo. The chosen rooms in Revit ended up with a green or red translucent color, depending on how well the room scored in the survey. One room turned yellow, three turned green and two turned red. In Figure 6-18 the yellow room C1 is pressed in Revit, and the scores from the survey are found in the properties page. For example, the occupant of C1 answered 3 (Neutral) in the “Temperature comfort in summer” criteria and therefore, the room is colored yellow in 3D. Similarly, room C2 was inspected in Figure 6-19, and the properties show that the occupant answered 2 (Dissatisfied) in the same criteria on the survey. Because of this, the room is colored red.

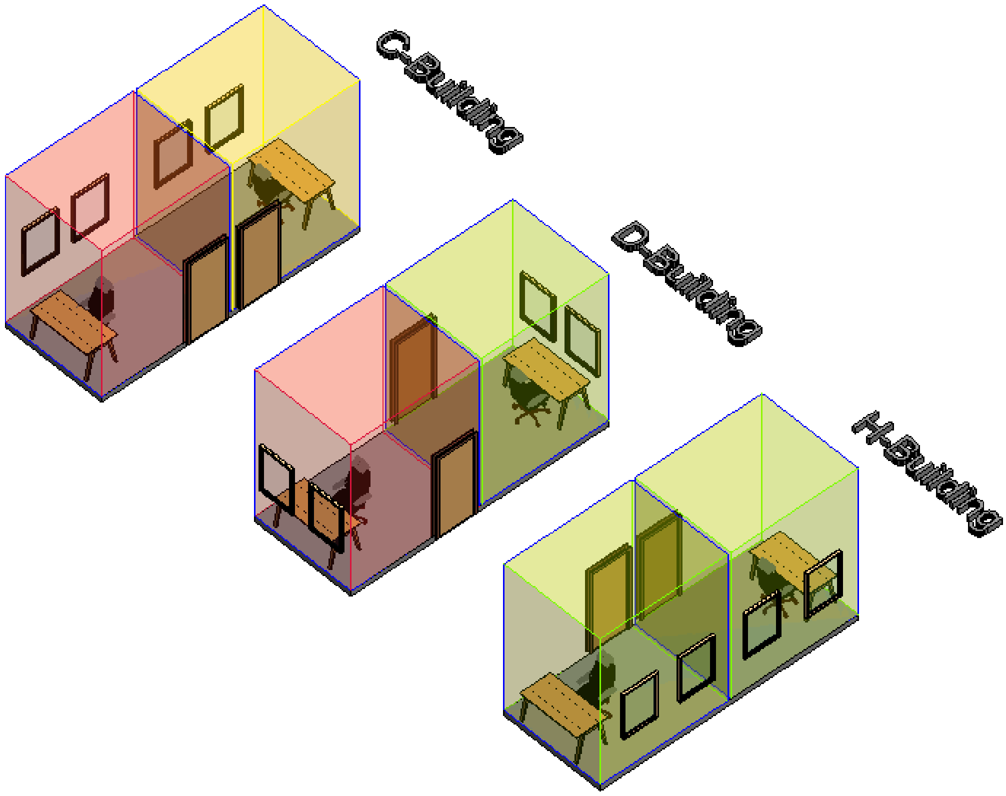

Figure 6-17: Colored rooms in Revit from the "Temperature comfort in summer" criteria

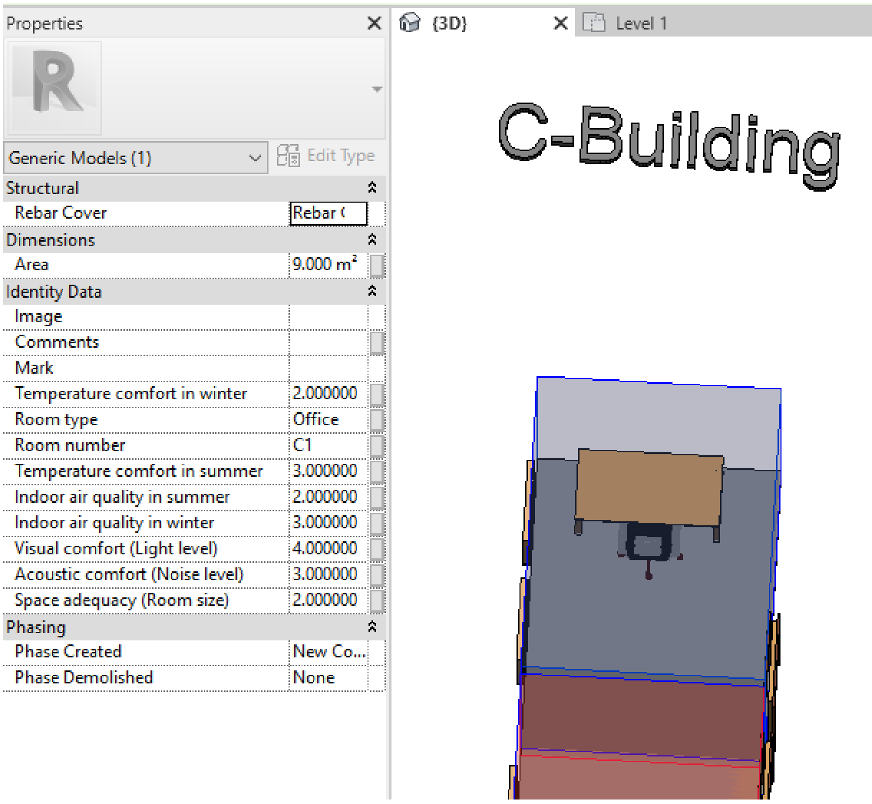

Figure 6-18: The properties of 3D room C1 in Revit

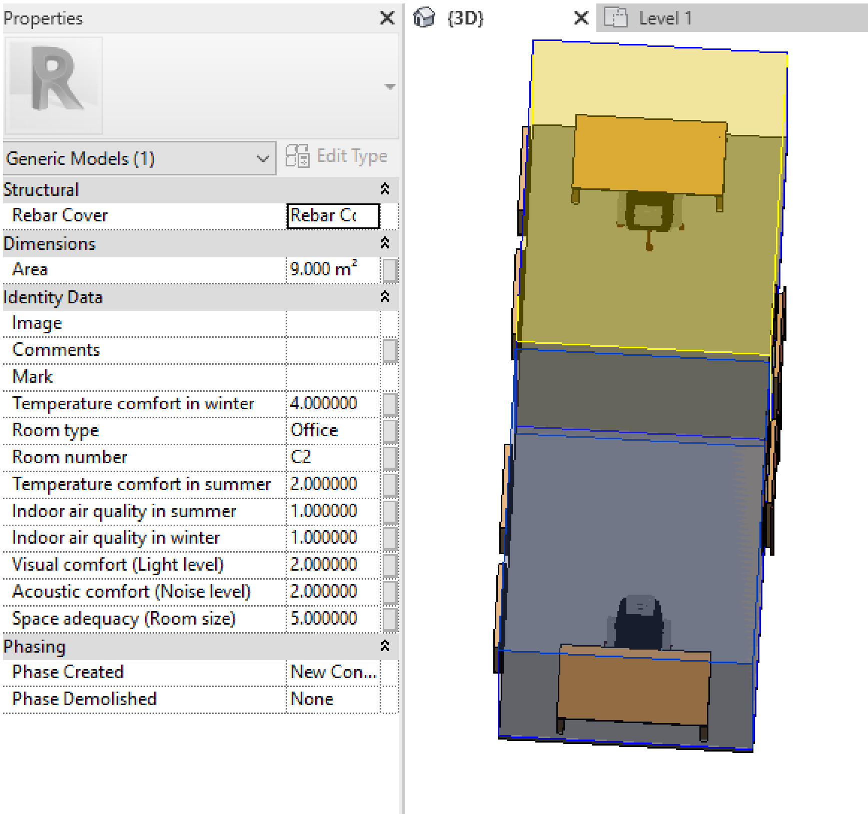

Figure 6-19: The properties of 3D room C2 in Revit

The method for part 4 is repeated for all the comfort criteria. Figure 6-20 below shows the complete script for part 4 with all the comfort criteria. Using the "freeze node" function in Dynamo, makes it possible to easily switch which criteria is used, while still having all the nodes in the script. The frozen nodes turn grey, which can be seen in the Figure 6-20. The coloration and properties of all the placed rooms based on all comfort aspects can be seen in chapter 7.3.2 Dynamo.

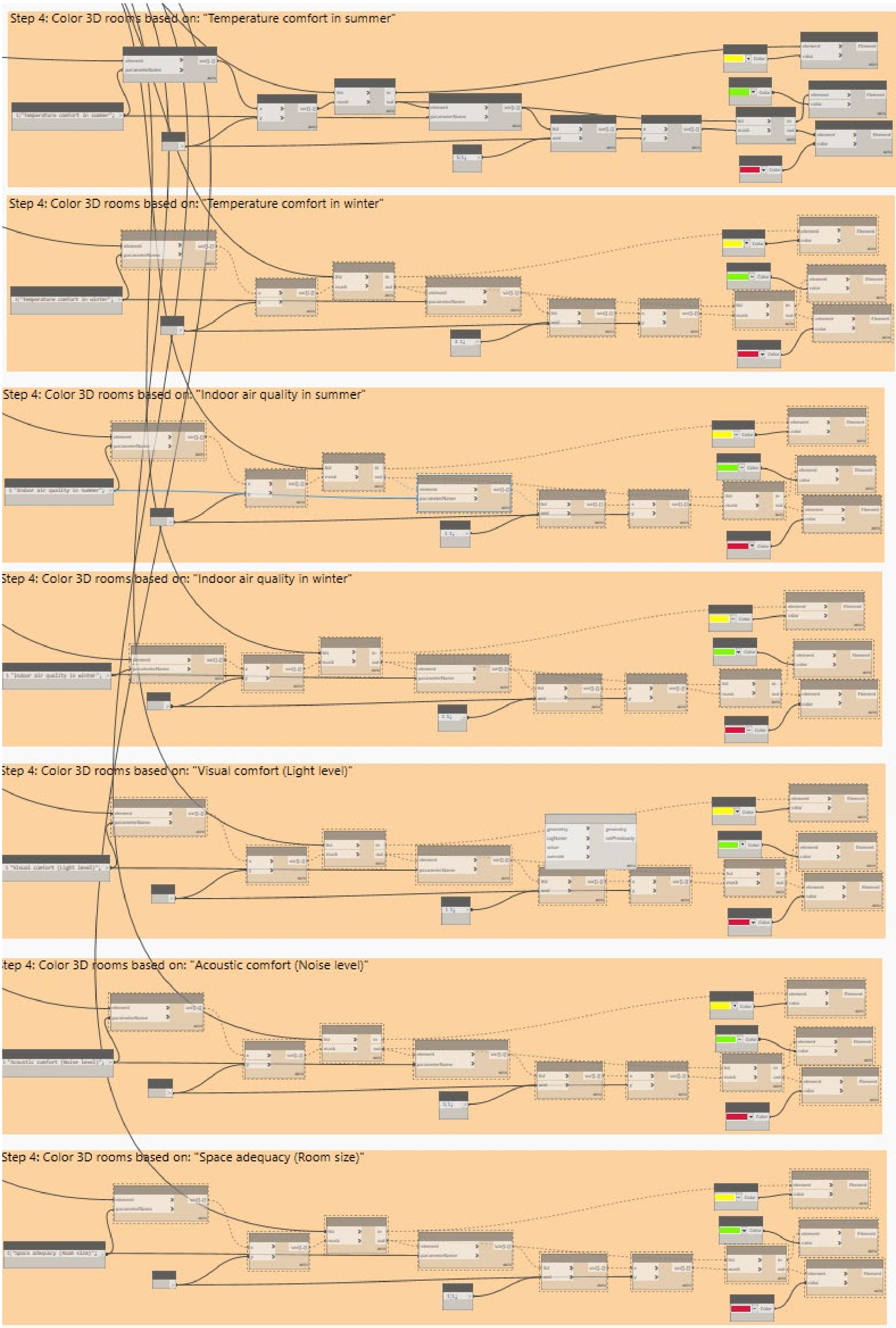

Figure 6-20: An overview picture of the script for part 4 with all comfort criteria

6.7 Visual Studio

In this subchapter the method used in Visual Studio 2022 for Revit is described in detail. The goal is that the method will be replicable, even for users with no coding experience. The Visual Studio subchapter includes the decision process to choose this method, learning materials used to complete the script, and step-by-step explanation of the method used in Visual Studio.

6.7.1 Decision Process

this subchapter explores the decision-making process behind choosing to try a different method of importing excel data into Revit, which involved using Visual Studio to create a Revit add-in using C#. As someone with no programming experience, Dynamo was the main focus of this thesis, given its beginner-friendly nature compared to programs like Visual Studio [44]. However, upon recommendation by Supervisor Haidar Hosamo, I decided to spend some time trying a different method of importing excel data into Revit. When researching this topic, the use of Visual Studio to create a Revit add-in using C# came up. Before diving into this method, I had to research the topic to ensure I understood it properly. This included conducting general Google searches and watching videos about the difference between using Dynamo and other add-ins, as well as videos on the basics behind the program. These videos are listed under 6.7.2 Learning Materials. While researching this topic, I found it very interesting to try learning another method of automating tasks and making the workflow more efficient. After a few days of coding and testing, I successfully implemented the add-in and imported the data into Revit.

It's important to note that in Chapter 3.3.3 Plug-ins vs Add-ins of the knowledge background, the difference between plug-ins and add-ins was presented. In this thesis the term "add-in" is used to describe the code made to import excel data to Revit using Visual Studio.

6.7.2 Learning Materials

To gain a better understanding of the Visual Studio method, various learning materials was utilized. In addition to conducting general google searches, following resources turned out to be very useful:

- “Dynamo or Add-ins - which to learn?” by “Aussie BIM Guru [58].
- “The Pros and Cons of Using Dynamo Versus a Revit Add-In” produced by Autodesk [53].
- “What is Revit API” by “Balkan Architect” [85].
- “Start programming with C# (for complete beginners)” by “Luke`s Programming School” [86].
- “How to write a plugin for Revit - Coding for AEC Lesson 2” by “That BIM Girl” [57].
- Autodesk lesson: Lesson 1: The basic plug-in [67].
- Autodesk lesson: Lesson 2: Programming Overview [87].
- Autodesk lesson: Lesson 3: A First Look at Code [62].
- “Learn to program the Revit API by Boost Your BIM” by Harry Mattison [66].

YouTube video “Dynamo or Add-ins - which to learn?” [58] and Autodesk video “The Pros and Cons of Using Dynamo Versus a Revit Add-In” [53] gave abroad understanding of the difference between add-ins and Dynamo and the potential uses and limitation of each method. To understand the basics behind an add-in multiple types of resources was utilized, including YouTube and Udemy courses. YouTube video “What is Revit API” [85] describes what a Revit API is, and the basics behind programming Revit. After a broad understanding of the Revit API was achieved, basic programming with C# was researched. Udemy course "Start programming with C# (for complete beginners)" is a free course that last a little over 3 hours that describes the important concepts of programming and creating a C# application [86].

When knowledge of the basics behind C# programming language was gained, it was time to learn how to build an add-in. YouTube video "How to write a plugin for Revit - Coding for AEC Lesson 2" [57] is a is a tutorial on how to write a basic add-in for Revit that follows an Autodesk lesson: "Lesson 1: The basic plug-in" [67]. The second lesson [87] and third lesson [62] from Autodesk in the same series also became very useful. Now the goal was to build an add-in for Revit that can import and read excel data. Udemy course "Learn to program the Revit API by Boost Your BIM" by user Harry Mattison [66] is a course that last 6,5 hours, and course describes how to write Revit API code in C# to perform a wide variety of tasks. Especially lesson 9: Create an external command and lesson 14: Read from Excel into a Revit API external command. The method behind the code in Visual Studio is based on the lesson 14 in this course. The course cost money, but supervisor Haidar Hosamo had used this course earlier and shared access.

6.7.3 Launching the Program

The following subchapter describes the first steps used of the method used in Visual Studio in detail. First step is launching the program and downloading the necessary references. The start of the method closely follows "Autodesk lesson: Lesson 1: The basic plug-in" [67]. A new project in Visual Studio 2022 was opened using the template "Class Library (.NET Framework)" with C# programming language and the latest framework such as ".NET 6.0", this is because Revit 2022 supports .NET Frameworks version 4.8 or later [59]. The first window is the editor screen and the window on the right is a solution explorer. The solution explorer contains a list of all the files that belong to the project.

We need to add a reference to RevitAPI and RevitAPIUI under references in the solution explorer. Depending on how you installed Revit the file path for them might be different, however, it is often under C:\Program Files\Autodesk\Revit 2022. Scroll down and find RevtitAPI.dll and RevitAPIUI.dll. When they are added, the properties for copy local, by default is set to true. This means that the referenced DLLs will get copied to the project's output folder when it is built [87]. This is unwanted in this case, and therefore the properties for "copy local" are set to false [87].

