WHO IS 'SMARTER', HUMANS OR BUILDINGS?

A MIXED-METHOD ASSESSMENT OF OCCUPANT BEHAVIOR IN SMART BUILDING ENVIRONMENTS

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Who is 'smarter', humans or buildings?

A mixed-method assessment of occupant behavior in smart building environments

By

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As I stand at the completion of my academic journey, it is crazy to realize that this thesis marks the final chapter. The past six months have flown by, filled with many learning experiences that went far beyond the specific subject matter. Learning about doing research in general, but especially working with a combination of qualitative and quantitative data, proved to be an interesting challenge. Moreover, this thesis has given me a deep appreciation for the dedication and effort researchers invest in creating meaningful studies.

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As a final note, I am excited about the next steps, driven by a renewed sense of motivation and energy. This journey has had its challenges and rewards, and I am eager to apply the lessons learned to future practices.

ABSTRACT

Given the building sector's significant impact on energy consumption and CO_2 emissions, there is a clear need for a sustainable solution. Here, smart building technologies are emerging as a promising response, as they offer the potential to improve operational efficiency while reducing environmental impact. However, the development of smart building solutions for the building sector often follows a technology-driven approach, in which technical feasibility and overall system optimization are prioritized over occupants' perspectives, preferences, and behavior. As a result, building systems and technologies are not fully aligned with how occupants use and interact with these spaces. Bridging the gap between theoretical knowledge and practical application is, therefore, crucial for unlocking the full potential of smart building technology.

This study focused on enhancing our understanding of the interaction between smart building technology and users. A specific focus is placed on climate control technology within the broader landscape of smart building systems. By employing an exploratory approach, in which a combination of qualitative and quantitative methods was utilized, smart building users' preferences and behavioral mechanisms were explored. Through semi-structured interviews with smart building occupants, the study delved deeper into understanding the motivations, barriers, and other aspects of occupant behavior and interactions with smart building technology. Additionally, insights from interviews with industry experts provided valuable perspectives on which key factors contribute to the increased adoption of smart building technology. These qualitative findings were complemented by quantitative data collected through an online survey (n=92), which allowed trends and preferences to be identified from a larger group of smart building occupants.

The study showed that the successful implementation of smart building technology goes beyond mere technological details. It provided empirical insights into the preferences and behavioral mechanisms of smart building occupants, filling a gap in the existing literature. By exploring these aspects, the research deepened our understanding of user interactions within smart buildings. Consequently, it advocates for a user-centered approach to smart building initiatives, emphasizing the importance of understanding human preferences and incorporating user feedback to effectively adapt technology to their specific needs and routines. However, the study revealed a diverse range of user preferences and motivations regarding interaction with smart building technology, including preferences regarding control levels, system feedback, transparency, flexibility, and interface design. This diversity highlighted the absence of a one-size-fits-all approach to implementing smart building technology. Consequently, specific practical recommendations were developed to guide stakeholders in smart building initiatives, emphasizing a more user-centered implementation that ensures adaptability to the unique needs and preferences of building users.

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LIST OF ABBREVIATIONS

Buildings Energy Management Systems (BEMS)
Building Management System (BMS)
Complex Systems Engineering and Management (CoSEM)
Energy Performance of Buildings Directive (EPBD)
Human-building interaction (HBI)
Heating, Ventilation, and Air Conditioning (HVAC)
Internet of Things (IoT)
Perceived Ease of Use (PEOU)
Perceived Usefulness (PU)
Technology Acceptance Model (TAM)
The Predicted Mean Vote (PMV)

CHAPTER 1: INTRODUCTION

1.1 Problem statement

The building sector is widely recognized as having a substantial impact on both energy consumption and carbon emissions (Bäcklund et al., 2023; Kim et al., 2022). Moreover, buildings within the European Union (EU) contribute to approximately 40% of the total energy consumption in the region (European Commission, 2020). Given this significant energy footprint, the building sector offers a promising opportunity for significant energy savings compared to other sectors (Kim et al., 2022). Therefore, in light of the urgency to foster a more sustainable society and fulfill sustainability objectives, understanding the energy efficiency of buildings is an important aspect. This has driven organizations to seek innovative solutions to optimize the performance of their buildings.

The application of smart building technologies facilitates the automation of building operations and services with the primary goal of improving occupant comfort, enhancing operational efficiency, and reducing the environmental footprint of the building (Pathmabandu et al., 2023). Moreover, from the user's perspective, smart building technologies offer a range of tangible benefits that directly impact their daily experiences in the built environment. For example, these technologies can significantly improve comfort levels by regulating factors such as temperature, lighting, and air quality to create optimal working conditions. In addition, features such as automated lighting and climate control systems contribute to a more comfortable and productive workplace, improving overall work performance. However, realizing the goals of smart building technology depends on the effective understanding and adoption of these solutions by the occupants (Li et al., 2023; SmartBuiling4EU, 2021). Neglecting to consider users' preferences and concerns may result in the failure to fully achieve the intended goals of smart building technologies, ultimately impacting the occupants' overall well-being and satisfaction within the building environment (Li et al., 2023). In other words, the effectiveness of smart building technologies is intricately linked to how occupants interact with and respond to these systems. In particular, extensive research highlights the central role of occupant behavior in influencing energy consumption in buildings (Xu et al., 2023; Bäcklund et al., 2023).

The increasing adoption of smart building technology highlights the growing demand to delve into occupant behavior and the intricate interactions between individuals and buildings (Li et al., 2023). This demand mainly stems from the fact that the intended design of technologies might differ from the actual performance in the built environment (Becerik-Gerber et al., 2022). In other words, the way people actually interact with technology may differ from how designers and engineers originally envisioned it. This imbalance could result in the so-called energy efficiency gap, a term that indicates the difference between the intended energy savings and the actual energy performance (Becerik-Gerber et al., 2022). The literature emphasizes the central role of occupants in influencing the energy performance of buildings, highlighting that human behavior and occupant preferences significantly contribute to this gap (Paone & Bacher, 2018; Tam, Almeida, & Lê, 2018). To illustrate this, imagine a building equipped with smart devices designed to enhance energy efficiency and user comfort. These devices can, for instance, be smart thermostats, occupancy sensors, or lighting controls. If the occupants of the building do not actively use or interact with these smart devices because they think it is too much hassle or their old behavior is ingrained, the intended benefits and goals of energy efficiency and comfort improvement cannot be fully achieved.

Furthermore, current research on technology integration in buildings has mainly followed a top-down approach (Becerik-Gerber et al., 2022). This implies a tendency to prioritize technical feasibility and overall system optimization without putting much emphasis on the user perspective, preferences, and behavior of building users. Moreover, the energy simulation programs used in building design are often based on theoretical values and schedules, which can differ significantly from the actual usage patterns that building users experience (Tam et al., 2018). This results in building systems and technologies not fully aligned with how users interact with and use these spaces. This misalignment can have several adverse consequences. For instance, the oversight of user perspectives and behavior can result in the implementation of technologies that are not user-friendly, which can lead to reduced user acceptance. Moreover, research suggests that better alignment between users and their work environment can positively affect work-related outcomes, including productivity and user satisfaction (Tuzcuoğlu et al., 2022). Additionally, failure to synchronize building systems with actual usage patterns can lead to inefficiencies in building energy performance (Yan et al., 2015). These inefficiencies not only compromise sustainability goals but can also lead to increased operational costs and reduced environmental benefits. To realize the full potential of smart building technology, it is therefore crucial to bridge this gap between the technical innovations and the building occupants.

1.2 Scope

In literature, the terms smart or intelligent buildings are defined in various manners and, at times, used interchangeably. However, the scope of this study is limited specifically to smart buildings. The difference between smart and intelligent buildings lies mainly in adapting or reacting to circumstances and the information gathered inside and outside the building (Buckman et al., 2014). Intelligent buildings are generally reactive. This means that, for example, an intelligent building collects information about the temperature conditions in the room and then reacts to this by adjusting the temperature to a more comfortable temperature for users. A smart building, on the other hand, is more adaptive. Smart buildings gather information, both internal and external, to adapt to a situation before the event has occurred (Buckman et al., 2014). The more data is available, the more smart buildings can prepare for changes at different time scales. The data is captured by a network of digital sensors and monitoring devices with the aim of better managing the building and modeling the data over time (Newton et al., 2021). The data can hence be used to interact between different buildings and the environment to improve energy use and contribute to occupant comfort (Newton et al., 2021).

Moreover, the transformation of traditional buildings into smart buildings relies on the integration of a range of advanced technologies (Aliero et al., 2022). The technologies must be present in order to facilitate the application of the smart features. Examples include smart lighting, climate control, and occupancy sensors. However, the scope of the research will focus on climate control technology within the broader landscape of smart building systems in order to conduct more focused research and thus be able to provide more accurate and insightful findings. By focusing on one technology, a more thorough and nuanced analysis can be carried out. This scope was chosen since the largest share of energy consumption in buildings is allocated to the operation of heating, ventilation, and air conditioning (HVAC) systems (Omarov et al., 2017). Moreover, HVAC systems often offer various control options and settings, making them an ideal case for exploring the interplay between occupant preferences and technology capabilities. In addition, HVAC systems directly impact indoor comfort, which is a crucial aspect of user experience. Therefore, investigating how occupants interact with and influence the operation of HVAC systems can provide valuable insights into optimizing both energy efficiency and occupant comfort.