To follow the method used in "Learn to program the Revit API by Boost Your BIM" by Harry Mattison [66] lesson 14:" Read from Excel into a Revit API external command" we need to add reference "System.Windows.Forms" which is added same way as the Revit ones but click assemblies in the tab on the left side and search for the reference. One last reference is needed to be able to read excel files. This can be installed using the NuGet package manger under the tools tab. Search for EPPlus and install in the project. Now all the necessary references have been added.

6.7.3 Creating the External Command for Importing Excel Data

The following chapter describes the method used to write the code for the External Command for Importing Excel Data in Visual Studio. Supplementary information about the functions and terms used in the program is found in chapter 3.4 Programming in C#. The method is from "Learn to program the Revit API by Boost Your BIM" by Harry Mattison [66] lesson 14:" Read from Excel into a Revit API external command". The finished code can be found in chapter 7.3.3 Visual Studio and in appendix 12.3 Figures from Visual Studio Revit Add-in.

The code is an example of a C# program that reads the content of an Excel file and displays it in a TaskDialog within Autodesk Revit. The first 5 lines of the code is using the several namespaces to import the necessary classes and functions [62]. After the using statements have been introduced, the code starts by declaring a namespace called "Jada". This is a made-up name by the programmer for the namespace.

```
using Autodesk.Revit.DB;
using Autodesk.Revit.UI;
using OfficeOpenXml;
using System;
using System.IO;

namespace Jada
{
```

After the namespaces has been declared the code specifies that the transaction mode for this command is read-only by using a read-only attribute. This is to help control the transaction behavior of the command [62]. The "ReadExcel" is the name of the public class. The "ReadExcel" public class implements the IExternalCommand interface. When a class implements the IExternalCommand interface, Revit can recognize the defined command [62].

```

[Autodesk.Revit.Attributes.Transaction(Autodesk.Revit.Attributes.TransactionMode.
ReadOnly)]
    public class ReadExcel : IExternalCommand
    {
```

The next part creates an AddInId object with the specified GUID. The GUID is found using the tool function in the ribbon, pressing "Create GUID" and choosing the 5. option. The GUID is copied and pasted into the code as follows:

```
        static AddInId appID = new AddInId(new Guid("D8822352-EC01-42AA-8165-
714A26786540"));
```

The next part implements the Execute method of the IExternalCommand interface. The method declaration starts with the word public in this case. This is the entry point for the program and is called when the user executes the command from within Revit [62]. The first line of the Execute method initializes a string variable called "filename" to store the filename of the selected Excel file.

```
        public Result Execute(ExternalCommandData commandData, ref string
message, ElementSet elementSet) // Implementing the Execute method of the
IExternalCommand interface
            string filename = "";
```

An instance of the OpenFileDialog class is created, which is a Windows Forms dialog that allows the user to select a file [88]. The initial directory of the OpenFileDialog is set to the user's My Documents folder, and the filter is set to display only Excel files with the .xlsx extension. An if-else statement is used to allow for conditional execution of the commands [89]. If the user selects a file and clicks the OK button, the filename is stored in the "filename" variable. If the user clicks the Cancel button, the program exits.

```
System.Windows.Forms.OpenFileDialog openDialog = new
System.Windows.Forms.OpenFileDialog();
            openDialog.InitialDirectory =
Environment.GetFolderPath(Environment.SpecialFolder.MyDocuments);
            openDialog.Filter = "Excel Files (*.xlsx)|*.xlsx";
if (openDialog.ShowDialog() == System.Windows.Forms.DialogResult.OK)
                filename = openDialog.FileName;
            else
                return Result.Cancelled;
```

A line declares a variable named data of type string and initializes it with an empty string. This variable will be used to store the data read from the Excel file. Once a file is selected, the content of the file is read using the ExcelPackage class. The ExcelPackage class is part of the OfficeOpenXml namespace, which is used for reading and writing Excel files [90]. A using statement is used to ensure that the ExcelPackage object is properly disposed of when it is no longer needed [91]. Within this block, an ExcelPackage object is created by passing a FileInfo object initialized with the filename variable. This line opens the specified Excel file for reading. The retrieved worksheet is assigned to the sheet variable of type ExcelWorksheet. The ExcelWorksheet object is used to access the content of the first worksheet in the Excel file, since the numbering for indexes starts at 0 [89] as the first worksheet is wanted. A for-loop is used to iterate through each row and column of the worksheet [89]. It initializes the row variable to 1, and the loop continues as long as row is less than 9999. An if statement is used to allow for conditional execution of the commands [89]. If a cell is not empty, its value is added to a string variable called "data". If the condition is true, it mean that the current row Is empty, and the loop is exited using the “break” statement. The value of each cell is converted to a string and concatenated with a comma separator. After each row, a new line character is added to the "data" variable.

```
   string data = "";
            using (ExcelPackage package = new ExcelPackage(new
FileInfo(filename)))
            {
                ExcelWorksheet sheet = package.Workbook.Worksheets[0];
                for (int row = 1; row < 9999; row++)
                {
                    var thisValue = sheet.Cells[row, 1].Value;
                    if (thisValue == null || thisValue.ToString() == "")
                        break;
```

This line starts another for loop within the outer loop, iterating over the columns of the worksheet. It initializes the col variable to 1, and the loop continues as long as the columns is less than 9999. This line retrieves the value of the cell at the current row and column of the worksheet, replacing the previous value of thisValue. This line checks if the retrieved cell value is null or an empty string. If either condition is true, it means that the current row is empty, and the inner loop is exited using the break statement. This line appends the string representation of the current cell value, followed by a comma and spaces, to the data string. This concatenation is performed for each non-empty cell in the worksheet. his line appends a new line character to the data string after each row, ensuring that the next row's data appears on a new line when displayed.

```
                    for (int col = 1; col < 9999; col++)
                    {
                        thisValue = sheet.Cells[row, col].Value;

                        if (thisValue == null || thisValue.ToString() == "")
                            break;

                        data += thisValue.ToString() + "    ,    ";
                    }
                    data += Environment.NewLine;
                }
            }
```

The for-loops continue iterating through the rows and columns until an empty cell is encountered, either in the row or column, causing the respective loop to break. Once all the rows and columns have been processed, the code inside the using block is finished executing, and the ExcelPackage resources are automatically disposed of due to the using statement. Finally, the content of the "data" variable is displayed in a TaskDialog. A TaskDialog is a dialog box that can display text, buttons, and icons to the user. In this example, the TaskDialog displays the content of the Excel file.

```
TaskDialog.Show("Excel", data);
            return Result.Succeeded;
        }
    }
}
```

The last step in Visual Studio to click “save all” under the file tab and to click “build solution” in the build tab. The build solution succeeded according to the output with 0 errors found in the error list.

6.7.4 Creating the Add-in Manifest

As soon as the script is completed, it needs to be incorporated into Revit. To do this, an add-in manifest is created in [67]. This is done by using the Notepad editor and saving the file as an “addin” file. The manifest contains amongst other things, information about the name and location of the script, and the Add-in Id (GUID) for the script in [67]. The code that was used in the manifest can be seen underneath and can also be found in appendix 12.3 Figures from Visual Studio Revit Add-in. The code follows a template in “Autodesk lesson: Lesson 1: The basic plug-in” [67] and “Learn to program the Revit API by Boost Your BIM” by Harry Mattison [66] lesson 14.

This first line declares the XML version and encoding used in the file [55], which in this case is version 1.0 and encoding utf-8. The manifest denotes that it is a Revit add-in and that the add-In Type is a type of command. The Name of the assembly is “ReadExcel” which is the applications name. The “FullClassName” is “Jada.ReadExcel”. The “Text” that will be the name of the button in Revit is “Read Excel” and the description is also “Read Excel” The “VisibilityMode” is set to “AlwaysVisible”, which means that The command is available in all possible modes supported by the Revit API [56]. The manifest includes an assembly that is the full path to the add-in assembly file [56], in this case the file is saved in “C:\Users\victoria.norve\source\repos\Jada\Jada\bin\Debug\Jada.dll”. The “AddInId” is the same GUID found for the code in Visual Studio when creating the external command in chapter 6.7.3 Creating the External Command for Importing Excel Data. The “VendorId” is a made up 4 letter word with the “VendorDescription” describing the Autodesk incorporation. Lastly the .addin was added to the name of the notepad file to make it an addin file in the placement: C:\ProgramData\Autodesk\Revit\Addins\2022. The “show hidden elements” was enabled in the file explorer to be able to see the ProgramData folder.

```
<?xml version="1.0" encoding="utf-8"?>
<RevitAddIns>
 <AddIn Type="Command">
     <Name>ReadExcel</Name>
     <FullClassName>Jada.ReadExcel</FullClassName>
     <Text>Read Excel</Text>
     <Description>Read Excel</Description>
     <VisibilityMode>AlwaysVisible</VisibilityMode>
     <Assembly>C:\Users\victoria.norve\source\repos\Jada\Jada\bin\Debug\Jada.dll</Assembly>
     <AddInId>D8822352-EC01-42AA-8165-714A26786540</AddInId>
   <VendorId>ADSK</VendorId>
   <VendorDescription>Autodesk, Inc, www.autodesk.com</VendorDescription>
 </AddIn>
</RevitAddIns>
```

Now the Revit file with the BIM model can be opened. When opening Revit, a security warning pops up claiming “The publisher of this add-in could not be verified”. The publisher is however known and therefore the “Always Load” button is pressed. Now an external tool has been loaded into Revit and can be found under Add-ins in the ribbon as shown down below chapter 7.3.3 Visual Studio. Pressing the “Read Excel” external tool makes the file explorer pop up in “C:\Users\UserName\Documents” and with the filetype Excel Files (*xlsx) already chosen. A excel table with fabricated data on temperature supply air was used to illustrate how this looks. The result of importing this file is shown in chapter 7.3.3 Visual Studio.

6.8 Compiling the Thesis Report

Following an extensive literature study that provided a comprehensive knowledge background and societal perspective, as well as research into similar cases, the methodology progressed with the creation and analysis of the POE survey. Subsequently, the basic Revit model was developed, accompanied by the implementation of the Dynamo script responsible for importing properties and coloring the rooms. The process continued with the creation of the Revit add-in and the successful importation of sensor data.

With these essential steps completed, it was time to compile the thesis report. The discussion chapter encompassed a comparison of the case study results with findings from other researchers' studies. Limitations and weaknesses of the thesis methodology and results were thoroughly examined, providing a comprehensive understanding of the research's boundaries. Moreover, the conclusion chapter addressed the key findings directly related to the research questions. Recommendations for future research within the same field were also provided, considering the limitations and potential areas for expanding the scope of the study.

To ensure the overall coherence and clarity of the document, the report involved organizing and sorting the appendixes, removing unused resources, and refining the overall structure. The compilation of the thesis report marks a significant milestone in the research process, consolidating the knowledge, findings, and insights gained throughout the study.

As one of the last steps in the master thesis process a poster was created to summarize the contents, key results, and findings. The poster aims to captivate a larger audience and evoke interest and curiosity. It includes a concise overview of the thesis, highlighting the most important figures. The goal is to present the research in an engaging manner, enticing viewers to explore the topic further. The poster is found in appendix 12.4 A3 – Poster.

7. Results

In the following chapter the results from the thesis are presented. First are the results from the literature study done in preparation, leading up to the POE survey results and ending in the BIM visualization that was achieved using the data from the survey.

7. 1 Literature study

The purpose of this literature study was to gather comprehensive insights and knowledge regarding the factors that influence occupant comfort in buildings. It focused on identifying the most common causes of discomfort and explored the use of POE to identify and address these issues. Additionally, the study explored the application of BIM as a tool for visualizing and analyzing occupant comfort factors, and Revit Add-ins to display data. In this report, the results of the literature study are presented and organized according to the relevant articles in which they were found.

The paper titled "**A probabilistic-based approach to support the comfort performance assessment of existing buildings"** [4] adopted a probabilistic-based methodology to evaluate the comfort performance of buildings. Through the POE data, the study aimed to assess the likelihood of various factors contributing to occupant discomfort. By integrating insights from the POE data with probabilistic analysis techniques, a comprehensive understanding of the buildings' comfort performance was sought. To gather information on occupant perception, preferences, and complaints, a user satisfaction survey was devised. This survey encompassed several convenience factors including thermal comfort, acoustic comfort, indoor air quality, visual comfort, and space adequacy [4].

The survey outcomes highlighted significant factors that contributed to occupant dissatisfaction [4]. During the summer, occupants commonly reported feeling excessively hot, indicating discomfort caused by inadequate temperature control. Similarly, in the winter, many occupants expressed being frequently cold, indicating a lack of temperature control as a source of discontent. Issues related to air quality discomfort were predominantly associated with stuffy air. Problems with glazing and shading, such as sun glare, insufficient daylight, and the inability to control lighting, were identified as main sources of discomfort related to visual comfort. Regarding acoustic quality, the most frequently reported causes of discomfort were noise generated by HVAC equipment, noise originating from exterior equipment, and noise from people conversing in the corridors. These issues were primarily linked to insufficient insulation of interior and exterior walls, affecting acoustic insulation. In terms of space adequacy, respondents commonly expressed dissatisfaction with furniture ergonomics, inflexible workspace design, and inadequate distribution of space [4].

The paper **"Evaluating design strategies, performance and occupant satisfaction: a low carbon office refurbishment**" [92] presents lessons for future buildings that can be learnt from a POE undertaken by the author of a large-scale refurbishment project in Sydney, Australia. The paper yielded the following findings: The study emphasized the significance of enhancing indoor environmental quality for occupants, specifically by incorporating measures such as increased fresh air ventilation, daylight availability, glare control, access to views, and effective noise management. Notably, employees expressed positive feedback regarding their ability to regulate glare by operating the installed blinds, highlighting its contribution to occupant satisfaction. In addition to the occupants` satisfaction the author evaluates the energy performance. The result of the study shows that the reduction in operational energy as a consequence of refurbishment and positive user feedback demonstrates the potential to future-proof existing buildings in the context of climate change [92].

The paper titled **"Nonlinear relationships between individual IEQ factors and overall workspace satisfaction"** [93] aimed to determine the relative significance of indoor environment factors on occupants' satisfaction. The study utilized Kano's model of satisfaction and analyzed post-occupancy evaluation (POE) data from 351 office buildings stored in the Centre for the Built Environment (CBE) database at the University of California [93].

Based on their analysis, the study identified certain factors as "Basic," which were essential for meeting minimum requirements and included temperature, noise level, amount of space, visual privacy, adjustability of furniture, color and textures, and workspace cleanliness [93]. They also categorized factors as "Proportional," where occupants' satisfaction changed proportionally to the performance of these factors. The "Proportional" factors included indoor air quality, lighting, sound privacy, ease of interaction, building cleanliness, and comfort of furnishings. The study found that overall occupant satisfaction increased or decreased linearly in relation to the building's performance in these factors [93].

The research was conducted using a large number of POE questionnaires (43,021) from diverse office buildings across various climate zones and countries (such as Australia, Canada, Finland, and primarily the USA) with different ventilation types [93]. The survey respondents had diverse characteristics, including age, gender, type of work, and hours spent in the workspace. Therefore, the findings of this study are believed to be applicable to office buildings in general [93]

In the 2022 paper titled "**Digital Twin framework for automated fault source detection and prediction for comfort performance evaluation of existing non-residential Norwegian buildings**" [27], an approach to assess the comfort performance of existing buildings was presented. The study utilized survey forms that were developed to gather occupants' feedback on convenience factors, including thermal comfort, acoustic comfort, indoor air quality, visual comfort, and space adequacy. Occupants were asked to specify their occupational settings in the Post-Occupancy Evaluation (POE) survey by identifying the building, floor, and room. Participants were specifically questioned about their perceptions of visual, acoustic, and space adequacy, as well as the quality of indoor air and thermal quality during the winter and summer months. The survey also provided a list of potential causes for discomfort and included a free-form text box for occupants to provide further comments [27].

To identify the causative variables impacting occupant comfort, a probabilistic model trained on a Bayesian Network (BN) was developed [27]. The survey findings were utilized to design the BN model, which considered the most important factors contributing to occupants' feelings of discomfort in Norwegian buildings. The Python box in Dynamo was employed to develop the BN model for occupant comfort. Overall, the study aimed to integrate occupants' feedback, real-time sensor data, the occupants' comfort probabilistic model, and predictive maintenance into a BIM framework for assessing the comfort performance of existing buildings. By importing occupants' feedback and spatial information into the BIM model in Dynamo, the study effectively visualized occupants' comfort levels using a color scale, where red indicated discomfort and green represented a pleasant environment [27].

Additionally, the study discussed the development of an add-in using C# and Visual Studio 2022, enabling the real-time streaming of sensor data from the HVAC system and rooms into the BIM model [27]. The integration of the BIM model, occupants' feedback, and the probabilistic model was achieved using the built-in add-in and visual programming interface for Autodesk Revit, Dynamo, and the Python programming language [27].

The research presented two case studies from Norway, specifically I4Helse and Tvedestrand upper secondary school [27] The findings indicated that occupants of Tvedestrand school classrooms reported high levels of acoustic comfort, while office occupants expressed complaints about noise levels. The study revealed that the primary source of acoustic discomfort was the acoustic insulation of internal walls rather than the ventilation system or the lack of attenuators.
Furthermore, the study identified occupancy density as a significant factor contributing to dissatisfaction with air quality in certain rooms of I4Helse. Higher occupancy levels in these spaces were associated with lower air quality comfort. Respondents also expressed dissatisfaction with the amount of daylight and artificial light in the I4Helse building, highlighting the importance of adequate lighting conditions for occupants' comfort [27].

The article "**Supporting Post-Occupant Evaluation Through Work Order Evaluation and Visualization in FM-BIM"** [35] highlights the benefits of real-time data mining and visualization of occupant complaints in FM-BIM for facility managers to address complaints and optimize building performance. The study conducted at Ryerson University integrates work order data into FM-BIM for comprehensive visualization and analysis [35].

Six subcategories of dissatisfaction (thermal, acoustic, IAQ, visual, condition, and functionality) are defined and aligned with POE requirements [35]. These categories are linked to relevant work order information. The overall metric of Occupant Dissatisfaction (OD) is calculated by summing the dissatisfaction category scores, enabling prioritization [35].

Python coding in Dynamo is utilized for data mapping and populating parameters. This mapping is done at the room, level, and building levels [35]. 3D visualizations help identify potential causes, such as high window-to-wall ratios affecting thermal comfort. Floorplans with increasing saturation represent higher dissatisfaction values, which serves as the primary navigational tool [35].

The article **titled "Assessment of indoor air problems at work with a questionnaire"** [94] conducted a study to assess complaints and symptoms related to the indoor environment among office workers. The study collected data from 122 workplaces between 1996 and 1999.

The findings of the study revealed dry air was the most common problem reported by 35% of the respondents and stuffy air was experienced by 34% of the participants [94]. Approximately 25% of the respondents reported issues with dust or dirt in the indoor environment and draught was a concern for 22% of the participants. These results highlight the prevalence of indoor air problems in office environments and the importance of addressing issues such as dryness, stuffiness, dust/dirt, and draught to create a healthier and more comfortable workspace [94].

The study titled "**Work-related symptoms in indoor environments: a puzzling problem for the occupational physician**" [95] focused on workers from 28 companies in the Latium region of Italy. During their routine medical examination at the workplace, the workers were asked to participate in a questionnaire. The findings of the study revealed several common complaints among the workers. These included sudden changes in indoor temperature, stuffy air, bad smells, tobacco smoke, and dust and dirt. Specifically, 23.1% of the workers reported sudden temperature fluctuations, 21.9% experienced discomfort due to stuffy air, and 21.6% were bothered by unpleasant odors. Additionally, tobacco smoke and dust/dirt were cited by 20.9% and 21.7% of the workers, respectively. 4,029 workers participated in the survey, providing a substantial dataset for analysis. The study also identified a significant correlation between the perception of stuffy air, dry air, and electricity and the occurrence of SBS cases [95].

The study titled **"Acoustical quality in office workstations, as assessed by occupant surveys"** [29] revealed consistent findings across various types of offices regarding the main sources of dissatisfaction. The research indicated that individuals were primarily dissatisfied with the following factors: Hearing other people talking on telephones, overhearing private conversations, and the sound of people talking in surrounding offices. These factors were identified as common sources of dissatisfaction among office occupants, regardless of the specific type of office environment. The study's findings shed light on the significance of addressing acoustical quality concerns to improve occupant satisfaction in office workstations [29].

The study titled "**The impacts of building characteristics, social psychological and cultural factors on indoor environment quality productivity belief**" [96] conducted an internet-based questionnaire among participants aged 18 and older. The participants were recruited from university staff, faculty, researchers, and graduate students occupying office buildings in six countries: Brazil, Italy, Poland, Switzerland, U.S., and Taiwan. The study aimed to identify the causes of occupants' discomfort in thermal, visual, acoustic, and air quality aspect [96].

The findings indicated that the majority of occupants attributed thermal discomfort to differences in temperature between the workspace and surrounding areas, as well as thermostat inaccessibility [96]. In terms of visual discomfort, inadequate natural lighting was identified as the primary cause, along with poor views and window glare. Noise from the inside was reported as the main cause of acoustic discomfort. Stuffy and stale air, along with insufficient natural ventilation, contributed to air quality discomfort among the participants. Furthermore, the study highlighted that the control of light had a more significant impact on the belief in indoor environment quality and productivity compared to other aspects of indoor environment quality [96].

In the paper titled **"Post-occupancy studies of an office environment: Energy performance and occupants' satisfaction"** [97]. The researchers confirmed previous findings regarding the key factors influencing employees' workplace satisfaction. The study highlighted the following factors as the most important:

- Amount of space: The availability of sufficient space in the office environment was identified as a significant factor impacting employees' satisfaction [97].

- Noise management: Effective management of noise levels within the office space emerged as a crucial factor contributing to employee satisfaction [97].

- Visual privacy: The provision of visual privacy, ensuring individuals feel comfortable and undisturbed in their workspace, was found to be a key determinant of workplace satisfaction [97].

Furthermore, the study revealed that satisfaction with the "interior use of space" played a pivotal role in influencing employees' overall well-being and enjoyment at work [97]. This aspect had the strongest correlation with employees' perceived well-being and enjoyment, highlighting its significance in creating a positive work environment [97].

This paper **"Spatial mapping of occupant satisfaction and indoor environment quality in a LEED platinum campus building"** [98] presents a POE study conducted on a university campus. The study utilized a GIS-based spatial mapping method as part of a multiple-tool POE approach to analyze and visualize occupant satisfaction and indoor environment quality.
The survey collected participant feedback on various aspects of their workspaces, including temperature, humidity, air quality, air movement, air freshness, lighting conditions, visual privacy, and speech privacy. Overall, occupants expressed satisfaction with the indoor environment, but there were areas of concern. Thermal comfort received lower satisfaction ratings, with a significant percentage of occupants reporting their workspaces as too cold. Speech privacy satisfaction was lower in individual offices due to construction details such as interior walls [98]**.**

The survey also identified reasons for thermal discomfort and 41 out of the 46 participants responded with at least one cause of dissatisfaction [98]. Issues with the heating/cooling system's responsiveness, thermostat adjustment by others, and inaccessible thermostats were the top reported causes of discomfort. Glazing and shading issues, such as incoming sun and difficulty operating blinds or shades, were cited as reasons for thermal discomfort. Participants across multiple floors and zones commonly described their workspaces as "too cold" during winter [98]**.**

The study presented in the paper "**Completing the missing link in building design process: Enhancing post-occupancy evaluation method for effective feedback for building performance**" [37] focuses on using spatial mapping in two campus buildings to demonstrate how POE can improve the feedback loop in building design. By linking performance outcomes with spatial information, this method enhances data management and visualization of POE data. It allows for the clear representation of occupancy satisfaction and indoor environmental conditions on vector layers with color-coded visuals [37].

The paper highlights the importance of sharing POE data to identify strengths and weaknesses in high-performance buildings [37]. However, the complexity of current analysis methods creates challenges for non-experts. To address this, there is a need to facilitate information sharing among stakeholders and the supply chain. Although BIM holds great potential in the AEC industry, there is a lack of established methodology or framework for integrating BIM with POE in existing literature. Integrating BIM with POE can significantly enhance performance analysis and visualization, ultimately contributing to more efficient project delivery [37].

The 2021 paper titled **"Enhancing occupants' comfort through BIM-based probabilistic approach"** [3] introduces a novel method that combines occupants' feedback and a comfort probabilistic model within Building Information Modeling (BIM). The authors employed tools like Autodesk Revit, Dynamo, and Python to integrate the occupants' feedback into the BIM model, enabling visualization and identification of factors contributing to occupants' discomfort [3].

To facilitate this integration, the authors created a POE survey using Google Forms, focusing on comfort criteria [3]. The collected feedback was then exported to Microsoft Excel as an intermediate format. Using Dynamo and Python scripts, the feedback for each comfort aspect was imported and matched with relevant rooms in the BIM model. This mapping process allowed for a comprehensive representation of occupants' satisfaction by color-coding the rooms in Revit. One noteworthy finding highlighted in the study is the significant impact of occupancy density (m^2/person) on indoor air quality perception [3].

The article "**Multiobjective optimization of building energy consumption and thermal comfort based on an integrated BIM framework with machine learning-NSGA II**" describes the use of Microsoft Visual Studio to create a Revit add-in [19]. This add-in enables the reading of real-time sensor data and the storage of the data in a database, while also ensuring that the BIM model remains up to date. To enhance the visualization of occupant comfort conditions, a color scheme based on comfort thresholds was incorporated into the add-in. Within the BIM model, sensor blocks were utilized to receive and display the sensor data [19].

7.2 The Post-Occupancy Evaluation Survey

The results are divided in two because one survey was in Norwegian and the other one in English. The results were combined and translated to English due to the language of this thesis. SurveyXact has a built-in analyze and report tool, making different types of graphs automatically [99]. Some of them are presented in this subchapter. The figures are also presented in appendix 12.1 SurveyXact Report.

7.2.1 Opening Questions

The survey had 51 respondents where about half of the respondents resided in the H building, and the rest resides in the D - and C-building in UiA's location in Grimstad. One of the first questions of this survey is "how long have you been working in this building?", the answers is shown in the pie chart Figure 7-1 down below. As shown, 56 percent had worked in the building between 1 and 5 years, 33 percent had worked there for more than 5 years, and 12 percent has worked there for less than one year. The survey has some seasonal based questions, since most of the respondents have worked in the same building for at lead 1 year, they may have experienced all the season related variables.

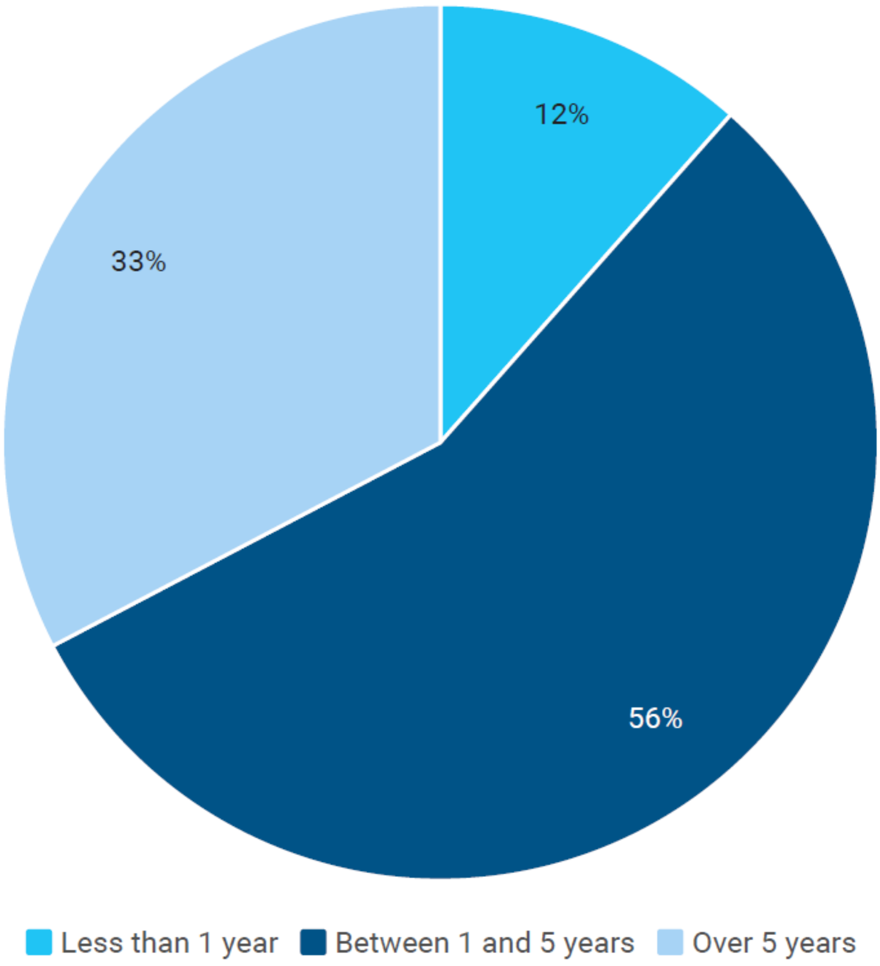

Figure 7-1: Pie chart from question: "How long have you been working in this building?"

When asked what the respondents could personally control or adjust in their workspaces, 72 percent answered curtains and 55 percent light level and clothes level. 49 percent had operable windows and 40 percent had an operable thermostat. This can be seen in Figure 7-2 below.

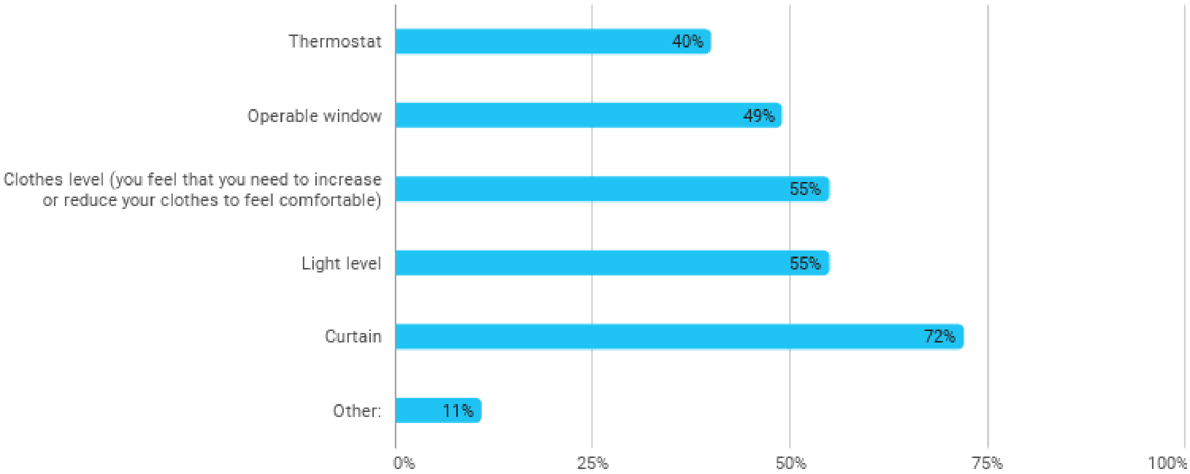

Figure 7-2: Answers to" Which of the following do you personally adjust or control in your workspace?"

7.2.2 Temperature Comfort

Section two of the survey questions the degree of satisfaction in relation to different aspects of the respondent's workplace. The respondents had 6 answering options under each aspect ranging from very satisfied to very dissatisfied, including not applicable. The first aspect is temperature comfort, both during summer and winter. During summer, as displayed by the Figure 7-3 underneath, 70 percent of the respondents answered neutral, satisfied, or very satisfied. With six percent answering non applicable it leaves 24 percent dissatisfied or very dissatisfied.

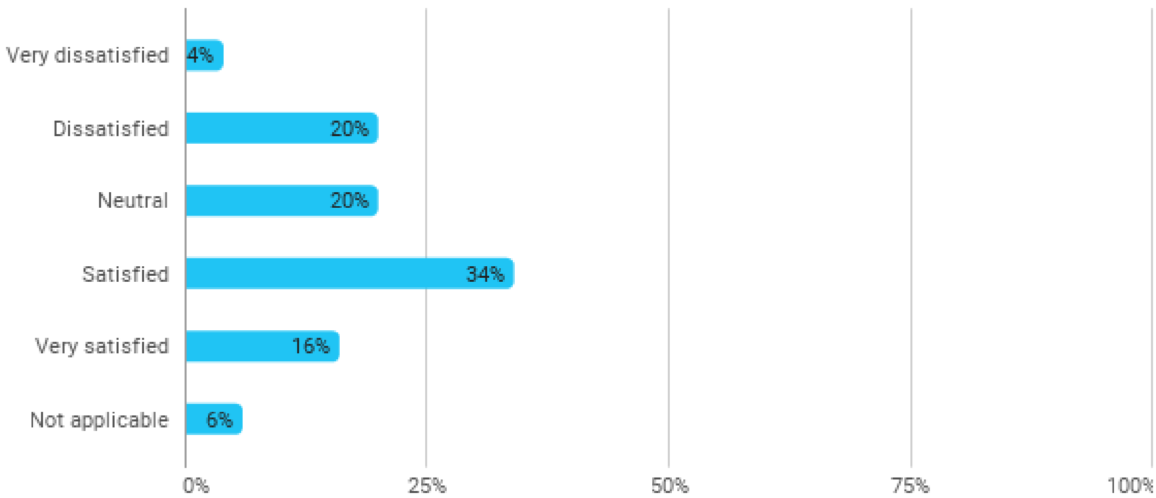

Figure 7-3: Answers to "Degree of satisfaction: Temperature comfort during summer"

The next question, temperature comfort in winter, is shown in the Figure 7-4 underneath. About 76 percent is either neutral, satisfied or very satisfied. The percentage respondents very satisfied with the temperature comfort is 16 percent, both during winter and summer.