Furthermore, this research will further delimit itself to office buildings. The reason for this is that human-building interaction is different in different kinds of settings (Adams et al., 2021). Office buildings were chosen primarily due to the fact that the available data is accessible only from a selective set of offices. Moreover, users in office environments are often not directly financially responsible for heating or electricity bills. This aspect raises questions about the extent to which users feel personally involved in energy-saving initiatives since they may not bear the direct financial impact of energy consumption.

In addition, it is worth noting that the geographical scope of this study is limited to the Netherlands. This limitation is rooted in the regulatory and policy landscape prevailing in the country. The Netherlands is actively participating in the Paris Agreement, striving to "Paris-proof" buildings and demonstrating its commitment to energy efficiency and environmental sustainability (Dutch Green Building Council, 2020). In addition, the country is joining the Energy Performance of Buildings Directive (EPBD), reinforcing its commitment to international standards. The Energy Performance of Buildings Directive IV (EPBD IV) aims to improve the energy performance of buildings and reduce carbon emissions (Dutch Green Building Council, n.d). This directive has a significant impact on energy performance and extends mandatory requirements for energy labels to different types of buildings. A crucial national mandate effective January 1, 2023, requires that all existing office buildings in the Netherlands achieve energy label C or better (Netherlands Enterprise Agency (RVO), 2020).

1.3 Knowledge gap & objective

Extensive research has been conducted on occupant behavior and human-building interaction in conventional buildings. This includes behavioral interactions such as manually adjusting thermostats or switching lights on and off for personal comfort. However, since conventional building technology is slowly being replaced with smart building technology, interactions between the building and its users are expected to change (Bäcklund et al. (2023). Moreover, the development of smart building solutions for the building sector often follows a technology-driven approach, where the focus is primarily on the features and capabilities of the technology itself (SmartBuilt4EU, 2021). However, this approach may not sufficiently account for the preferences and behaviors of building occupants. In other words, while the technology may be advanced and promising, it might not align well with how people actually use and interact with buildings (Becerik-Gerber et al., 2022). This emphasizes the need to understand user preferences and behaviors in order to align the technology with the real-world interactions and utilization patterns of building occupants.

In addition, Bäcklund et al. (2023) conducted a systematic literature review on the behaviors of building occupants and their implications on energy utilization in smart buildings. They argue that as building systems become smarter, the way people behave in buildings is changing. Moreover, they emphasize a significant research gap in that there is no paper showing a detailed analysis of the interconnections among smart building systems, potential energy savings, and occupant behavior (Bäcklund et al., 2023). They emphasize a critical need for future research to comprehensively understand how occupants are adapting to these smart building environments.

Therefore, this research investigates the interplay between smart building technology and occupant behavior. This research is specifically limited to climate control technology within the extensive domain of smart building technology. As stated before, climate control, including heating, ventilation, and air conditioning (HVAC) systems, stands as one of the most significant contributors to energy consumption within buildings (Omarov et al., 2017). Consequently, it examines the dynamics between occupant behavior and climate control technology.

The aim is to explore the preferences and behavioral mechanisms of building occupants regarding climate control in smart office environments. By understanding occupants' preferences and behaviors, the research seeks to shed light on the adoption of smart building technology. Ultimately, the findings aim to provide practical recommendations for building designers, managers, researchers, and occupants to promote more energy-efficient approaches and optimize the use of smart building technologies.

Main research question: What are building occupants' key preferences and behavioral mechanisms that are contributing to the adoption of climate control technology in smart office buildings?	
Sub-question	**Method**
1. What are the key factors identified by industry experts that contribute to the increased adoption of smart building technology?	Semi-structured interviews
2. What are the underlying motivations and barriers driving occupant behaviors in smart office buildings?	Semi-structured interviews and online survey
3. To what extent do smart building occupants in different office environments exhibit common preferences and behavioral mechanisms regarding climate control technology?	Semi-structured interviews and online survey

Table 1 Research questions

1.4 Research questions

Table 1 provides an overview of the research questions. The first sub-question involves exploring the factors that are driving the increased adoption of smart building technology through semi-structured interviews with industry experts. This approach goes beyond just understanding users' perceptions and includes a broader perspective recognized by experts in the implementation of smart building technology. This approach provides insight into the factors influencing the widespread implementation of smart technology in buildings. Moreover, this starting point allows for a deeper exploration of the research context in practice.

Subsequently, the second sub-question delves deeper into the perspective of building occupants. This research phase investigates the underlying motivations and barriers shaping occupant behaviors within smart buildings. By examining these factors, the study aims to explain the decision-making process that leads individuals to interact with the indoor environment (D'Oca et al., 2018). This exploration contributes to understanding user perceptions and interactions with technology.

Lastly, the third sub-question seeks to test the findings of the first two sub-questions through a quantitative survey among building occupants. This step is crucial for validating and strengthening the insights gained through qualitative research to a broader audience. This made it possible to make more generalized statements regarding the preferences and behavioral mechanisms that occupants experienced in their interaction with smart building technology and specific climate control technology.

1.5 Societal and scientific relevance

This research has both societal and scientific relevance. Specifically, this is motivated by the urgent need to reduce energy consumption and limit carbon emissions from buildings. Buildings currently contribute substantially to total energy usage, making them a key area for intervention in the fight against climate change. Specifically focusing on smart office buildings, the research aims to explore user preferences and behavioral mechanisms, recognizing the pivotal role of occupants in shaping energy usage patterns.

The identified lack of empirical data on the experiences of smart building occupants not only highlights a significant gap in our current understanding but also underscores the scientific relevance of this study. By addressing this gap, the study not only contributes to a more comprehensive understanding of user preferences and behaviors but also plays a crucial role in the development of effective smart building technologies. The empirical approach seeks to provide tangible, data-driven insights, ultimately informing user-centric strategies for optimizing smart building technologies.

In addition, this study is scientifically relevant as it extends existing knowledge in the field of human-building interaction and smart building technology adoption. First, by emphasizing the occupants as the central stakeholders of the smart building, the study not only confirms several factors already identified in the literature on HBI but also introduces new constructs that influence how users interact with technology in smart buildings. Moreover, this research contributed to the existing literature on the adoption of smart building technology by delving into users' decision-making processes related to the adoption of smart building technology.

Moreover, as the adoption of smart building technologies becomes more widespread, bridging the gap between theoretical knowledge and practical application is crucial. By uncovering the underlying mechanisms driving technology adoption within the context of smart office buildings, this study enriched our understanding of how and why people interact with and motivate them to adapt to smart building technologies in real-world settings. Consequently, it sheds light on the factors that influence the adoption of smart building initiatives.

Therefore, this research is both socially and scientifically relevant as it addresses the pressing societal challenge of energy efficiency in buildings while advancing the scientific understanding of occupant behavior in smart building contexts. The findings have the potential to inform practical recommendations for stakeholders, from designers and managers to researchers and occupants.

1.6 Connection to CoSEM program

This master's thesis is in line with the learning objectives of the CoSEM master's program, which emphasizes the ability to design interventions within complex socio-technical systems. The master's program places a strong emphasis on considering a wide range of factors beyond technology and includes aspects such as human behavior, cultural nuances, and ethical dimensions when conceptualizing and implementing technological innovations.

This aligns with the research on smart building technology and occupant behavior since it embodies the essence of designing interventions in a socio-technical system by addressing the complex interplay between technology, human behavior, culture, and ethics within the context of smart building technology adoption. It, therefore, reflects the holistic approach of the CoSEM program, recognizing that the success of technological innovations, in this case in the field of smart buildings, inherently depends on how well they navigate the complex dynamics beyond just the technological approach.

1.7 Collaboration

This thesis is the result of a collaboration with Royal Haskoning DHV (RHDHV). RHDHV is a global consulting and engineering firm dedicated to creating positive impacts on both people and the planet. RHDHV specializes in helping clients with a variety of challenges, including climate change, digital transformation, changing customer demands, and the energy transition.

The collaboration with RHDHV was motivated by their considerable interest in smart buildings. Despite their active participation in a large number of smart building projects, there was a distinct lack of empirical data, so they asked for more in-depth research on this aspect. Ultimately, we decided to focus on the user perspective as the main focus of the research.

Throughout the collaboration, RHDHV has provided valuable support, resources, and extensive industry connections. This support has been crucial in shaping the research process, allowing me to delve into unknown areas and gain insights into the research topic.

1.8 Report outline

Figure 1 shows the schematic structure of the study, which illustrates that the first two sub-questions serve as input to the third sub-question. This visual representation clarifies the sequence of the study. In terms of the chapter sequence, the next chapter presents the theoretical framework that establishes the research context and functions as the foundation for the study. Following this, I explain the methodology and introduce the mixed-methods approach that combines qualitative and quantitative methods. The subsequent sections will discuss the methodology and results of the interview phase, followed by the methodology and results of the survey. Subsequently, in the discussion section, I will thoroughly analyze the findings from both the interviews and the survey and make recommendations. The final section summarizes the main conclusions of the study.