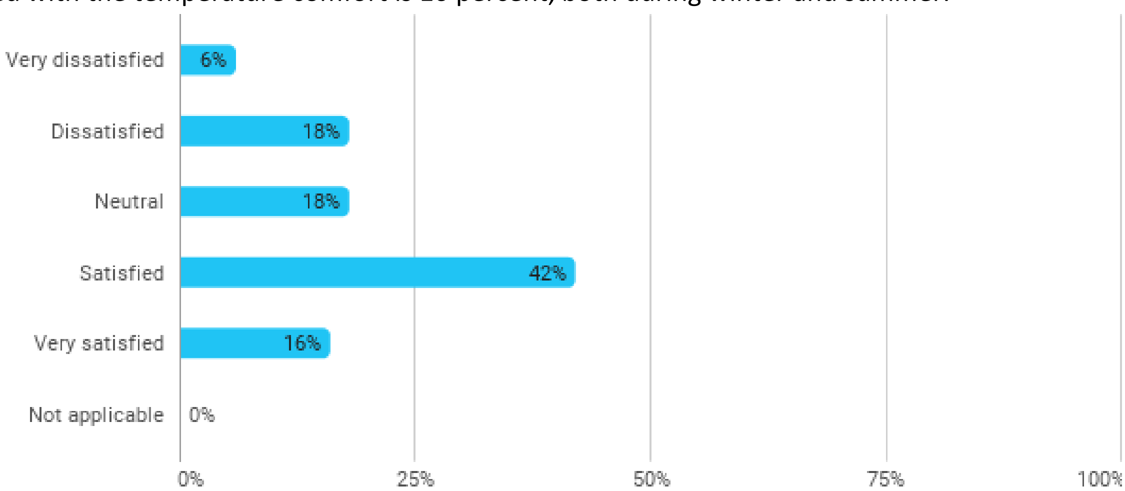

Figure 7-4: Answers to: "Degree of satisfaction: Temperature comfort during winter"

For those that answered unsatisfied, a prompt to further explain their discomfort, shown in Figure 7-5 below. 42 percent answered that it was "occasionally too cold", 11 percent answered "often too

cold", and 8 percent answered, "always too cold". Together, about 61 percent answered that some form of cold temperatures contributed to temperature discomfort.
31 percent answered, "occasionally too hot", 17 percent answered "often too hot", 6 percent answered "always too hot". Together, about 54 percent answered that some form of hot temperatures contributed to temperature discomfort. In this question it was possible to pick more than one answer, resulting in a total over 100 percent.

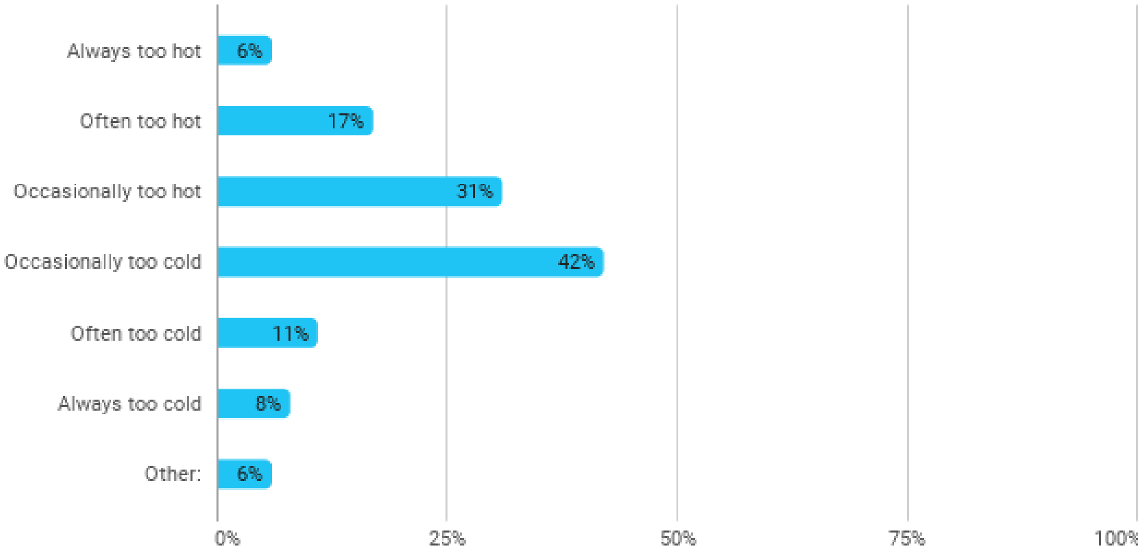

Figure 7-5: Answers: "What contributes to the respondent's possible temperature discomfort."

7.2.2 Indoor Air Quality Comfort

The next topic under section two: " *2.1. Indicate the degree of your satisfaction in relation to the different aspects of your workplace*" is indoor air quality. Same as temperature comfort, the question is split between summer and winter. First up is summer indoor air quality shown in Figure 7-6 below. 66 percent of the respondents were either neutral, satisfied or very satisfied. 28 percent answered a degree of dissatisfaction, and 6 percent answered not applicable.

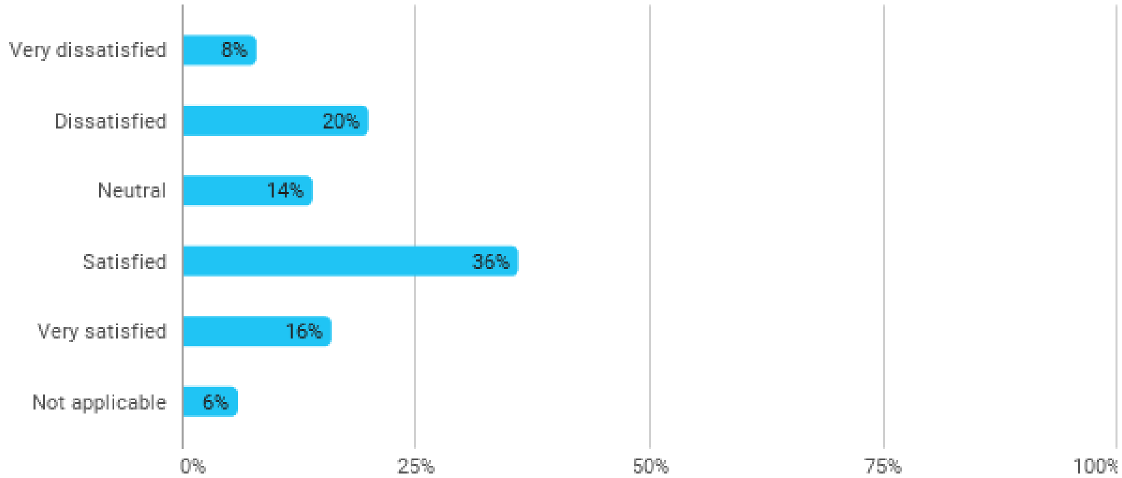

Figure 7-6: Answers to: "Degree of satisfaction: Indoor air quality during summer"

Figure 7-7 below shown answers to the degree of satisfaction in indoor air quality during winter. 82 percent of the respondents answered neutral or a degree of satisfaction, and 18 percent answered a degree of dissatisfaction.

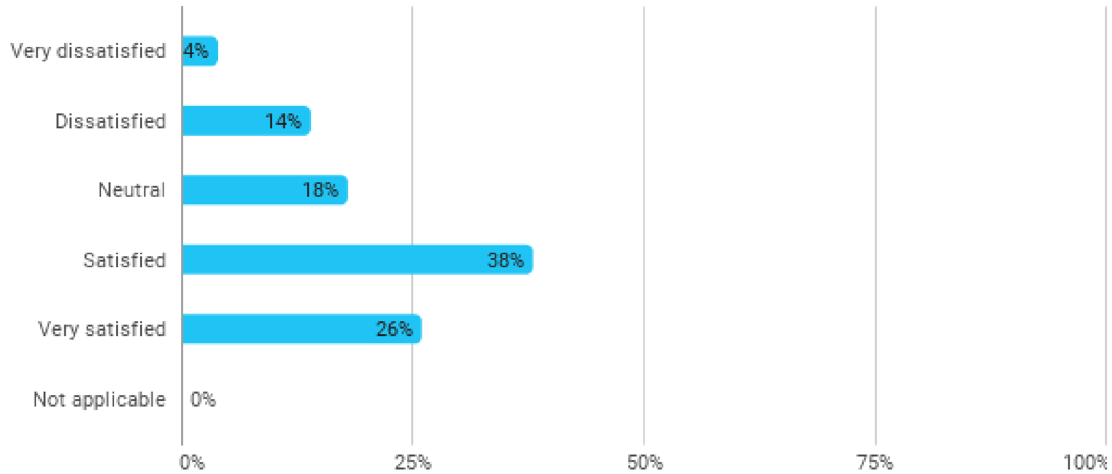

Figure 7-7: Answers to: "Degree of satisfaction: Indoor air quality during winter"

Under section 2.2 *"If you are dissatisfied, which of the following contribute to your discomfort regarding:"* the following answered was collected for "indoor air quality" shown in Figure 7-8 below. "The air being stuffy" was the most chosen answer with 59 percent of the answers, followed by 36 percent for "there ae disturbing odors", 26 percent for "other" and 19 percent for "the air is dry". None of the respondents that were dissatisfied with the air quality chose "the air is humid" as a contributing factor for their dissatisfaction. Some respondents used the other tab to write a contributing factor that wasn't a suggested answer, some of these included bad air circulation, dissatisfaction with the ventilations operating times, and air pollution seeping through open windows.

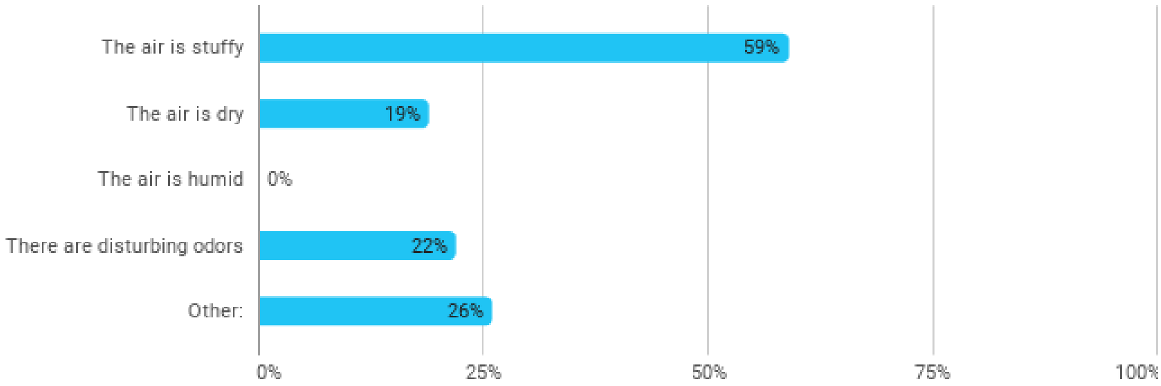

Figure 7-8: "What contributes to the respondent's possible indoor air quality discomfort."

7.2.3 Visual Comfort

The next topic under section two: " *2.1. Indicate the degree of your satisfaction in relation to the different aspects of your workplace*" is visual comfort or in other words: light level. 78 percent of the respondents were either neutral or satisfied in some form, leaving 22 percent feeling a form of dissatisfaction. This can be seen in Figure 7-9 below.

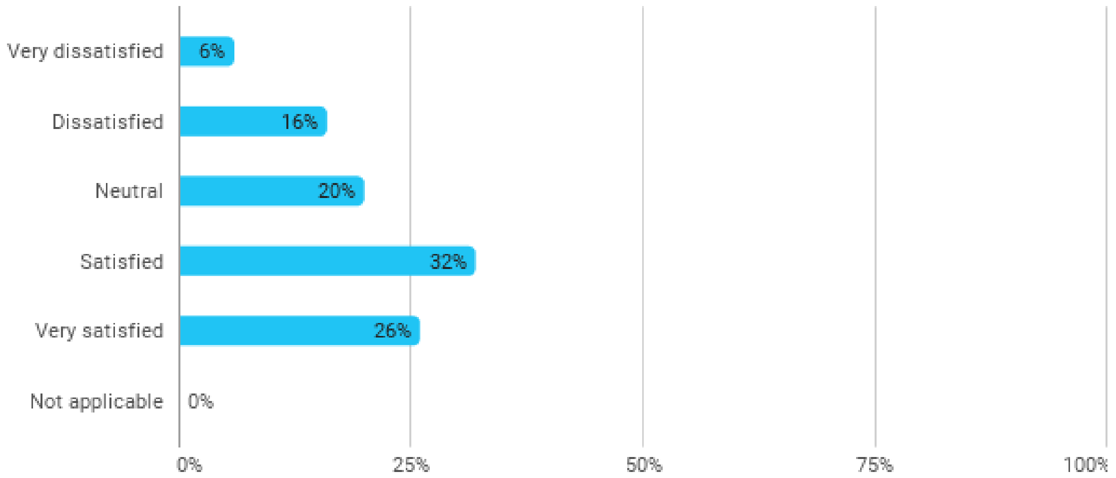

Figure 7-9: Answers to: "Degree of satisfaction: Visual comfort (light level)"

Under section 2.2 *"If you are dissatisfied, which of the following contribute to your discomfort regarding:"* the following answered was collected for "visual comfort" is shown in Figure 7-10 below. 42 percent of the respondents that are dissatisfied with the visual comfort listed "Impossibility to control light" as a contributing factor, 35 percent answered, "glare of sunlight", 26 percent answered, "lack of daylight", 16 percent answered: "low level of artificial light", 6 percent answered: "dark" and 3 percent answered: "high level of artificial light". 19 percent answered: "other", and some of the respondents wrote a reason under the "other tab", some of these included a variant of: "automatic outside blinds, not controllable for the occupants" and "automatic room lights that turn of while occupants are in the rooms".

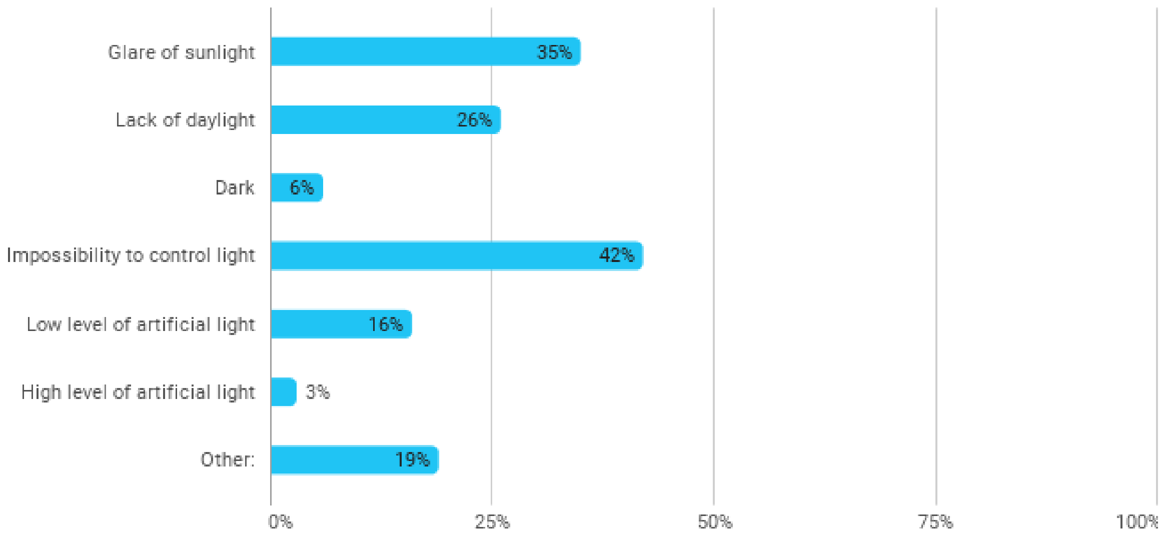

Figure 7-10: Answers to: "What contributes to the respondent's possible visual discomfort."

7.2.4 Acoustic Comfort

The next topic under section two: “ *2.1. Indicate the degree of your satisfaction in relation to the different aspects of your workplace*” is acoustic comfort or in other words: noise level. 76 percent of the respondents were either neutral or satisfied in some form, leaving 24 percent feeling a form of dissatisfaction. This can be seen in Figure 7-11 below.

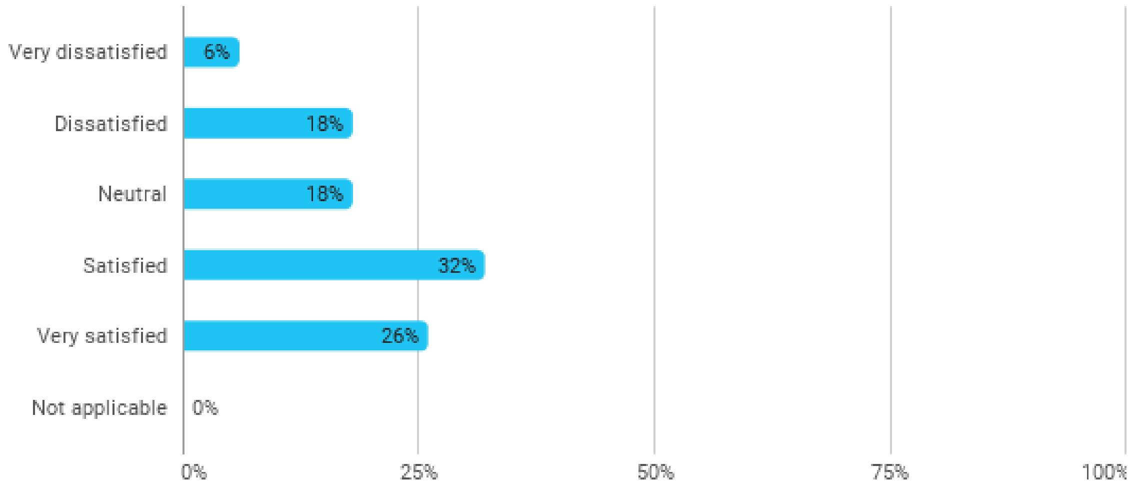

Figure 7-11: Answers to: "Degree of satisfaction: Acoustic comfort (light level)"

Under section 2.2 *“If you are dissatisfied, which of the following contribute to your discomfort regarding:”* the following answered was collected for “Acoustic comfort” is shown in Figure 7-12 below. 58 percent of the respondents that are dissatisfied with the acoustic comfort answered: “no sound insulation between rooms” as a contributing factor, 46 percent answered: “people talking loud in the corridor”, 35 percent answered: “noise from exterior machines”, and 8 percent answered: “noise from air conditioner unit. None of the respondents answered: “noise from lights” or “noise from elevator”. 12 percent answered “other” and some of the respondents wrote a reason under the “other tab”, some of these included a variant of: “Noise from people/ workstations in the same room”.

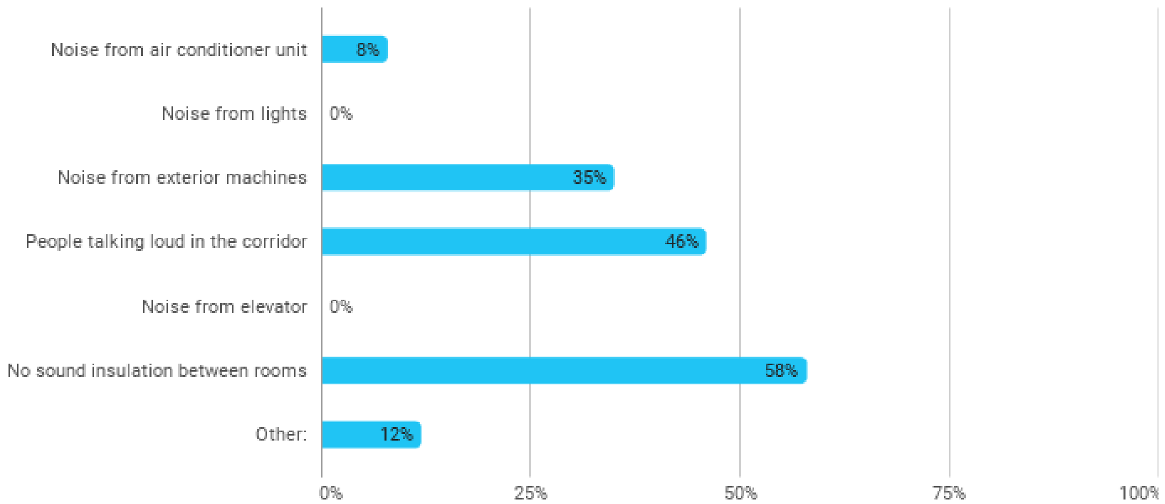

Figure 7-12: Answers to: “What contributes to the respondent’s possible acoustic discomfort.”

7.2.5 Space Adequacy Comfort

The next topic under section two: " *2.1. Indicate the degree of your satisfaction in relation to the different aspects of your workplace*" is space adequacy comfort. 88 percent of the respondents were either neutral or satisfied in some form, leaving 12 percent feeling a form of dissatisfaction. This can be seen in Figure 7-13 below.

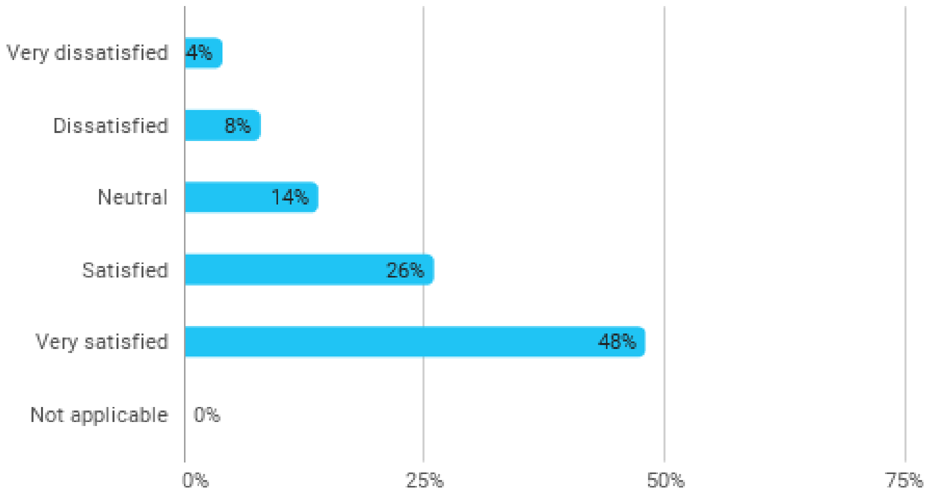

Figure 7-13: Answers to: "Degree of satisfaction: Space adequacy comfort"

Under section 2.2 *"If you are dissatisfied, which of the following contribute to your discomfort regarding:"* the following answered was collected for "Space adequacy comfort" is shown in Figure 7-14 below. 42 percent of the respondents that are dissatisfied with the acoustic comfort answered: "quantity of space (m2)" as a contributing factor, 37 percent answered: "ergonomics of char and table", 21 percent answered: "privacy", 21 percent answered, "lack of flexibility", and 16 percent answered: "circulation space. None of the respondents answered: "availability of equipment (furniture, printer, etc.)". 26 percent answered "other" and some of the respondents wrote a reason under the "other tab", some of these included a variant of: "limited space for meeting student and colleagues".

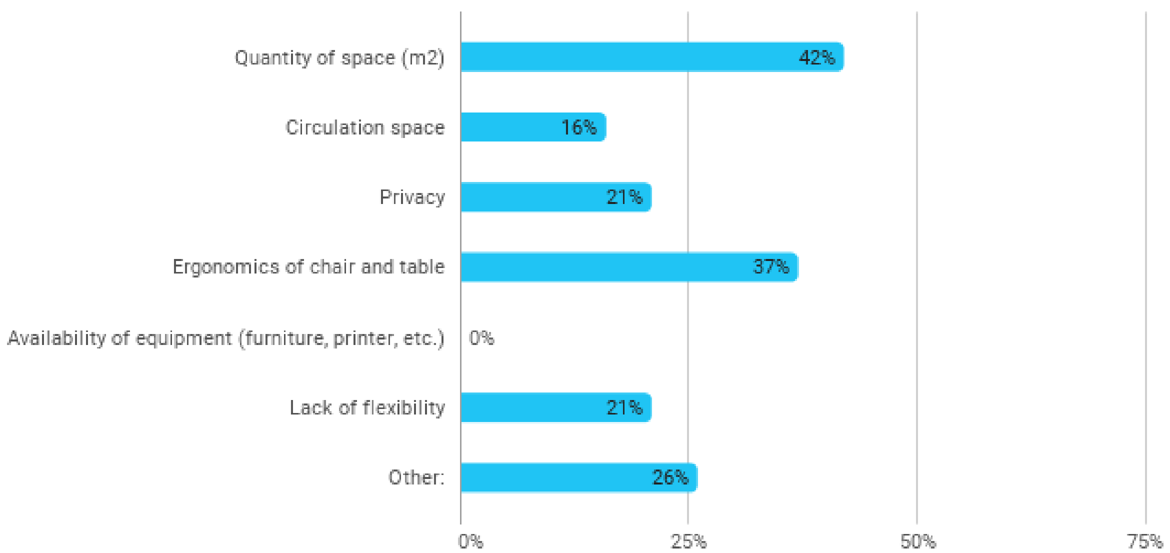

Figure 7-14: Answers to: "What contributes to the respondent's possible space adequacy discomfort."

7.2.6 Comparative Data

In this subchapter, data from the previous subchapter under 7.2 Survey on comfort criteria is visualized in other ways and compared.

In Figure 7-15 down below, the degree of satisfaction of each comfort criteria are gathered and compressed to one model. Under each comfort criteria such as “temperature comfort in summer” the number of the respondents is divided by color showing how each respondents answered.

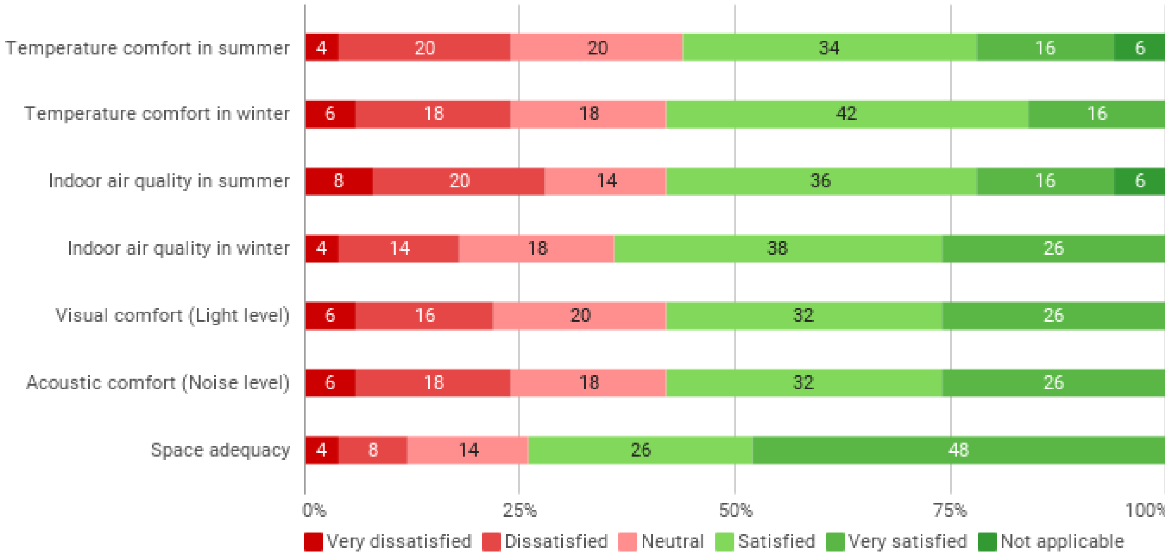

Figure 7-15: Answers from "degrees of satisfaction" compacted.

The figure makes it easier to compare the degrees of satisfaction through the different criteria. The figure shows that “indoor air quality in summer” is the criteria with the most respondents answering: “very dissatisfied”, and “dissatisfied”, followed by “temperature comfort in summer”, “temperature comfort in winter”, and “acoustic comfort”. Space adequacy is the criteria with the highest number of respondents answering: “very satisfied”, it is almost double the amount the other criteria get.

7.3 The BIM Visualization

Chapter 7.3 The BIM Visualization describes the results gained from importing and visualize occupants comfort level data in and sensor data in the BIM. First the BIM model was created in Revit as seen in 7.3.1 The BIM Model. Then Dynamo was used to import the room data and colorize the 3D rooms based on this data in chapter 7.3.2 Dynamo. Lastly Visual Studio was used to import and read sensor data into the BIM model in chapter 7.3.3 Visual Studio.

7.3.1 The BIM Model

The BIM model was made using Revit 2022 and generic room data from floor plans. Each of the rooms have the same geometry with an area of 9 m^2. Two rooms from each building were chosen to demonstrate the possibilities in excel. The room number has been modified to the generic C1, C2, D1, D2, H1, and H2 to protect the anonymity of the occupants of these offices. The base model created in Revit before any coding and scripting is displayed in Figure 7-16 in 3D and in Figure 7-17 in 2D.

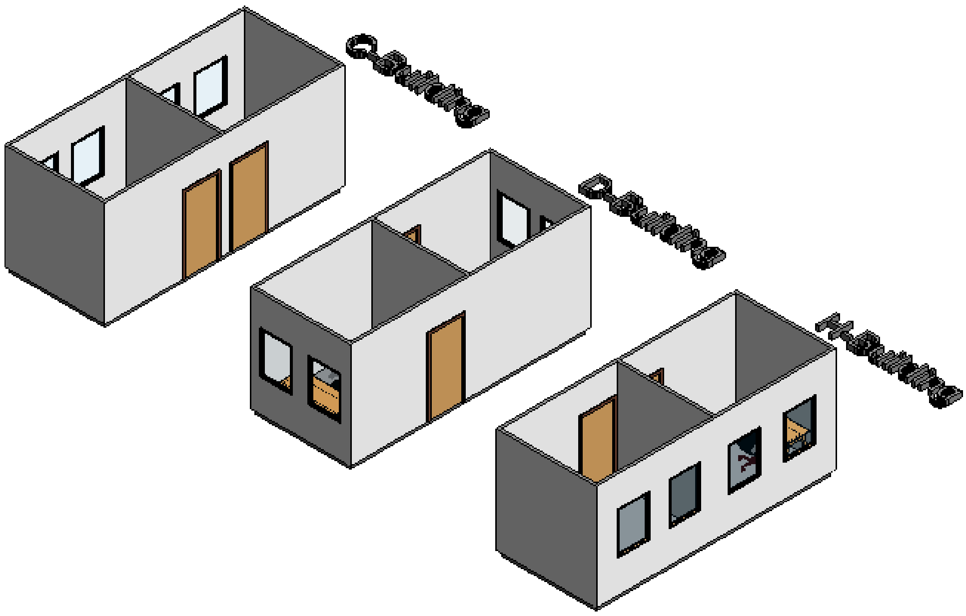

Figure 7-16: The base of the BIM model in 3D

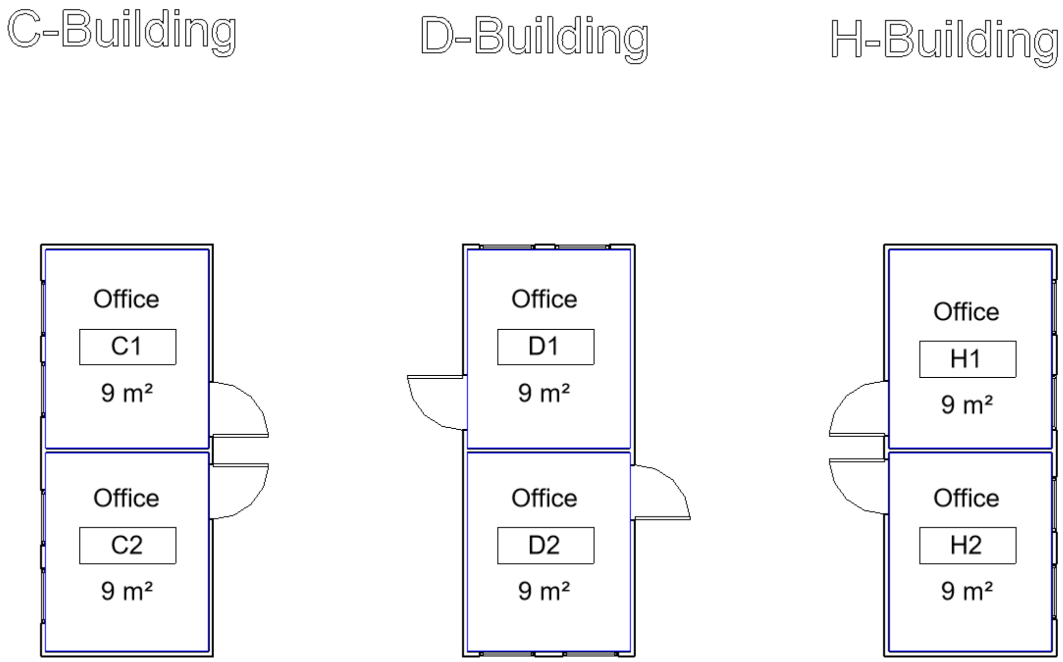

Figure 7-17: The base of the BIM model in 2D

7.3.2 Dynamo

Dynamo 2022 was chosen to create a script that imports the properties into each room in 2D and 3D based on data from the POE-survey and colors the rooms in 3d based on these parameters. The finished script in Dynamo is displayed in figure Figure 7-18. An in-depth look at the script can be found in chapter 6.6 Dynamo, and more pictures can also be found in appendix 12.2 Figures from Dynamo Script.