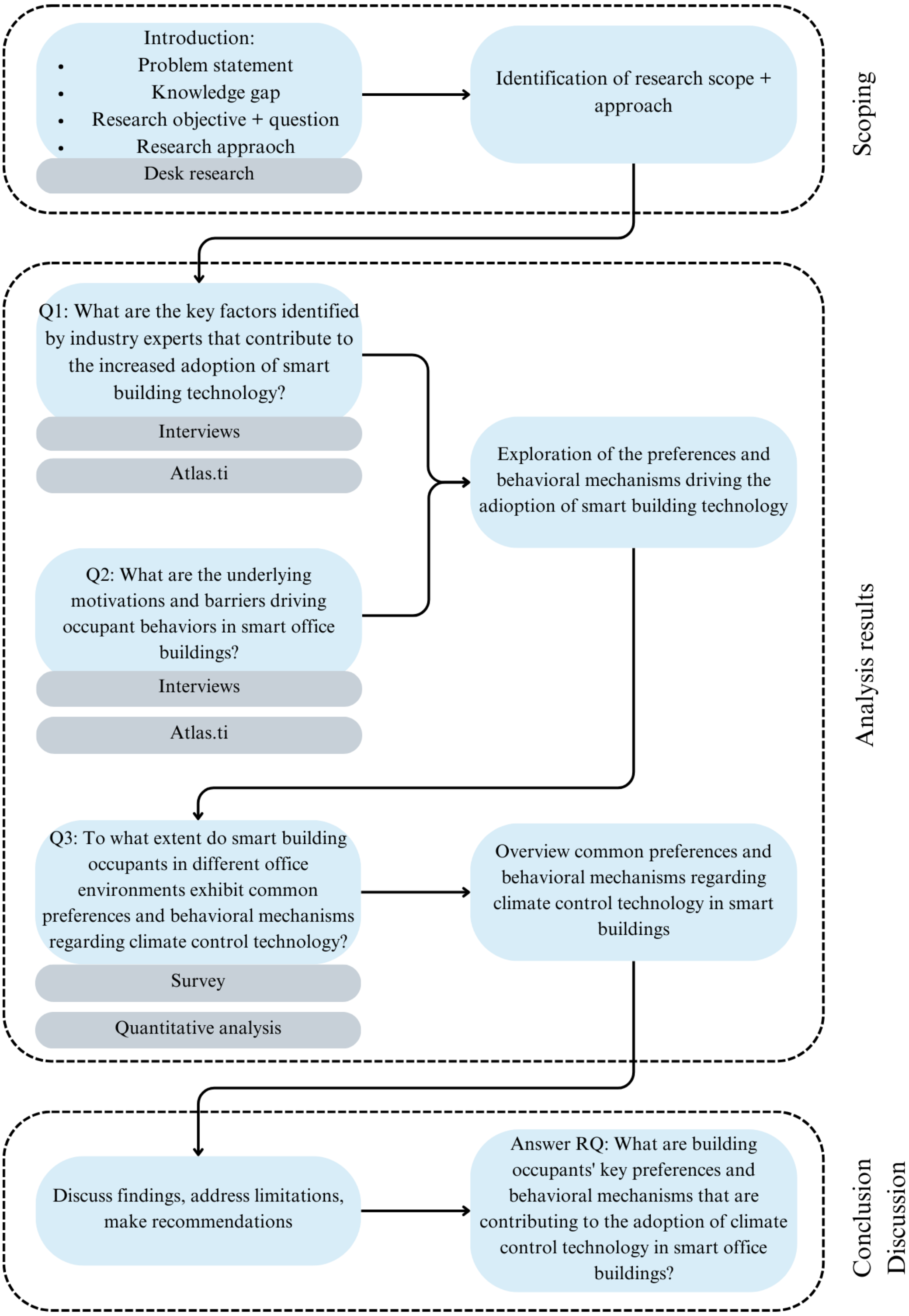

Figure 1: Research structure

CHAPTER 2: THEORETICAL FRAMEWORK

2.1 Smart building & technology

Several definitions of smart buildings have been given in the literature. However, there is no universal standard for smart buildings. The following sections discuss several definitions and concepts that form the basis of the study. The first section delves into the smartness of building systems, and then the role of technology integration is discussed. Followed by the role of climate control technology in enhancing thermal comfort. These concepts provide more background knowledge to better understand the context in which the research takes place but also provide the knowledge necessary to conduct meaningful interviews. Section 2.2 further elaborates on the role of the user in relation to the smart building.

2.1.1 Smartness of building systems

Smart buildings can be characterized as buildings that make use of advanced Internet of Things (IoT) technologies to autonomously manage a wide range of building functions and services (Pathmabandu et al., 2023). The primary goals of this automation are to improve occupant comfort, enhance operational efficiency, and reduce the environmental footprint of the building (Pathmabandu et al., 2023). It is crucial to note again that these goals cannot be fully achieved by focusing on technology alone. The role of the user is just as important in realizing the potential benefits of smart buildings. The goals of smart building technology reflect a commitment to creating working spaces that are not only responsive to the needs of their occupants but are also environmentally responsible. Furthermore, the benefits of smart buildings extend beyond these primary objectives. Several studies have highlighted additional advantages such as significant cost savings, increased flexibility, and improved safety (Kim et al., 2022). These features make smart buildings highly attractive to diverse stakeholders, from building owners to real estate developers and users.

The IoT technology in the buildings is composed of a network of interconnected objects connected through sensors, applications, and various technologies. This interconnected network enables seamless data exchange and integration (Shah et al., 2022). As a result, smart buildings are constantly informed by real-time data, allowing them to adapt to changing conditions with precision and efficiency. Moreover, the data gathered from diverse sensors and devices must undergo algorithmic analysis and transformation into meaningful information (Qolomany et al., 2019). This process allows for the extraction of knowledge, enabling machines to gain a deeper understanding of human behavior. Consequently, smart buildings are no longer just conventional structures but smart ecosystems that seamlessly integrate sustainability, cost efficiency, user well-being, asset valuation, and operational excellence (see Figure 2).

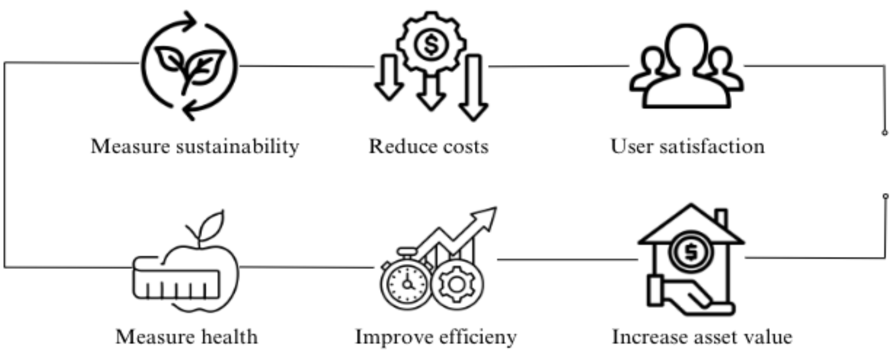

Figure 2: Smart building objectives (Autor)

Yet, this does not reveal what features the smart building must fulfill to be 'smart.' This aspect has again been described in multiple ways across the literature. Through a literature review, Dakheel et al. (2020) examined the essential features of smart buildings, uncovering the presence of the following four distinct features. First, the aspect of climate response indicates the ability of the building to respond to external climate conditions (Dakheel et al., 2020). Second, the ability of the building to interact with the grid. For example, to reduce grid overload to maximize energy efficiency. Third is the building's ability to interact with occupants and technology. For instance, occupants can interact with the Buildings Energy Management Systems (BEMS) to indicate their comfort preferences. Here, the BEMS is the connection for users to interact with the automated energy systems. Fourth, the building's ability to monitor and control the operation of the building in real time. This also helps to facilitate the above features and enable efficient operation. In addition, the European Commission uses a number of similar indicators to describe the ‘smartness’ of a building: the functionality to (1) optimize energy efficiency and overall in-use performance, (2) adapt to the needs of the occupants and (3) adapt to the wider energy environment like the energy grid (European Commission, z.d.). Although both are visualized differently, the indicators largely overlap in terms of control mechanisms, human-building interaction, and adaptation to the energy grid.

Buckman et al. (2014), on the other hand, describe the smartness of the building from a different point of view. Their paper establishes a comprehensive definition of smart buildings that builds on previous terminology. They approach the concept of smart buildings through the lens of adaptability, considering it the central element in their definition. The notion of adaptability is not unique to their work but is rather a recurring theme in various scholarly papers (Dakheel et al., 2020; Aliero et al., 2022; Ejidike & Mewomo, 2023). This adaptability is constructed upon three foundational pillars: control, enterprise, and materials and construction. Regarding control, Buckman et al. (2014) interpret this as that there needs to be a balance between the control of users and the automation of the building systems to manage energy consumption. Additionally, enterprise refers to any method by which the building can collect the data. The materials and construction pillar encapsulates both the physical structure of the building and the integrated smart functionalities within it.

Broadly summarized, the smartness of building systems entails the utilization of information, both internally and externally sourced from diverse channels, to proactively prepare the building for specific events and circumstances (Buckman et al., 2014). This, in turn, aligns well with Dakheel et al.'s (2020) statements on adaptability, which corresponds to the idea that smart buildings should be flexible and responsive to changing environmental conditions, occupant preferences, and energy needs (see Figure 2).