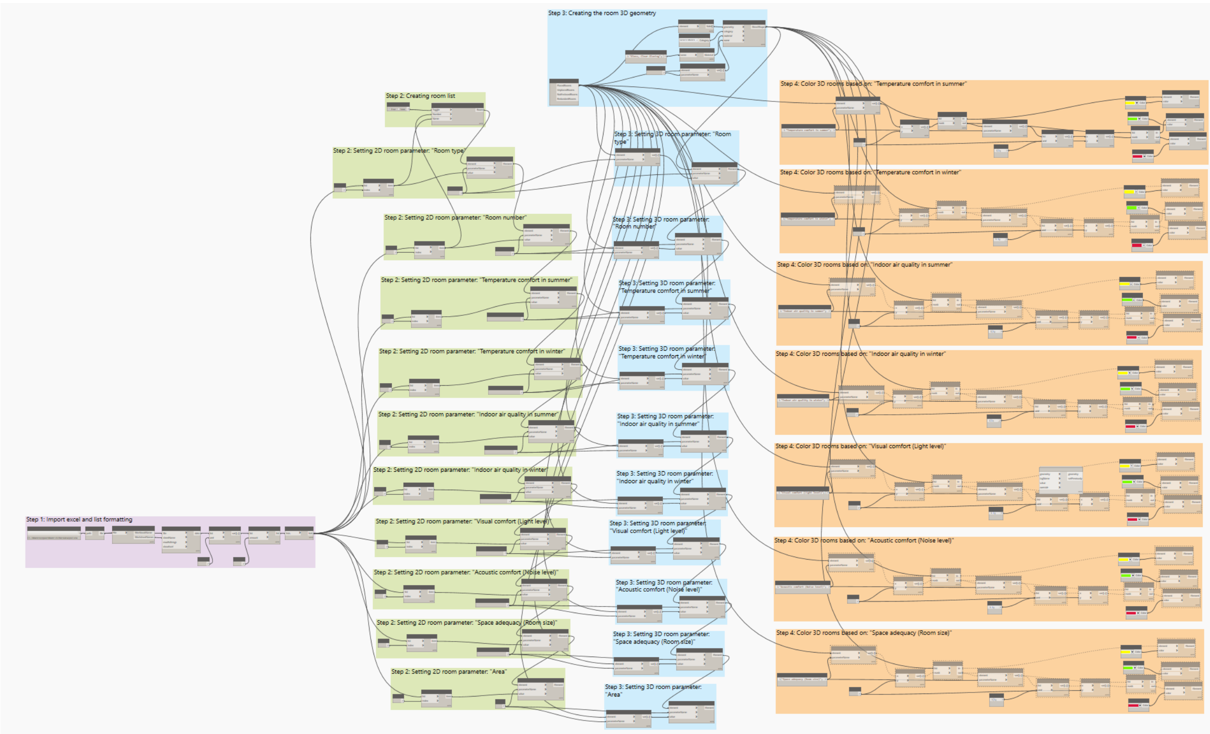

Figure 7-18: Overview picture of the whole Dynamo Script

The group of nodes in the script that are colored purple and green imports the excel data of the rooms from the POE survey and sets the data as parameters for the 2D rooms in the BIM model. The blue colored group of nodes creates the 3D geometry of the rooms and imports the same properties to the rooms in 3D. These properties can be seen in figures: Figure 7-19, Figure 7-20, Figure 7-21, Figure 7-22, Figure 7-23, and Figure 7-24. In the figures each room has parameters that depicts the level of satisfaction from the occupants of the rooms on the comfort criteria on a scale of 1 to 5, which originates from the scale very dissatisfied to very satisfied. The orange group of nodes colorize the rooms on how well the room scored on each of the comfort criteria. The rooms that scored 3 or higher is colored green and the rooms that scored 2 or lower is colored red. The operation is done for each comfort criteria by freezing the other colorization based on other criteria. The colorization of each room based on the comfort criteria can be seen in figures: Figure 7-25, Figure 7-26, Figure 7-27, Figure 7-28, Figure 7-29, Figure 7-30, Figure 7-31.

Identity Data	
Image	
Comments	
Mark	
Temperature comfort in winter	2.000000
Room type	Office
Room number	C1
Temperature comfort in summer	3.000000
Indoor air quality in summer	2.000000
Indoor air quality in winter	3.000000
Visual comfort (Light level)	4.000000
Acoustic comfort (Noise level)	3.000000
Space adequacy (Room size)	2.000000

Figure 7-20: Properties of 3D room C1

Identity Data	
Image	
Comments	
Mark	
Temperature comfort in winter	4.000000
Room type	Office
Room number	C2
Temperature comfort in summer	2.000000
Indoor air quality in summer	1.000000
Indoor air quality in winter	1.000000
Visual comfort (Light level)	2.000000
Acoustic comfort (Noise level)	2.000000
Space adequacy (Room size)	5.000000

Figure 7-19: Properties of 3D room C2

Identity Data	
Image	
Comments	
Mark	
Temperature comfort in winter	4.000000
Room type	Office
Room number	D1
Temperature comfort in summer	4.000000
Indoor air quality in summer	4.000000
Indoor air quality in winter	4.000000
Visual comfort (Light level)	5.000000
Acoustic comfort (Noise level)	5.000000
Space adequacy (Room size)	5.000000

Figure 7-22: Properties of 3D room D1

Identity Data	
Image	
Comments	
Mark	
Temperature comfort in winter	1.000000
Room type	Office
Room number	D2
Temperature comfort in summer	1.000000
Indoor air quality in summer	1.000000
Indoor air quality in winter	1.000000
Visual comfort (Light level)	1.000000
Acoustic comfort (Noise level)	1.000000
Space adequacy (Room size)	1.000000

Figure 7-21: Properties of 3D room D2

Identity Data	
Image	
Comments	
Mark	
Temperature comfort in winter	4.000000
Room type	Office
Room number	H1
Temperature comfort in summer	4.000000
Indoor air quality in summer	4.000000
Indoor air quality in winter	4.000000
Visual comfort (Light level)	2.000000
Acoustic comfort (Noise level)	1.000000
Space adequacy (Room size)	1.000000

Figure 7-23: Properties of 3D room H1

Identity Data	
Image	
Comments	
Mark	
Temperature comfort in winter	5.000000
Room type	Office
Room number	H2
Temperature comfort in summer	5.000000
Indoor air quality in summer	4.000000
Indoor air quality in winter	5.000000
Visual comfort (Light level)	5.000000
Acoustic comfort (Noise level)	5.000000
Space adequacy (Room size)	5.000000

Figure 7-24: Properties of 3D room H2

In figures: Figure 7-25, Figure 7-28, and Figure 7-30 the rom C1 is colored yellow, this is because the occupant of room C1 is neutral to some of the comfort criteria, more specifically temperature comfort in summer, Indoor air quality in winter, and acoustic comfort, which can be seen by them scoring 3 on the criteria in the properties of the room in Figure 7-20. In Figure 7-29 the rom C1 is colored green, this is because the occupant of room C1 is satisfied with the Visual comfort (Light level), which can be seen by them scoring 4 on the criteria in the properties of the room in Figure 7-20. In figures: Figure 7-26, Figure 7-27, and Figure 7-31 the rom C1 is colored red, this is because the occupant of room C1 is dissatisfied with temperature comfort in winter, Indoor air quality in summer, and space adequacy, which can be seen by them scoring 2 on the criteria in the properties of the room in Figure 7-20.

In figures: Figure 7-25, Figure 7-27, Figure 7-28, Figure 7-29, and Figure 7-30 C2 is colored red, this is because the occupant of room C2 is dissatisfied with some of the comfort criteria, more specifically the temperature comfort in summer, the indoor air quality in summer and winter, the visual comfort, and the acoustic comfort. In the properties of the room that is shown in Figure 7-19 the occupants rated these criteria 1 or 2. However, the occupant of room C2 is satisfied with temperature comfort in winter and space adequacy, rating them 4 and 5. This makes the room green as seen in Figure 7-26 and Figure 7-31.

In Figure 7-25 to Figure 7-31 the rooms D1 and H2 are green, this is because the occupants of Rooms D1 and H2 are satisfied with all comfort criteria, which can be seen by them scoring 4 or 5 on all criteria in the properties of the rooms in Figure 7-22 and Figure 7-24.

In Figure 7-25 to Figure 7-31 the room D2 is red, this is because the occupant of rooms D2 is dissatisfied with all comfort criteria, which can be seen by them scoring 1 on all criteria in the properties of the room in Figure 7-21.

The occupant of room H1 is dissatisfied with visual comfort, acoustic comfort and space adequacy, rating all of them 2 and 1 as seen in Figure 7-23. The occupant of room H1 is satisfied however with temperature comfort in summer and winter and indoor air quality in summer and winter, rating all of them 4. Together this gives the room in Figure 7-29, Figure 7-30, Figure 7-31 a red color and Figure 7-25, Figure 7-26, Figure 7-27, Figure 7-28 a green color.

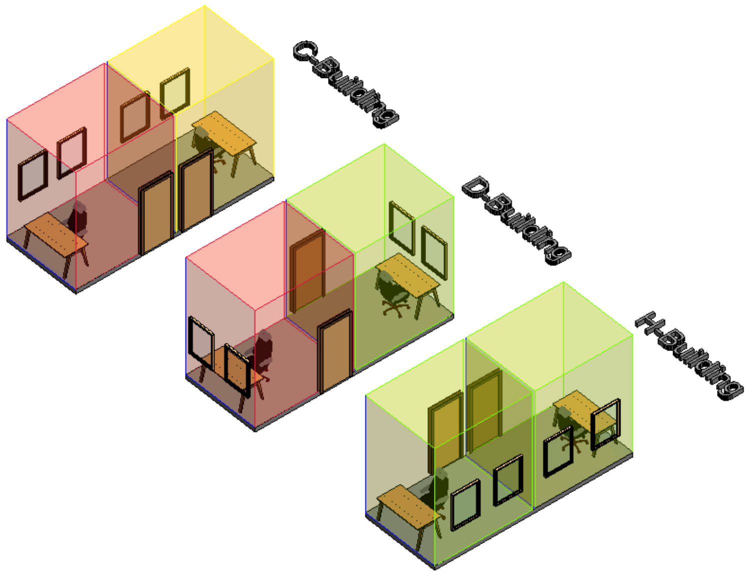

Figure 7-25: Coloring Based on Temperature comfort in summer.

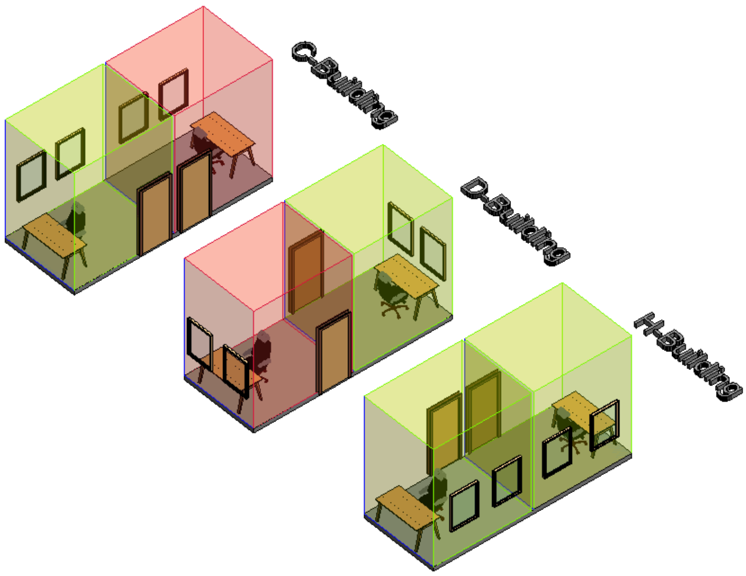

Figure 7-26: Coloring Based on Temperature comfort in winter.

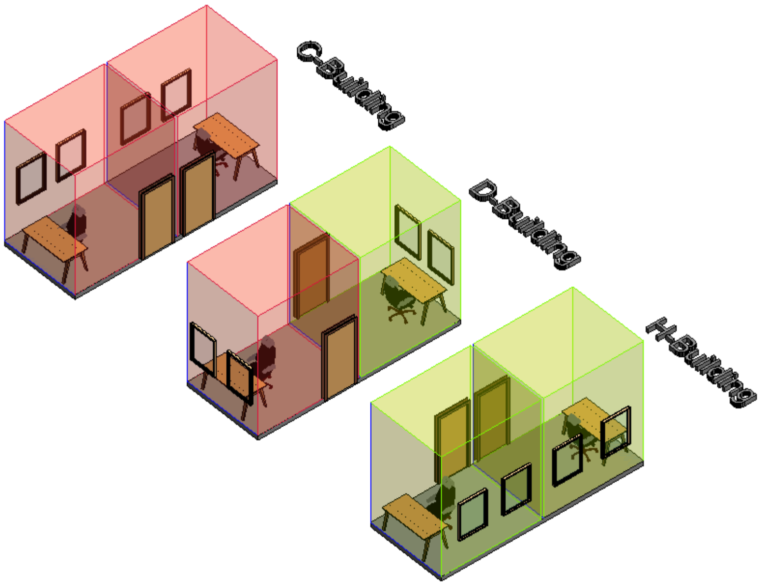

Figure 7-27: Coloring Based on indoor air quality in summer.

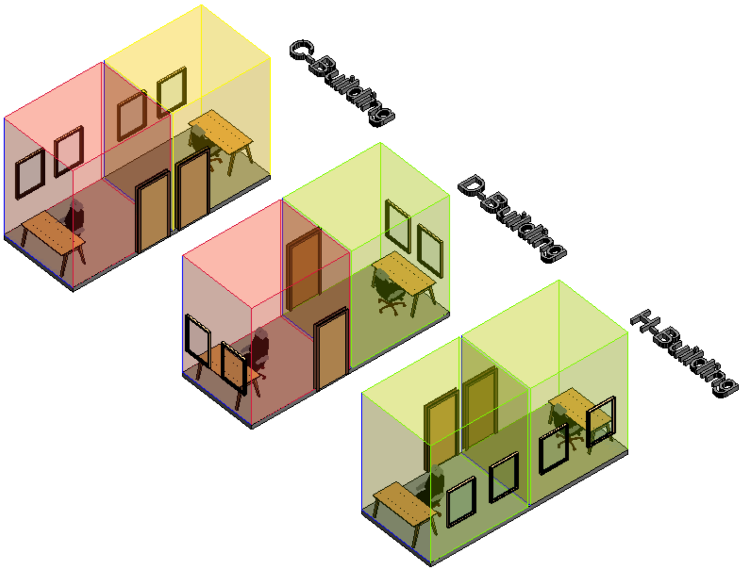

Figure 7-28: Coloring Based on indoor air quality in winter.