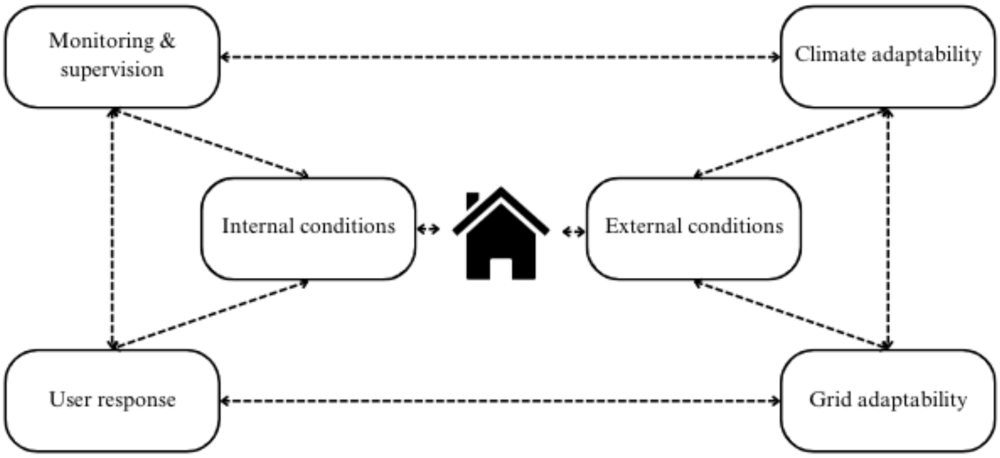

Figure 3: Simplified schematic representation of smart building features. Figure adapted from Dakheel et al. (2020)

2.1.2 Technology integration

The transformation of traditional buildings into smart buildings relies on the integration of a range of advanced technologies (Aliero et al., 2022). Linking these smart technologies with the Smart Building Energy Management System (SBEMS), also known as a Building Management System (BMS), facilitates automated control and operation of buildings. This integration is essential to achieve significant energy conservation on all building equipment and increase indoor comfort (Aliero et al., 2022). SBEMS uses different types of information gathered from external data, such as weather conditions, sensor data, and occupant information, to manage and control the building operations (Sari et al., 2023). In addition, it facilitates intercommunication between different IoT technologies over a network (Aliero et al., 2022). The SBEMS thus plays a crucial role in managing technologies such as HVAC systems, smart lighting, and other integral components within the smart building environment.

The SBEMS has different levels of automation, or in other words, the degree to which users can interact with it (Lazarova-Molnar & Mohamed, 2017). In certain building systems, occupants have the ability to manually override the technology, such as opening windows or adjusting climate settings to suit their preferences. However, in some buildings, these adjustments are entirely automated, and occupants may have limited or no control over these aspects. Moreover, Heschong & Day (2022) highlight that when entire building systems are automated, this is an ineffective way of controlling the building operations. In this case, the operations are decided by the building engineers or managers to organize the operations most efficiently. However, from the user's perspective, individual preferences for the level of control and automation can differ. The diversity in preferences can significantly impact the occupant's comfort within the building (Lazarova-Molnar & Mohamed, 2017). Moreover, when occupants lack control, they may actively seek opportunities to regain it, as noted by Heschong & Day (2022). Therefore, it is important to find the right balance between automation, control, and the occupants (Heschong & Day, 2022).

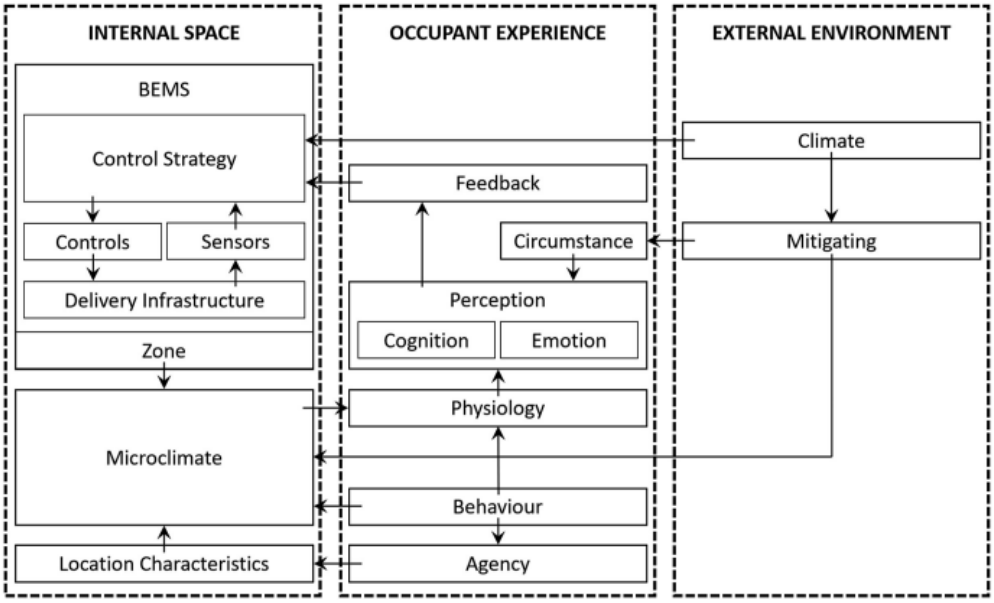

Figure 4: Interaction schema BEMS, ***occupants,*** and the external environment (Newton et al., 2021)

In Figure 4, as presented by Newton et al. (2021), the occupant emerges as a central character positioned between the internal space and the external environment. This arrangement visually underscores the pivotal role of the occupant in the dynamic interplay of the Building Energy Management System (BEMS), occupant experience, and external factors. Notably, the diagram illustrates how various zones within a building, encompassing discrete infrastructure elements like heating, cooling, lighting, and air conditioning, are individually managed by the BEMS (Newton et al., 2021). This management occurs within a broader control strategy set by the building's facility manager, who in turn is influenced by user feedback on their comfort experience in the building. Furthermore, the right side of the figure shows that this data is often complemented by external environmental information and inputs from external systems (Newton et al., 2021). These external factors encompass elements such as local climate conditions and occupancy schedules, adding an extra layer of complexity to the BEMS's decision-making process.

2.1.3 Climate control technology

As described earlier, the scope of the study is on climate control technology within the larger scope of smart building technologies. Climate control technologies, often referred to as smart HVAC (Heating, Ventilation, and Air Conditioning) systems, are advanced systems used in buildings to manage and regulate indoor temperature and air quality with a primary objective of ensuring occupants' thermal comfort (Aliero et al., 2022). The HVAC systems are equipped with various sensors that continuously collect data on factors like temperature, humidity, air quality, and occupancy within the building (King & Perry, 2017). This data is then managed by the BEMS, as indicated in the previous section. One key feature that sets smart HVAC systems apart from traditional systems is their ability to not only identify malfunctions but also pinpoint their location and root causes (King & Perry, 2017). This enhanced diagnostic capability provides valuable insights for optimizing energy usage and efficiency. Smart building software uses data from a large number of HVAC sensors, enabling precise control of HVAC systems. It is an essential part of saving energy for the building (King & Perry, 2017; Aliero et al., 2022). This is achieved by implementing strategies such as minimizing HVAC consumption in building zones that are not occupied, instantly detecting and diagnosing faults, and strategically reducing HVAC use during peak energy demand periods (Shah et al., 2022; King & Perry, 2017).

2.1.4 Thermal comfort

As stated earlier, the primary objective of climate control systems is ensuring thermal comfort for the users in the building. Thermal comfort can be described as one's own awareness of the thermal atmosphere (Emetere, 2022). This evaluation is based on subjective assessments and reflects the occupant's satisfaction with the thermal environment. The Predicted Mean Vote (PMV) model, formulated by Fanger in the 1970s, stands out as one of the most widely acknowledged models for evaluating thermal comfort (Park & Rhee, 2018). This model considers six key parameters, including indoor air temperature, airflow, mean radiant temperature, humidity, clothing, and the metabolic activity of the occupant, to determine thermal comfort. Despite the integration of multiple variables, the PMV model has received much criticism in the literature (Jia, 2018). This criticism mainly stems from the highly subjective nature of thermal comfort, which is strongly influenced by the specific comfort preferences of individuals (Jia, 2018).

Literature shows the importance of providing occupants with certain control options to meet these individual preferences (Karjalainen, 2013). For the focus of the study on climate control, these control options might include temperature adjustment, fan speed control, ventilation control, scheduling, and more. Users can employ smartphone apps or personalized profiles to interact with these systems. Furthermore, the more advanced systems use AI and machine learning to adapt to occupants' preferences over time. Allowing occupants to interact with these systems can promote a stronger connection to the system, potentially increasing interest in energy efficiency (Karjalainen, 2013). Therefore, exploring the dynamics of occupant interaction with these climate control systems within the smart office environment is important for achieving both occupant comfort and energy efficiency goals.