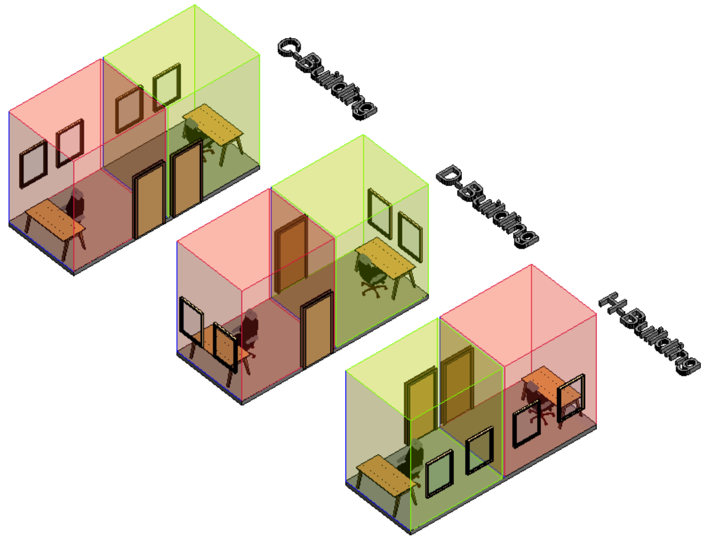

Figure 7-29: Coloring Based on Visual comfort (Light level)

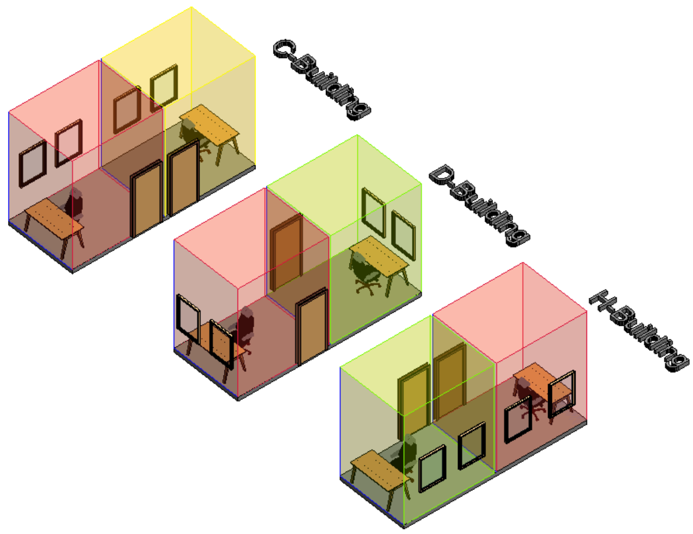

Figure 7-30: Coloring Based on Acoustic comfort (Noise level)

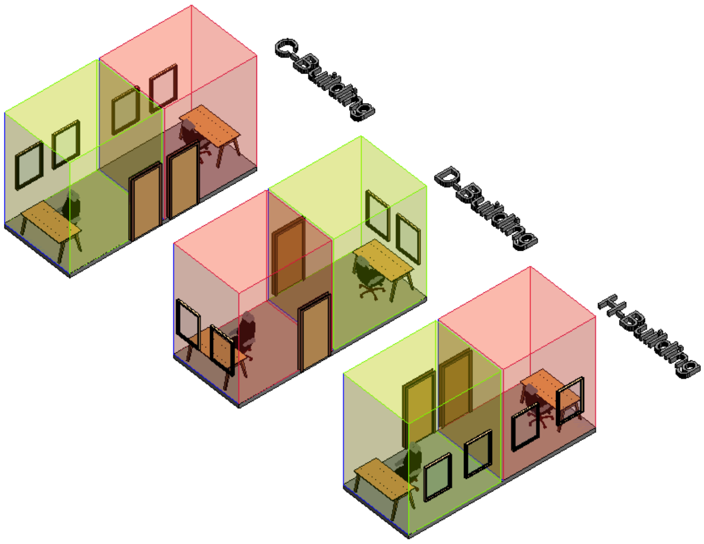

Figure 7-31: Coloring Based on Space adequacy (Room size)

7.3.3 Visual Studio

Visual Studio 2022 was used together with C# programming language to code a Revit add-in that imports, reads, and displays excel data. The code used for importing sensor data is shown below with further explanation of the code found in chapter 6.7 Visual Studio.

```
using Autodesk.Revit.DB;
using Autodesk.Revit.UI;
using OfficeOpenXml;
using System;
using System.IO;

namespace Jada
{

[Autodesk.Revit.Attributes.Transaction(Autodesk.Revit.Attributes.TransactionMode.
ReadOnly)]
    public class ReadExcel : IExternalCommand
    {
        static AddInId appID = new AddInId(new Guid("D8822352-EC01-42AA-8165-
714A26786540"));
        public Result Execute(ExternalCommandData commandData, ref string
message, ElementSet elementSet)
        {
            string filename = "";
            System.Windows.Forms.OpenFileDialog openDialog = new
System.Windows.Forms.OpenFileDialog();
            openDialog.InitialDirectory =
Environment.GetFolderPath(Environment.SpecialFolder.MyDocuments);
            openDialog.Filter = "Excel Files (*.xlsx)|*.xlsx";
            if (openDialog.ShowDialog() == System.Windows.Forms.DialogResult.OK)
                filename = openDialog.FileName;
            else
                return Result.Cancelled;

            string data = "";
            using (ExcelPackage package = new ExcelPackage(new
FileInfo(filename)))
            {
                ExcelWorksheet sheet = package.Workbook.Worksheets[0];
                for (int row = 1; row < 9999; row++)
                {
                    var thisValue = sheet.Cells[row, 1].Value;
                    if (thisValue == null || thisValue.ToString() == "")
                        break;

                    for (int col = 1; col < 9999; col++)
                    {
                        thisValue = sheet.Cells[row, col].Value;

                        if (thisValue == null || thisValue.ToString() == "")
                            break;

                        data += thisValue.ToString() + "     ,     ";
                    }
                    data += Environment.NewLine;
                }
            }

            TaskDialog.Show("Excel", data);
            return Result.Succeeded;
        }
    }
```

```
}
```

The result of this code is shown in Figure 7-32 and Figure 7-33. An external tool is made under the Add-in tab in Revit. Clicking on it prompt the user to import an excel file within the documents folder on the computer. The add-in reads the data from the imported excel file and displays it in a task dialog pop up.

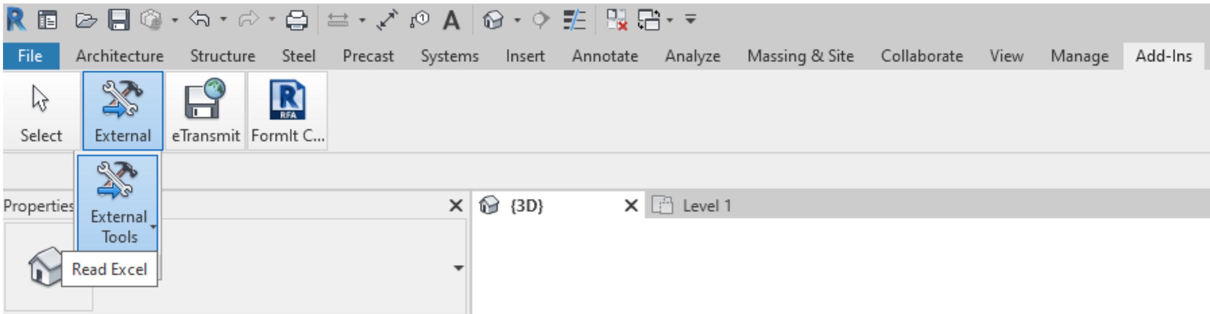

Figure 7-32: An external tool has been added to Revit.

Figure 7-33: An excel table with sensor data was imported using an Add-in.

8. Discussion

This chapter presents a discussion of results from the literature study carried out in the knowledge background, the POE survey, and the BIM visualization against previous findings in the thesis. As well as weaknesses and limitation of the research.

8.1 Using POE Surveys to Find Comfort Level and Sources of Discomfort

The POE survey conducted in this thesis included 51 respondents, all employees of the department of engineering science at UiA's Grimstad location. The survey gathered information on various aspects of comfort and satisfaction within the workplace such as temperature comfort, indoor air quality, visual comfort, acoustic comfort, and space adequacy. Other research papers have used POE methods to find comfort levels, and a some of them are discussed below.

In the study in paper [92] the author undertakes a similar POE survey as the thesis case study on a large-scale refurbishment project in Sydney, Australia. However, in this study, the author evaluates the energy performance in addition to the occupants` satisfaction. This introduces an important an interesting aspect as the results of the study shows that the reduction in operational energy because of refurbishment and positive user feedback has the potential to future-proof existing buildings in the context of climate change [92].

The study in paper [93] aimed to determine the relative significance of indoor environment factors on occupants' satisfaction. It utilizes and analyzes similar POE survey data as the thesis case study from 351 office buildings stored in the Centre for the Built Environment (CBE) database at the University of California. This study however, much like the study in paper [96] introduces an interesting aspect by conducting the survey across diverse office buildings across various climate zones and countries with different ventilation types [93]. Compared to the thesis case study, the study in [93] introduces an interesting aspect by mapping and including occupants with diverse characteristics, including age, gender, type of work, and hours spent in the workspace. Making the findings of this study more applicable to office buildings in general [93].

The study in paper [4] adopted a probabilistic-based methodology to evaluate the comfort performance of buildings. Through POE data, the study aimed to assess the likelihood of various factors contributing to occupant discomfort. In similar fashion as the thesis, the survey gathered information on occupant perception, preferences, and complaint by a using a satisfaction survey . The survey encompassed several convenience factors that match the thesis case study, including thermal comfort, acoustic comfort, indoor air quality, visual comfort, and space adequacy. The study, as opposed to the thesis case study, used a probabilistic analysis technique to achieve a comprehensive understanding of the buildings' comfort performance. [4]. In fact, several studies , such as [27] and [3] have used a probabilistic method together with POE.

The study in paper [98] conducted a POE study on a university campus, similar to the thesis case study. Similar aspects of their workspaces where analyzed, including temperature, humidity, air quality, air movement, air freshness, lighting conditions, visual privacy, and speech privacy.

The study however utilized the spatial data aspect as part of a multiple-tool POE approach to analyze and visualize occupant satisfaction and indoor environment quality. Other POE studies such as the done in paper [27] have used spatial data in combination with the POE. The spacial data aspect is interesting because it introduces a new area to automize and opportunities for a more complex visualization.

Lastly the study in paper [35] from the literature study into the use of POE to find Comfort Level and Sources of Discomfort provides another interesting aspect to the use of POE. The study uses real-time data mining and visualization of occupant complaints into BIM. Six subcategories of dissatisfaction are defined and aligned with POE requirements that is also linked to relevant work order information. Not only does the study introduce the aspect of the relevant work orders for the facility managers, but it calculates an occupant dissatisfaction (OD) score by summing the dissatisfaction category scores, enabling prioritization [35]. This aspect is interesting because it provides the facility managers to identify complaints and optimize building performance all within the same BIM program.

8.2 The Most Common Sources of Discomfort for Building Occupants

This chapter examines and compares the findings and research related to the most prevalent sources of discomfort experienced by building occupants.

The POE survey conducted in the thesis case study encompassed various aspects of comfort and satisfaction within the workplace, including temperature comfort, indoor air quality, visual comfort, acoustic comfort, and space adequacy. Additionally, respondents provided insights into personal control and adjustment options available to them, such as curtains (72%), light levels (55%), clothing choices, and operable windows (44%), with 40% having access to operable thermostats.

To provide further context, several other research papers have conducted their own investigations to identify the common sources of discomfort among building occupants. The following sections explore these studies and compare their findings with those from the thesis survey.

8.2.1 Temperature Comfort

In the thesis POE survey, temperature comfort was assessed, revealing that 70% of respondents were neutral or somewhat satisfied with summer air quality, and 76% expressed similar sentiments about winter temperature comfort. The most commonly cited factor contributing to temperature discomfort quality discomfort was “occasionally too cold” followed by “occasionally too hot”. Temperature comfort in both summer and winter were some of the aspects the occupants expressed the most discomfort with. The importance of temperature comfort is shown in study [93] where temperature was classified as a “basic” essential for meeting minimum requirements .

Similar findings were observed in a referenced study [4], where occupants commonly reported feeling excessively hot in summer and frequently cold in winter, indicating inadequate temperature control as a source of discomfort. As opposed to the thesis POE study, the article from [32] found that occupant satisfaction with room temperature tends to be lower in summer surveys, where the temperature differential is smaller. The study [96] identified differences in temperature between the workspace and surrounding areas, as well as inaccessibility of thermostats, as major contributors to thermal discomfort. Another study [98], revealed lower satisfaction ratings for thermal comfort, with occupants reporting their workspaces as too cold. Issues with the heating/cooling system's responsiveness, thermostat adjustment by others, inaccessible thermostats, and glazing and shading issues were cited as reasons for thermal discomfort.

The thesis POE didn't specifically include "differences in temperature between the workspace and surrounding areas" and "inaccessibility of thermostats" as listed reasons in the survey and could be beneficial to include in future POE surveys.

8.2.2 Indoor Air Quality Comfort

Indoor air quality was assessed in the thesis POE survey, with 66% of respondents being neutral or some form of satisfied with the summer air quality and 82% expressing similar sentiments about winter air quality. The most commonly cited factor contributing to indoor air quality discomfort was "the air being stuffy". This finding aligns with the study referenced as [4], where issues related to air quality discomfort were predominantly associated with stuffy air. Compared to other aspects, the occupants of the thesis case study are the most dissatisfied with the indoor air quality in summer. Paper [93] highlights the importance of indoor air quality by categorizing it as a "Proportional" factor, which means that occupants' satisfaction changed proportionally to the performance of that factor in that study.

The study referenced as [94] identified dry air and stuffy air as the primary factors contributing to air quality dissatisfaction, followed by issues with dust or dirt in the indoor environment and draught. Although these specific reasons were not included as listed options in the thesis case study survey, some respondents mentioned "bad air circulation" in the "other" text option, and "circulation space" was listed under space adequacy. Including these reasons as listed options, along with issues with dust or dirt, in future POE surveys could be beneficial.

Additionally, findings from another study [95] highlighted complaints of sudden temperature changes, stuffy air, unpleasant odors, tobacco smoke, and dust/dirt among workers, in that order of popularity. The study referenced as [96] associated air quality discomfort with insufficient natural ventilation and high occupancy density. While the thesis POE did not include the factor of occupancy density, it would be beneficial to include it in future surveys.

Furthermore, studies referenced as [3] and [27] emphasized the significant impact of occupancy density on indoor air quality perception, indicating its relevance in assessing indoor air quality in future POE surveys.

8.2.3 Visual Comfort

The results from the visual comfort aspect of the thesis case study survey shows a general satisfaction with 78 percent of the respondents being either neutral or satisfied in some form. Amongst the dissatisfied the most common reasons chosen were Impossibility to control light, glare of sunlight and lack of daylight. Very similar to the case study, the study in paper [4] found problems with glazing and shading, such as sun glare, insufficient daylight, and the inability to control lighting were identified as main sources of discomfort related to visual comfort. The study in paper [92] also noted the power sun glare can have on occupant discomfort as employees expressed positive feedback regarding the ability to regulate glare by operating the installed blinds, highlighting its contribution to occupant satisfaction. The study in paper [96] also identified window glare as one of the primary causes to visual discomfort, along with , inadequate natural lighting and poor views.

In summary, the POE survey conducted in the thesis identified the impossibility to control light, glare from sunlight, and insufficient daylight as the main causes of visual discomfort. This finding is consistent with multiple research papers in the literature on this topic, which also reached similar conclusions. However, in study [93] visual privacy was classified as a “basic” essential for meeting minimum requirements for comfort. This aspect was not included in the thesis POE. Therefore, it would be beneficial to include this aspect in future POE surveys. The [93] study, similar to the other studies highlight the importance of lighting on occupants’ comfort by classifying it as a “proportional” factor.

8.2.4 Acoustic Comfort

In terms of acoustic quality, the respondents in the thesis POE survey expressed relatively higher dissatisfaction with the acoustic comfort aspect compared to other aspects. Among the respondents, 76% were either neutral or satisfied to some extent. Among those who were dissatisfied, the most common reasons chosen were the lack of sound insulation between rooms and people talking loudly in the corridor. A study referenced as [4] also highlighted similar findings, identifying noise generated by HVAC equipment, noise from exterior equipment, and noise from people conversing in corridors as the most frequently reported causes of discomfort. These issues were primarily attributed to inadequate insulation of interior and exterior walls, which affected acoustic insulation [4].

The thesis case study aligns with the issue of poor sound insulation of interior walls and people talking loudly in the corridor but doesn't place as much emphasis on noise from HVAC systems. In contrast, the study mentioned in paper [27] shares a similar perspective with the thesis case study, as its results indicated that the acoustic insulation of internal walls was the primary source of acoustic discomfort rather than the ventilation system. Additionally, the study referenced as [98] discovered that low speech privacy satisfaction was related to construction details such as interior walls.

Moreover, the study in paper [29] found that hearing other people's conversations and the sound of people talking in surrounding offices were the most common sources of dissatisfaction among office occupants, regardless of the specific type of office environment. Although the thesis case study survey did not specifically list "hearing other people's conversations within the same office" as a proposed reason for acoustic discomfort, some respondents mentioned "Noise from people/workstations in the same room" in the "other" text option. It would be interesting to investigate if more respondents would have agreed with this reasoning if it had been included as a listed reason in the survey. Similarly, a survey mentioned in paper [96] highlighted the significance of noise originating from components inside the office, reporting "noise from the inside" as the primary cause of acoustic discomfort. The importance of acoustic comfort is shown in study [93] where noise level was classified as a “basic” essential for meeting minimum requirements and sound privacy was categorized a "Proportional" factor.

8.2.5 Space Adequacy Comfort

In terms of space adequacy comfort the respondents in the thesis POE survey expressed the most positive feedback, with 88% of respondents being either neutral or satisfied. However, factors such as the quantity of space, ergonomics of chair and table, privacy, and lack of flexibility were mentioned as contributors to discomfort.