2.2 Technology adoption and user acceptance

As explained earlier, smart building technologies have significant potential, such as enhanced energy efficiency, occupant satisfaction, and work performance within buildings. However, realizing these benefits hinges on the effective understanding and adoption of these solutions by the occupants (SmartBuiling4EU, 2021). To realize the full potential of smart building technology, it is therefore crucial to bridge this gap between the technical innovations and the building occupants.

In the context of adoption and technology acceptance, numerous theoretical frameworks have emerged to explain the complex dynamics that influence individuals' decisions to adopt new technologies. I will briefly discuss two widely cited frameworks in the literature: the Everett Rogers model and the Technology Acceptance Model (TAM). These frameworks provide a valuable understanding of the complex processes involved in how individuals adopt and accept new technologies. Subsequently, I will elaborate on human-building interaction and user behavior in buildings. The exploration of human-building interaction and occupant behavior underscores the critical importance of considering the user perspective in the context of smart building technologies.

2.2.1 Diffusion of innovation (Rogers)

Rogers's theory, developed in the 1960s, seeks to explain how new ideas, products, or technologies spread within a social system. According to Rogers, the adoption of an innovation proceeds through a number of stages, including understanding, persuasion, decision-making, implementation, and confirmation. These stages ultimately lead to the characteristic S-shaped adoption curve introduced by

Rogers (1995). This curve illustrates the categories of adopters, ranging from innovators and early adopters to the early and late majority, all the way to the group called laggards (see Figure 5).

The progression along the S-shaped adoption curve, as described by Rogers, is inherently uncertain. To mitigate this uncertainty, Rogers puts forth a set of innovation attributes aimed at reducing uncertainty regarding the adoption of innovations. These attributes encompass five key characteristics of innovations: relative advantage, compatibility, complexity, trialability, and observability. Collectively, these attributes help determine an innovation's appeal and its likelihood of gaining acceptance within a given social system.

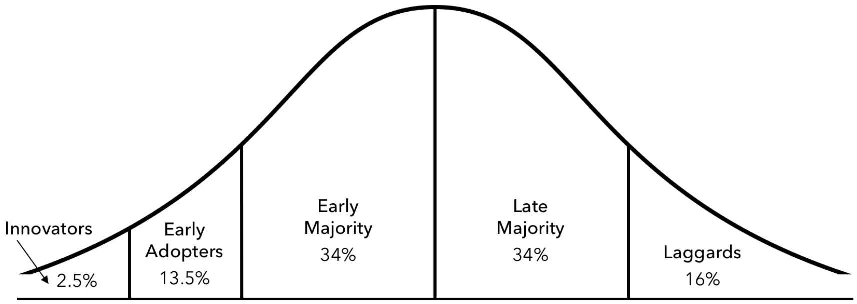

Figure 5: Adoption curve (Rogers, 2003)

In the context of the adoption of smart building technology and research on occupant behavior, Rogers's Diffusion of Innovation theory serves as a valuable framework. It enables a thorough exploration of the decision-making processes individuals undergo as they adapt to the smart building environment. While not directly incorporating specific elements such as relative advantage, compatibility, complexity, trialability, and observability, this research will leverage the overarching concepts of the theory. Particularly, the study focuses on how innovations, such as smart building technologies, spread within a social system. By emphasizing these dynamics, the research aims to capture the evolving patterns of user acceptance and resistance within the context of smart building technology adoption in office buildings.

2.2.2 Technology Acceptance Model

The Technology Acceptance Model (TAM) is another theoretical framework widely used in information systems and technology adoption (Ma & Liu, 2011). It was originally developed by Fred Davis in 1989 and later extended by other researchers. In contrast to Rogers's theory, the TAM attempts to explain and predict individuals' acceptance of new technologies based on their perceptions and attitudes toward the technology. Rather than directly applying all components of the TAM framework, as shown in Figure 6, this study will leverage TAM as a guiding principle. Specifically, it will focus on two key constructs: 'perceived ease of use' (PEOU) and 'perceived usefulness' (PU). These constructs serve as fundamental indicators of individuals' attitudes toward technology adoption, offering insights into the likelihood of acceptance. The model is widely known and tested in various industries (Ma & Liu, 2011).

Within the realm of smart building technology, individuals are inclined to embrace the technology when they perceive it as beneficial. For instance, if technology contributes to their comfort, individuals are more likely to accept and incorporate it into their routines. Perceived ease of use concerns an individual's perception of the simplicity of using the technology. For example, if smart building systems and interfaces are user-friendly, users experience the technology as convenient and free of hassle, making them more likely to adopt and use it. On the other hand, if a technology is perceived as complicated or difficult to navigate, users may experience more hassle and inconvenience, leading to lower adoption rates. Therefore, it is essential to ensure that technology is perceived as easy to use to increase user adoption and acceptance.

However, despite its widespread use, the TAM model has certain limitations, mainly related to its simplicity (Ajibade, 2018). These limitations pose a challenge in capturing the complexity and multifaceted nature of individual attitudes and behaviors in technology adoption scenarios. As such, in this study, TAM rather serves as a starting point for exploring the interaction between smart buildings and occupants.

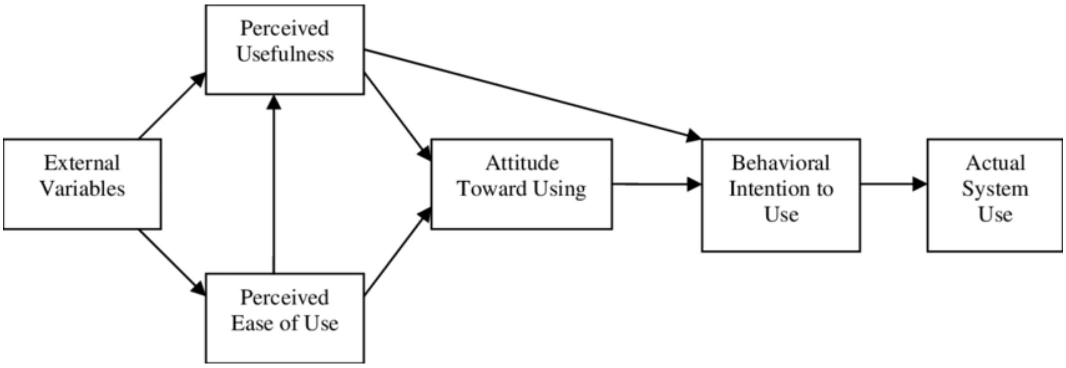

Figure 6: Technology Acceptance Model

2.2.3 Human-building interaction

Both the model of Rogers and the TAM underscore the significance of comprehending user perspectives and responses to technological innovations. Bridging into Section 2.2.3, the focus shifts to Human-Building Interaction (HBI), which delves deeper into the dynamic interplay between users and smart buildings.

HBI research encompasses three overarching research areas, including human factors, building structures, and technology integration (Becerik-Gerber et al., 2022). This diverse field of HBI deals with various aspects, including human experiences, well-being, building design, operational processes, and sensor-based technologies within built environments. Research on HBI seeks to explore how the design, operation, and technology integration within the built environment impact human experiences, well-being, and productivity. However, research on technology integration in buildings has mainly followed a top-down approach (Becerik-Gerber et al., 2022). This implies a tendency to prioritize technical feasibility and overall system optimization without putting much emphasis on the user perspective, preferences, and behavior of building users.

HBI research can, therefore, in the context of smart buildings, be a bridge to understanding the interaction between smart building technology and building occupants. This user-centric approach places a central emphasis on understanding human preferences and needs when engaging with the environment (Alavi et al., 2019). It delves into the nature of human interaction within the built environment and offers insights into the underlying mechanisms that determine users' engagement with the building and technologies (Shen et al., 2016). So, by exploring the "why" and "how" of these interactions, the approach reveals the factors that shape our energy consumption patterns in buildings (Shen et al., 2016). In this context, as Syse and Mueller (2015) explained, habits are formed by consistently repeating specific interaction patterns between individuals and their environment. This means that occupants' behavior is not random but rather influenced by repeated and ingrained ways of interacting with their environment. Through this approach, this research aims to uncover these patterns and shed light on the relationship between occupants and smart building technologies.

2.2.4 Occupant behavior

As highlighted in the problem statement, the behavior of occupants within smart buildings plays a pivotal role in the effective implementation and optimization of smart building technologies. Moreover, occupant behavior is a crucial focus within the field of HBI research (Ji et al., 2023). Occupant behavior includes various aspects, such as the physical movements and control actions of building occupants (Yang et al., 2021). In essence, it examines how individuals navigate and interact within the built environment, primarily focusing on their choices and actions concerning building systems and technologies. Occupants' choices depend on their individual preferences for personal comfort (Delzendeh et al., 2017). This can be reflected in actions such as thermostat adjustment to achieve their desired indoor temperature comfort, or building occupants may open or close windows to regulate ventilation, airflow, and indoor air quality. Comfort in this context is a subjective state that is affected by a large number of factors, including physiological, psychological, and social parameters (Delzendeh et al., 2017).

Occupant behavior is closely related to energy consumption in buildings. Studies show that when occupant behavior is not factored into building energy performance, this can lead to a significant difference between predicted and actual energy consumption (Yang et al., 2021; Tam, Almeida, & Lê, 2018). Therefore, this made researchers realize the urgency of understanding the reason for this deviation in energy performance (Tam, Almeida, & Lê, 2018).

The way occupants behave in buildings can depend on several contextual factors, ranging from environmental conditions, geographical location, and time-related aspects to the accessibility of building features ((Mylonas et al., 2023; Tam, Almeida, & Lê, 2018). Additionally, subjective factors like expectations, habits, personal values, and perception of comfort significantly shape occupant behavior (Tam, Almeida, & Lê, 2018; Heydarian et al., 2020). Also, several papers highlight the importance of building occupants' awareness of their energy-saving behavior and their control levels (Nia et al., 2022). Lack of awareness may act as a significant barrier to adopting energy-saving behavior (Bäcklund et al., 2023). Because if building occupants do not fully understand the importance of energy conservation, they will not embrace energy-efficient practices. Regarding the degree of control, many studies show that the degree of control occupants have over their work environment is associated with several benefits, such as greater user satisfaction (Buckman et al., 2014). Moreover, Karjalainen (2013) emphasizes that personal control is widely acknowledged in studies on thermal comfort. However, the degree of control depends on the level of automation in smart buildings. As explained earlier, the level of automation in smart buildings can vary, which thus has a direct impact on the occupants' level of control.

Besides that, external factors, including cultural, political, and economic influences, can also trigger specific behaviors among building occupants (Tam, Almeida, & Lê, 2018). This intricate interplay of internal and external factors highlights the complexity of understanding and predicting occupant behavior in smart building environments. Figure 7 visualizes the above-mentioned complex aspects of occupant behavior.

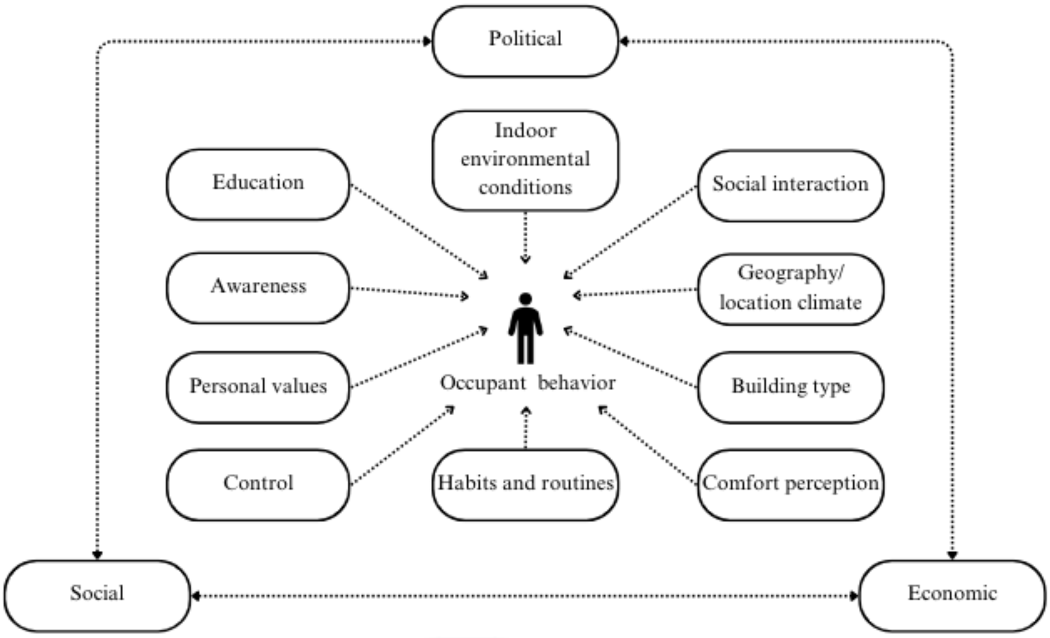

Figure 7: Factors influencing occupant behavior. Figure adapted from (Tam, Almeida, & Lê, 2018)

Furthermore, delving deeper into the interaction between building systems and occupants, Karjalainen (2013) investigated the attitude of occupants towards various control systems. He underscored the significance of trust between building technologies and users. Moreover, Karjalainen (2013) identified several constructs that contribute to enhancing this trust between automation systems and occupants. He emphasized the aspects of predictability, transparency, and feedback as crucial for comprehending the system's actions. The aspect of feedback also came forward in the study of Hu et al. (2020), who highlighted that providing feedback to users is an effective strategy for promoting behavioral change in energy-related actions (Hu et al., 2020). Furthermore, Nia et al. (2022) show that feedback between building systems and users can reduce unwanted occupant behaviors. Furthermore, Karjalainen (2013) noted the importance of simplicity, usability, and suitability for everyday life. This emphasized that the interaction between the occupants and the automated building systems should fit into their everyday lives to align with their behavioral patterns.

Moreover, it is crucial to recognize the privacy implications associated with users' interactions with smart building technologies. These smart systems collect data about user’s behavior and preferences to customize their experiences. However, this collected data may inadvertently reveal patterns that reveal whether people are present or absent, along with their activities, raising concerns about privacy violations (Pappachan et al., 2017). Moreover, challenges arise in obtaining consent for data collection and enabling users to exercise control over and choose the data they share (Pathmabandu et al., 2023).

2.3 Organizational stakeholders

To better understand the research environment, it is beneficial to delve further into the interactions between the key stakeholders who directly impact the functionality and management of smart buildings. This section serves as an introductory step by presenting the stakeholders who will later become the focus of the qualitative part of the study. While recognizing the broader network of actors, it is crucial to highlight the direct relevance of specific stakeholders: building occupants, facility managers, IT professionals, and HR personnel. These key players are directly involved in the daily dynamics of smart building environments.

Of these key players, the users of the building are the most important. As described earlier, these are the individuals who work in the buildings. They play a vital role in providing real-time feedback on their comfort preferences and needs. Occupants are at the heart of the system, and their daily experiences inform decisions about technology and design.

In addition, facility management forms an important stakeholder in this case. Facility managers oversee the day-to-day operations of (smart)buildings, ensuring that everything runs smoothly. From climate control to lighting, facility managers use technology to create comfortable and efficient environments for occupants. Their decisions directly impact the occupants' experience, ensuring that the building's systems are efficient, comfortable, and aligned with occupants' needs.

Moreover, HR professionals have a great influence in shaping workplace culture within smart buildings. Through the design of programs, schedules, and initiatives that promote work-life balance and overall well-being, they directly impact how occupants interact with various aspects of the smart building environment.

Beyond the key stakeholders, the involvement of government bodies, architects, designers, and technology providers in the smart building landscape contributes to the broader contextual framework. While their influence may be indirect, these actors play essential roles in shaping the regulatory environment, architectural designs, and technological infrastructure that impact smart building initiatives. Government bodies, for instance, establish the regulatory framework that shapes industry practices. Architects and designers contribute to the physical form and functionality of smart buildings, influencing their overall success. Technology providers, on the other hand, play a crucial role in developing and supplying technological solutions and systems. They are essential in enhancing the occupant experience by designing systems and solutions that anticipate occupant needs.

CHAPTER SUMMARY - Theoretical framework

Chapter 2 presented the theoretical framework to better understand the context in which the research takes place. It delved into the smartness of building systems, technology integration, and the role of climate control technology in enhancing thermal comfort. The chapter then investigated the psychological dimensions of technology adoption and user acceptance through theories like the Diffusion of Innovation and the Technology Acceptance Model (TAM). Next, the aspects of Human-Building Interaction (HBI) and occupant behavior within smart building environments were discussed. Lastly, the framework considered the influence of organizational stakeholders in shaping the adoption and integration of smart building technologies.

What emerged here is that there is no universal definition for what makes a building smart. In this context, smart buildings can be characterized as buildings that make use of advanced IoT technologies to autonomously manage a wide range of building functions and services (Pathmabandu et al., 2023). The primary goals of this automation are to improve occupant comfort, enhance operational efficiency, and reduce the environmental footprint of the building (Pathmabandu et al. (2023). These goals reflect a commitment to creating working spaces that are not only responsive to the needs of their occupants but are also environmentally responsible.

Regarding the smartness of building systems, this entails the utilization of information, both internally and externally sourced from diverse channels, to proactively prepare the building for specific events and circumstances (Buckman et al., 2014). This, in turn, aligns well with Dakheel et al.'s (2020) statements on the importance of the adaptability of smart buildings, which corresponds to the idea that smart buildings should be flexible and responsive to changing environmental conditions, occupant preferences, and energy needs.

Additionally, various theories are employed to understand the adoption of smart building technology. What emerged here is that the occupant is at the center of the smart building. Consequently, careful consideration must be given to examining the dynamic interaction between the building and its users. A notable observation is the predominant top-down approach in technology integration within buildings (Becerik-Gerber et al., 2022). This approach tends to prioritize technical feasibility and system optimization without putting much emphasis on the user perspective, preferences, and behavior of building users.

To bridge this gap between building technology and users, Human-Building Interaction (HBI) research emerged as a clear thread. This approach emphasizes understanding human preferences and needs in smart environments (Alavi et al., 2019). Within the HBI domain, there is a specific focus on the study of occupant behavior (Ji et al., 2023). The complex dynamics of occupant behavior are influenced by a wide range of factors. As this study looked from the perspective of the user in the building, it focused on the personal factors that influence occupant behavior.