A study referenced as [4] reported similar findings regarding space adequacy. Respondents commonly expressed dissatisfaction with furniture ergonomics, inflexible workspace design, and inadequate distribution of space. While the thesis results align closely with this study, the thesis case study does not specify flexibility as a distinct factor; instead, it only mentions flexibility in a general sense. It could be beneficial to include a more specific version of this reasoning in future POE surveys. Study [93] also highlights the importance of furniture ergonomics by classifying “comfort of furnishings “ as a “proportional” factor.

Additionally, the study referenced as [97] discovered that the availability of sufficient space in the office environment was a significant factor impacting employees' satisfaction. Furthermore, satisfaction with the "interior use of space" played a crucial role in influencing employees' overall well-being and enjoyment at work. Notably, this aspect showed the strongest correlation with employees' perceived well-being and enjoyment [97]. The importance of space adequacy comfort is shown in study [93] where amount of space was classified as a “basic” essential for meeting minimum requirements. Additionally, workspace cleanliness was classified as a “basic” and building cleanliness was classified as a "proportional” factor to occupants’ satisfaction in study [93], and since they were not included in the thesis POE, it should be included in future POE surveys.

8.3 Using BIM and Dynamo to Visualize and Communicate POE Data

Chapter 7.3.2 Dynamo provides an overview of the results obtained from importing and visualizing occupants' comfort level data from a POE survey in the BIM model using Dynamo, and chapter 6.6 Dynamo describes the method behind the results. This chapter describes the use of BIM and Dynamo to visualize POE data in other studies found in the literature study and compared to the method in this thesis. First, a quick summarize of how outcomes of how POE survey was visualized and communicated using BIM and Dynamo in the thesis case study.

The basic Revit model in the thesis study was created in Revit using generic dimensions gathered from floor plans of the buildings. Dynamo was utilized to import room data and colorize the 3D rooms based on this data using visual programming. Two rooms from each building were selected to demonstrate the visualization. Dynamo 2022 was chosen to create a script that imports properties into each room in 2D and 3D based on data from the POE-survey. The script also colorizes the rooms in 3D according to these parameters. The script in Dynamo is divided into different groups of nodes by color and function: purple and green nodes import the Excel data of the rooms from the POE survey and set the data as parameters for the 2D rooms in the BIM model, blue nodes create the 3D geometry of the rooms and import the same properties into the rooms in 3D, and orange nodes colorize the rooms based on their scores for each comfort criterion. Rooms that score 4 or higher are colored green, rooms that score 3 is colored yellow, and rooms scoring 2 or 1 are colored red. Each comfort criterion is colorized individually by using freezing nodes in the Dynamo script.

The paper referenced as [27] visually represent occupants' opinions on various comfort aspects, in a very similar manner as the thesis study, with a color scale ranging from "Very happy" to "Very dissatisfied". This data was imported into the BIM model in Dynamo with red indicating discomfort and green representing a pleasant environment [27]. As a matter of fact, the use of Revit, Dynamo, and color to visualize level of comfort and occupancy satisfaction has also been demonstrated in study [37], [3]. The study [35] uses dynamo and 3D visualizations to help identify potential causes for discomfort. The increasing saturation in color represent higher dissatisfaction values, which serves as the primary navigational tool [35].

8.4 Using Revit Add-ins to Display Sensor Data in BIM

Visual Studio 2022 was used together with C# programming language to code a Revit add-in that imports, reads, and displays excel data. The code used for importing sensor data and the result in Revit is shown in chapter 7.3.3 Visual Studio and explained in chapter 6.7 Visual Studio. In this chapter the use of Revit-add ins for displaying data, especially sensor data is discussed.

Similarly, to the thesis case study, the studies referenced as [27] and [19] use Visual Studio to create a Revit add-in. This add-in enables the reading of real-time sensor data and the storage of the data in a database, while also ensuring that the BIM model remains up to date. Within the BIM model, sensor blocks were utilized to receive and display the sensor data. The thesis case study is based on fabricated sensor data in a excel table to display the future opportunities as opposed to actual real-time sensor data in [19] and [27] study. This is however an interesting aspect that could be implemented in similar case studies in the future.

8.5 Benefits and Limitations of Using BIM With Dynamo and Revit Add-ins to Visualize Data in Buildings?

In this chapter, the advantages, and disadvantages of utilizing Dynamo and Revit Add-ins, as discussed in the knowledge background chapter 3.5 Dynamo vs Revit Add-in are compared and examined based on the personal experience of using them in the methodology of this thesis.

While Dynamo's visual programming tool is generally regarded as an accessible programming tool that doesn't require a coding background [53], it did require a significant amount of time during the thesis process to understand and customize scripts beyond online tutorials. The steep learning curve predicted in the literature [53] proved to be true, and basic logic behind visual programming was gained as dependency on learning materials diminished. The open-source nature of Dynamo [53] proved beneficial, with a lot of free online resources and expert forums available for assistance.

However, the use of connection lacing between nodes in Dynamo resulted in scripts that appeared disorganized and challenging for others to read, presenting difficulties when trying to comprehend external scripts and when presenting the final script in the thesis report. In addition to this, understanding the purpose and logic behind each node in Dynamo was not always straightforward, particularly due to outdated information online that didn't align with all the versions of the program.

In contrast, Revit add-ins offered clear advantages by providing complete control over the code logic, potentially saving some time compared to using packages and nodes in Dynamo [53].

The aspect of having to regularly do maintenance on Dynamo scripts when updating the program because nodes becoming outdated [53] became apparent during the process of this thesis meaning that the knowledge gained, and results achieved through Dynamo scripting will become partially outdated. Additionally, the project-specific nature of the script poses challenges for implementation in real-world facility management, especially considering the lack of an established methodology or framework for integrating BIM with POE in existing literature [37].

Dynamo may not be the most efficient computing language compared to Revit add-ins with program code [41]. This didn't prove to be a challenge in this thesis however, probably because the algorithms relatively aren't very complex with a moderate number of nodes. However, this is the reason for wanting to explore the use of Revit Add-ins, displaying data from an excel file to Revit can be done relatively easy in Dynamo, as shown in this thesis, but when using a continuous exchange of data , such as real time sensor data, It can be very time-consuming and demanding on the Revit software to use Dynamo [41]. Therefore, by using a smart code editor, such as Visual Studio, it ensures efficient tools and faster computing times [53]. However, using C# and Revit in Visual Studio presented challenges such as having to restart Revit every time a logic change was made and dealing with constant warning pop-ups due to the Revit add-in lacking digital signature [53].

Prior research indicated that learning a coding programming language like C# can be time-consuming and challenging for beginners, such as the author of this thesis, given the deeper understanding of the Revit API required [53]. Despite focusing mainly on Dynamo in this thesis, venturing into learning C# and Revit add-ins was deemed interesting due to the limitless options and usefulness in the field. However, the time constraints of the research made the learning process behind C# and Revit add-ins particularly challenging, perhaps raising questions about whether this method poses significant challenges for non-experts, especially considering the thesis's potential target audience of facility managers with limited programming backgrounds. Nonetheless, it resulted in a basic understanding of the C# language and the Revit API's functionality, providing a useful foundation for future research and the development of a plug-in.

8.6 Weaknesses and Limitation

Multiple potential weaknesses and limitation with the master thesis was identified during the thesis process, in this chapter they are described and discussed.

In hindsight, it is evident that the progress plan formulated at the initial stages of the thesis process was not very realistic. This lack of realism arose from challenges in accurately predicting achievable goals within the given time frame and the occurrence of unforeseen obstacles. Furthermore, the progress plan was not adequately updated throughout the process, which could have transformed it into a valuable tool.

The literature study in this thesis has a few potential weaknesses that should be acknowledged. Firstly, a significant portion of the literature was obtained during the later phase of the research, which may introduce some subjectivity. Additionally, relying primarily on Google Scholar as a search engine could be a limitation, and it could have been advantageous to use multiple search engines for a more comprehensive review. Moreover, the reliance on secondary data sources due to paywall restrictions limits access to primary sources, making it challenging to verify the consistency of conclusions with the original data. Lastly, the use of non-scientific sources for programming and other methods with limited detailed scientific sources can also be considered a limitation.

Several weaknesses and limitations have been identified in relation to the POE survey conducted in this thesis. Firstly, the survey was created and distributed early in the thesis process to maximize the number of responses within the given time limit. As a result, the survey content relied primarily on previous surveys, which led to some missing information that could have provided more nuanced results, such as the occupants' age, physical condition, and detailed questions about their control over office spaces aspects and satisfaction with them These aspects, along with others discussed in 8.2 The Most Common Sources of Discomfort for Building Occupants could have provided valuable insights.

Furthermore, although efforts were made to collect as many respondents as possible, the relatively small sample size of 51 respondents could make the results sensitive and project-specific, despite aligning with previous POE surveys to a large extent. Another potential weakness is that the survey was conducted in two separate versions, one in Norwegian and one in English, which introduces the possibility of different interpretations due to varying wordings.

Another limitation lies in the visualization of the POE survey in BIM. Since this approach is relatively new, it may be challenging to find comprehensive information in existing literature, particularly regarding critical aspects and real-life implementation. Moreover, indoor climate is a complex domain with numerous nuances, making it difficult to capture all the intricacies in a POE survey. As a result, there is a risk of oversimplifying this multifaceted process. The major limitation of this thesis is that it focuses on a single context demonstration. To overcome this limitation, future research should include new case studies to allow for rigorous testing and generalization. Additionally, POEs informed by the visualizations produced in this study would provide further insights for refining the visualization techniques.

9. Conclusion

This chapter presents the concluding remarks and findings of the thesis research, addressing the main research question and sub-questions A-E.

What are the main factors that contribute to discomfort for building occupants, and how can they be identified, visualized, and communicated using a combination of Post-Occupancy Evaluation (POE) surveys, dynamo and Revit-add-ins?

In conclusion, the main factors contributing to discomfort for building occupants are temperature, indoor air quality, visual comfort, acoustic comfort, and space adequacy. Post-occupancy evaluation (POE) surveys are an effective method for assessing comfort levels and identifying the root causes of discomfort. BIM and Dynamo can be utilized to visualize and communicate the outcomes of POE surveys, providing a clear representation of comfort levels and occupancy satisfaction. Revit add-ins can effectively display sensor data information within BIM, offering opportunities for real-time data visualization. However, there are advantages and disadvantages to utilizing Dynamo and Revit add-ins for data visualization, including the learning curve, script customization, maintenance requirements, and the need for programming knowledge. Considering the target audience of facility managers, the use of Revit add-ins may pose challenges for those with limited programming backgrounds.

A. What are the predominant factors contributing to occupant discomfort in buildings?

The most common factors contributing to occupant discomfort in broken down to each aspect:

The thesis POE survey revealed that occupants expressed the most discomfort with temperature comfort, particularly in summer. The main factors contributing to temperature discomfort were occasionally feeling too cold or too hot. Similar studies also found that occupants commonly reported feeling excessively hot in summer and frequently cold in winter, indicating inadequate temperature control as a source of discomfort. Issues with heating/cooling systems, thermostat adjustment, and glazing and shading problems were cited as reasons for thermal discomfort.

Indoor air quality was another significant aspect affecting occupant comfort. The thesis survey showed that occupants were most dissatisfied with indoor air quality in summer, with stuffy air being the most commonly cited factor contributing to discomfort. Other studies also highlighted issues related to stuffy air, dry air, unpleasant odors, dust/dirt, and insufficient natural ventilation as causes of air quality dissatisfaction.

The thesis survey indicated a general satisfaction with visual comfort, but some respondents expressed dissatisfaction with the impossibility to control light, glare from sunlight, and lack of daylight. Other studies also identified problems with glazing and shading, sun glare, insufficient daylight, poor views, and inadequate natural lighting as main sources of visual discomfort.

Acoustic comfort was an aspect that received relatively higher dissatisfaction ratings in the thesis survey compared to others. Lack of sound insulation between rooms and people talking loudly in corridors were the most commonly cited reasons for acoustic discomfort. Similar studies identified issues with noise from HVAC equipment, exterior equipment, people conversing in corridors, and poor acoustic insulation as sources of discomfort.

Occupants expressed the most positive feedback regarding space adequacy comfort in the thesis survey. However, factors such as the quantity of space, furniture ergonomics, lack of flexibility, and privacy were mentioned as contributors to discomfort. Similar studies reported dissatisfaction with furniture ergonomics, inflexible workspace design, inadequate distribution of space, and the availability of sufficient space as sources of discomfort.

B. How can post-occupancy evaluation be effectively employed to assess the comfort levels of building occupants and identify the root causes of their discomfort?

Post-occupancy evaluation (POE) is an effective method for assessing the comfort levels of building occupants and identifying the root causes of their discomfort. The thesis case study and the discussed research papers demonstrate the applicability and benefits of conducting POE surveys**.**

The thesis case study, which included a survey of employees in a specific department, assessed various aspects of comfort such as temperature comfort, indoor air quality, visual comfort, acoustic comfort, and space adequacy. The results obtained from the survey provided insights into the comfort levels and sources of discomfort experienced by the occupants.

The research papers discussed in the literature review also employed POE methods to evaluate comfort levels. These studies expanded the scope by considering factors such as energy performance, diverse characteristics of occupants, and probabilistic analysis techniques. Some studies even utilized spatial data and real-time data mining techniques to enhance the evaluation process and provide valuable information for facility managers.

C. How can BIM and Dynamo be utilized to effectively visualize and communicate the outcomes of post-occupancy evaluation surveys?

In the thesis case study and other literature review studies, BIM and Dynamo were used to import and represent POE data visually. The process involved creating a Revit model, using Dynamo to import room data and colorize rooms based on POE survey data. Color schemes were used to indicate comfort levels, with green representing pleasant environments, yellow for moderate satisfaction, and red for discomfort. Similar approaches were seen in other studies, demonstrating the effectiveness of BIM and Dynamo for visualizing comfort levels and occupancy satisfaction. Dynamo and 3D visualizations were also helpful in identifying potential causes for discomfort. Overall, BIM and Dynamo offer powerful tools for importing, analyzing, and visually presenting POE survey data, enabling better understanding and informed decision-making for building design and operation.

D. How can sensor data information be displayed within BIM using Revit add-ins?

Sensor data information can be effectively displayed within BIM using Revit add-ins. The use of Visual Studio and C# programming language allows for the creation of Revit add-ins that import, read, and display excel data. This approach was successfully implemented in the thesis case study and demonstrated in other studies from the literature review. While the thesis case study used fabricated sensor data, the inclusion of actual real-time sensor data in other studies presents an interesting opportunity for future implementations.

E. What are the advantages and disadvantages of utilizing Dynamo, and Revit add-ins for data visualization?

In conclusion, utilizing Dynamo and Revit add-ins for data visualization offers both advantages and disadvantages. Dynamo's visual programming tool provides accessibility without requiring a coding background, although it has a steep learning curve and requires time to customize scripts. The open-source nature of Dynamo provides ample online resources for assistance. However, connection lacing in Dynamo scripts can make them appear disorganized and challenging to read. Outdated information online and the need for regular maintenance of scripts when updating the program can be drawbacks. The lack of an established methodology for integrating BIM with post-occupancy evaluation (POE) poses challenges for real-world facility management. Revit add-ins offer complete control over code logic and potentially save time compared to Dynamo. However, using Revit add-ins with C# and Visual Studio may require restarting Revit for logic changes and dealing with warning pop-ups. Learning C# and Revit add-ins can be time-consuming and challenging for beginners, but it provides a useful foundation for future research and development. Considering the potential target audience of facility managers with limited programming backgrounds, the use of Revit add-ins may pose significant challenges.

10.Recommendations

Recommendations for further research within this topic, based on the findings from the knowledge background, literature study, POE survey, BIM visualization, and discussions presented in the previous chapters, include:

- Collecting actual building information, including building characteristics, HVAC system data, and spatial information such as occupancy density, for each comfort aspect. This would provide valuable insights into the factors contributing to occupant discomfort.

- Building upon the Revit add-in by incorporating real sensor data. This enhancement would improve the accuracy and reliability of the visualization and analysis process, allowing for a more realistic representation of comfort levels.

- Incorporating shared office spaces and multiple responses from occupants in the analysis and visualization process. This would provide a comprehensive understanding of the overall office environment. To achieve this, survey methodologies would need to be nuanced, and modifications to the Dynamo script may be necessary.

- Exploring the application of Bayesian Networks (BN) for predicting occupant discomfort. This approach could offer new possibilities for understanding and addressing the various factors that contribute to discomfort.

- Expanding the survey to include more details and nuances, such as differentiating the reasons for discomfort based on winter and summer conditions. This would provide a deeper understanding of how seasonal variations impact occupant comfort.

These recommendations serve as potential avenues for future research, aiming to further advance knowledge in the field and improve the design and operation of buildings to enhance occupant comfort.

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12.Appendix

12.1 SurveyXact Report

12.2 Figures from Dynamo Script

12.3 Figures from Visual Studio Revit Add-in

12.4 A3 – Poster

12.5 Progress Plan

12.6 Letter from the Norwegian Center for Research Data