The literature highlights the central role of comfort preferences, expectations, habits, and personal values in shaping occupant behavior. Moreover, it highlights the importance of occupants' awareness of energy-saving behavior and their degree of control over the building environment. This exploration sheds light on the multifaceted relationship between users and smart building technology.

CHAPTER 3: RESEARCH APPROACH

3.1 Research approach

An exploratory research approach is used to realize the objective of the study. The exploratory research approach helps to understand better occupants' preferences and behavioral mechanisms regarding climate control in smart buildings. The approach was chosen with the aim of gaining initial insights into how users adapt to these smart building environments, which cannot be found in the literature so far. An exploratory approach is an effective way to lay the foundation that can be used for future studies (Dudovskiy, J. (z.d.). Also, the approach has a flexible characteristic, allowing it to adapt to changes that become apparent over time (Saunders et al., 2012). However, an exploratory approach also has its drawbacks. Since exploratory is only meant to explore the research question, it usually does not provide a definitive solution to the problem and leaves room for future research. Given the multidisciplinary nature, which involves integrating technology, human behavior, sustainability, and various engineering and design fields, a mixed-methods approach is likely suitable.

3.2 Mixed-method approach

A mixed-methods approach in research combines both qualitative and quantitative methodologies. It includes collecting and analyzing data using both approaches within one study. The underlying idea behind using this mixed-method approach is that it provides a more comprehensive understanding of the research problem compared to using either qualitative or quantitative methods separately (Malina et al., 2011).

This study's qualitative part of the mixed-methods approach consisted of in-depth interviews with building occupants and industry experts. The primary objective was to capture a broad contextual understanding of the research problem while exploring multifaceted aspects of users' preferences and behavior with the interaction with smart building technology. Accordingly, these semi-structured interviews delved into the motivations, barriers, and various aspects of users' behavior and interaction with smart building technology. In contrast, the quantitative phase employed an online survey to identify broad-scale trends and preferences among a larger participant sample. This larger-scale analysis complemented the in-depth insights gained from qualitative methods. This is further discussed in the following chapters.

Moreover, the order of the mixed method approach is specifically chosen for this study. One part doesn't start until the other is completed. The qualitative phase is first and then the quantitative phase, allowing the insights gained from the qualitative part to be used in designing the quantitative part. This ensured that the findings from the interviews could be tested across a larger sample. Combining these two approaches, this mixed-methods approach offers a comprehensive perspective on the interplay between smart building technology and occupant behavior. Figure 8 visualizes this arrangement. And will recur in the chapters as a common thread throughout the study. This will be further explained in the following chapters.

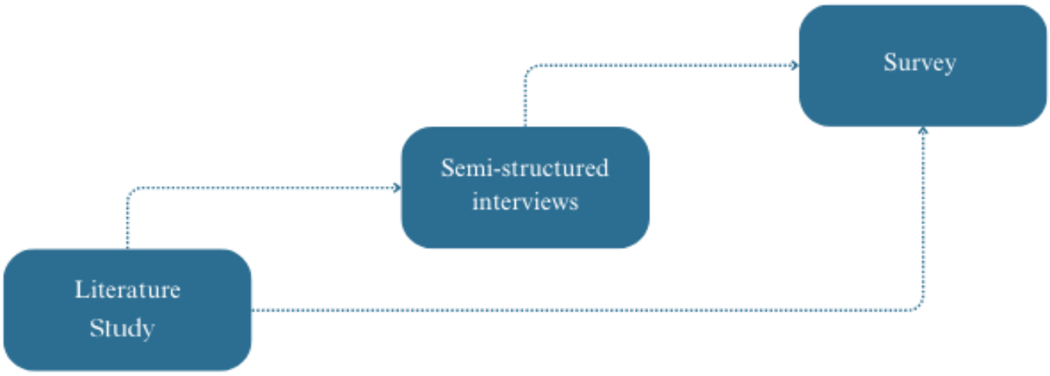

Figure 8: Structure mixed-method approach

3.3 Research structure

The following chapters, four and five, are the qualitative part of the study. First, the qualitative methodology, followed by the results of the part. Subsequently, chapters six and seven deal with the quantitative methodology and its results. Chapter eight provides a discussion, incorporating the findings from qualitative and quantitative research and delving into their implications. In addition, this chapter assesses the strengths and limitations of the study and offers recommendations for future research. Chapter nine summarizes the key insights and provides concluding remarks based on the findings of the study.

3.4 Overall approval by the Human Research Ethics Committee (HREC)

The qualitative and quantitative components of this research were both approved by the Human Research Ethics Committee (HREC) at TU Delft. This approval was granted following the submission of the necessary checklist, a comprehensive data management plan, and informed consent materials for both research methods. Consequently, the entire thesis study has been verified to adhere to the ethical guidelines and data management protocols established by the HREC. Informed consent forms are given in Appendix A and B.

CHAPTER 4: METHODOLOGY INTERVIEWS

This chapter elaborates on the qualitative part of the study, which consists of semi-structured interviews. This is the first part of the mixed-method approach, as shown in Figure 9. The chapter begins by outlining the setup of the method, followed by data collection, data operationalization, and data analysis.

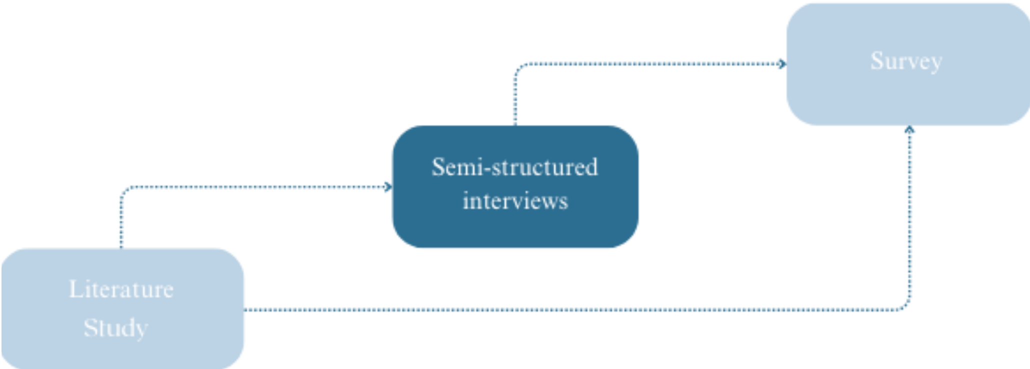

Figure 9 Overview mixed-method approach

4.1 Qualitative research set-up

Qualitative research seeks to gain insights into the personal experiences and perceptions of individuals within a social context (Fossey et al., 2002). It emphasizes understanding the subjective meanings and behaviors of people. Hence, this fits well with the research, as the aim of this part of the study is to find out more about the context in which the research takes place and to explore the multifaceted aspects of users' preferences and behavior with the interaction with smart building technology. This allows the first two sub-questions to be addressed:

- *What are the key factors identified by industry experts that contribute to the increased adoption of smart building technology?*
- *What are the underlying motivations and barriers driving occupant behaviors in smart office buildings?*

The qualitative nature of the approach involves semi-structured interviews with smart building occupants and industry experts. Semi-structured interviews enable the capturing of complex data on human-building interactions in smart office buildings (Li et al., 2023). By interviewing both occupants and industry experts in the field, a more comprehensive perspective can be created. Occupants' interviews shed light on their preferences, comfort levels, and any barriers they may face when using smart building technology, while industry experts bring technical expertise and industry knowledge to the table. Their insights into smart building systems' design, implementation, and functioning provide valuable context and can help interpret occupants' experiences more effectively. The data will be analyzed through thematic content analysis. Moreover, the qualitative results will help determine the precise questions to be asked for the quantitative research. Below, these steps will be discussed in more detail.

4.1.1 Data Collection

The qualitative research phase of this study involved two distinct participant groups: smart building occupants and industry experts. Smart building occupants were selected from different office buildings in the Netherlands to ensure diverse experiences and perspectives. Smart building experts were chosen based on their expertise in the field. This expertise could vary from technical knowledge of the development of smart technologies, the project management side of the development of smart building initiatives, or other involvement in the field of smart building initiatives.

I approached a number of the participants through the Royal Haskoning DHV (RHDHV) network. This involved searching within the company for employees who were involved in smart building initiatives. Additionally, I contacted some of the experts through my own network. Contact with the participants was made via Teams on the RHDHV platform or via LinkedIn messages to experts outside RHDHV. Table 2 provides an overview of all the participants in the interviews, including the motivation for why their expertise is valuable to the research. The participants were given a number (P1, P2, etc.) to distinguish the quotations later in the result section. As shown in the table, there were two participants working in a research institute. One participant from a technology and engineering company specializing in energy-efficient solutions. One director of workspace solutions (WPS). This is someone who is involved in a wide range of services related to the physical and digital workplace. And two consultants in the real estate sector. Participants with various backgrounds were included to explore the issue from multiple viewpoints. This approach allowed for a more comprehensive understanding of the developments regarding smart building technology.

Due to the diverse geographical locations of participants, I conducted most interviews with both occupants and experts via video calls using the Microsoft Teams platform. However, I personally met with the interviewees who preferred a face-to-face interview. The interviews lasted roughly between 30 and 90 minutes and were conducted between September 2023 and November 2023. Moreover, the interviews were transcribed via Microsoft Teams.

Number	**Function participant**	**Motivation**
P1	Researcher at Center of People and Buildings (CfPB)	Works on the relationship between people, work, and workplace environments. Experience in multiple smart building initiatives. Mostly active in the public sector.
P2	Researcher at Brain4Buildings (B4B)	Conducts research into the development of smart building user interfaces to ensure an energy-efficient and healthy indoor environment for the user.
P3	Consultant Real Estate at Deloitte & RHDHV	Expertise in smart building project implementation at existing Edge building Amsterdam and project management at RHDHV.
P4	Development Manager at Bosch Energy Solutions	Expertise in design, integration, and maintenance of high-quality safety, security, and smart building solutions. Responsible for ASML smart building implementation.
P5	Consultant at RHDHV	Knowledge and experience in smart building projects, vision, and implementation. Worked on

		the implementation of new smart building technologies.
P6	Director workspace solutions at RHDHV	Knowledge of global ICT operations, regional real estate, and facility management operations. Working on how to create value for users and make the workplace as efficient and convenient as possible.
P7	Director Industry & Buildings RHDHV	Knowledge and experience in smart building projects, vision and implementation. Director and responsible for the implementation of new smart building initiatives.

Table 2: Overview of interview participants with selection motivation

4.1.2 Data operationalization

Qualitative data collection was chosen for its ability to provide in-depth insights into the complexities of human behavior. It allowed participants to express their experiences and perspectives in their own words, thereby capturing nuances that quantitative methods might overlook. Open-ended questions were used to encourage participants to share their experiences and insights. Moreover, qualitative research aligned with the exploratory nature of this study, aiming to explore and uncover multifaceted aspects of occupant behavior in smart buildings.

For this study, the interview questions aimed to better understand the context of the study and, in addition, to uncover the preferences and behavioral mechanisms influencing behaviors within smart office buildings. The data was operationalized through a combination of inductive and deductive approaches. The deductive approach used two different interview protocols designed to answer different questions for various types of interviewees. It was often the case that the interviewee was both an expert and a smart building occupant. However, because this was not the case for all interviewees, two different protocols were created. For example, industry experts with no experience working in a smart building needed a different protocol than those familiar with interacting with the technology. The constructs of the interview protocol guided the interviews and ensured that key variables and concepts were covered.

The interview protocols were formed by using the information from the theoretical framework. First of all, the HBI approach provided the starting point for setting up the protocol, as the approach emphasized understanding human preferences and needs when engaging with a smart environment. However, before delving into the elements that were found in the theoretical framework, the interviews started with a brief introduction, with initial questions about the interviewee's familiarity and experience with smart building technology. This inclusion assessed the interviewee's knowledge base and gained insight into the depth to which follow-up questions could be addressed.
Following this introduction, the interview protocol used different constructs that were found in the literature to guide the conversations. The literature emphasized the technology-driven focus on implementing smart building technology and highlighted the tendency to prioritize technical feasibility and system optimization without putting much emphasis on the user perspective, preferences, and behavior of building users. Consequently, the constructs aimed to address this imbalance.

For example, literature found that attention should be given to predictability, transparency, feedback, simplicity, usability, and alignment with everyday life (Karjalainen, 2013; Hu et al., 2020). Moreover, it highlighted the importance of occupants' awareness of energy-saving behavior and their degree of control over the building environment. However, the constructs in the interview protocol were not one-to-one identical to the findings in the literature but were tailored to investigate different kinds of factors influencing individuals' interactions with smart building technology. Moreover, the interview protocol included constructs such as suggestions, success factors, and future considerations. These constructs were deliberately included to encourage open conversations and gain valuable insights for guiding future research.

The interview protocol can be found in Figures 3 and 4 and served more as a guiding framework rather than a strict set of instructions. The reason for this was to promote open conversation and to be able to explore knowledge and experiences in the field instead of testing theoretical assumptions. This was in line with the study's exploratory nature and referred to the study's inductive approach. The inductive approach involved an exploratory and open perspective during the interview process. This allowed themes and insights to emerge directly from the interviewees' experiences and stories. In this inductive phase, industry experts and building users were encouraged to share their experiences, thoughts, and perceptions without preconceived categories or assumptions guiding the discussion.

Topic	**Question**	**Examples indication**	**Comments**
Introduction			
Personal introduction	Can you briefly introduce yourself and your expertise in the field of smart building technology?		
Research introduction			Explain research to the participant
Constructs			
Experience	What is your experience with smart building technology, and to what extent are you involved in this in your work/projects?	Eg. research, advice, interests	
Current trends	Could you describe some of the most significant trends or developments you've observed in recent years?		
Climate control interaction	What kind of interactions are there, in your experience, with building occupants and the climate control technology?		Discuss the concept of occupant behavior

Preferences & concerns	What factors, in your opinion, influence the willingness of building occupants to adopt and engage with smart building technologies, such as climate control systems?	Eg. technical complexities, hassle factors, personal comfort, etc.	
Comfort & energy efficiency	What do you think are some of the key challenges in balancing occupant comfort with energy efficiency in climate control technology?	(eg. devices that allow occupants to set and adjust the temperature and climate settings in their workspace using a smartphone app),	
Feedback	Regarding project X, what role does the aspect of user feedback play? Both during the design process and after project completion.		Explain occupant-centric building
Success factors & challenges	What are factors that we should or should not bring to future projects?		
Future considerations	Where do you foresee the field of smart building technology heading in the next 5-10 years?		
Interview closing			

Table 3 Interview protocol Industry experts

Topic	**Question**	**Examples indication**	**Comments**
Introduction			
Personal introduction	Can you please introduce yourself briefly? What is your role or occupation within the office building?		
Research introduction			Explain the research to the participant
Topics			

Familiarity	Are you familiar with the smart building technology implemented in this office building?	E.g. occupancy sensors, climate control, etc.	
Experience	Can you describe your experiences or interactions with the technology?	E.g. What specific features have you used or encountered?	
Preferences	What are your preferences when it comes to indoor temperature and air quality? How do these preferences impact your comfort and productivity?		Discuss the link between indoor environment and productivity
Control	How do you typically control the climate (e.g., heating, cooling, ventilation) within your workspace? And to what extent do you value this sense of control?	Or are there restrictions here?	
User experience	In your opinion, how effective are smart building technologies in enhancing your overall comfort and work satisfaction?		Discuss whether this is important for the participant or not
Behavior and routines	Have you noticed any changes in your behavior or routines since the implementation of smart building technology?	E.g. Do you adjust your workspace based on climate preferences?	
Habits	Are there any specific habits or practices you've adopted related to energy conservation or comfort optimization?		
Barriers & concerns	Are there any concerns or reservations you have regarding the use of smart building technology?	E.g. privacy concerts	What makes the participant hesitant to fully embrace it?
Challenges	Have you encountered any difficulties or hassles while using the technology?	E.g. technical complexities or time-consuming	
Feedback & suggestions	If you could suggest improvements or changes to the smart building technology in this office, what would they be?	E.g. Are there features or functions you believe are	

		missing or could be enhanced?	
Interview closing			

Table 4 Interview protocol building occupants

4.1.3 Data analysis

The qualitative data collected from interviews was analyzed using specialized software, ATLAS.ti. This software aids in organizing, coding, and analyzing qualitative data efficiently. Thematic analysis was employed to identify recurring themes, patterns, and connections within the interview transcripts. The analysis process involved coding segments of text, categorizing codes into groups, and iteratively refining the groups into themes through an inductive approach.

The initial step in the analysis process involved transcribing the recorded interviews. These transcriptions served as the data source for analysis. Once the transcripts were ready, they could be imported into ATLAS.ti. The next step was the coding, which involved segmenting the text into meaningful units, assigning labels or codes to these units, and organizing them systematically. For this research, a combination of deductive and inductive coding was employed. Deductive coding was based on predefined categories derived from the theoretical framework (see interview protocol). Inductive coding allowed for the emergence of new themes and patterns from the interviews themselves. After coding the data, the next step was to identify and develop groups. Subsequently, the groups could be categorized into several overarching themes that could then be linked back to the research objectives. The final step was the broader interpretation and data synthesis. This step involved the integration of quotations and codes to better understand the research topics.

CHAPTER SUMMARY - Interview methodology

In summary, the qualitative research phase of this study involved semi-structured interviews with smart building occupants and industry experts. These interviews were conducted primarily via video calls but accommodated face-to-face interactions when preferred. The questions during the interviews encouraged participants to share their experiences. A combination of inductive and deductive approaches was used during the interviews, enabling the inclusion of elements from the theoretical framework while also discovering new insights. This was followed by an analysis in ATLAS.ti to uncover the complex details and mechanisms of occupant behavior and preferences in smart buildings.

CHAPTER 5: RESULTS INTERVIEWS

To organize and clarify the insights from the qualitative interviews, a hierarchical structure was used with three different layers: codes, groups, and themes. This systematic framework facilitated a comprehensive and in-depth analysis of the data. The codes were aggregated into groups, eventually coming together to form a limited number of themes. The section below will further explain the different themes (social, technology, organization, and next steps). Figure 10 contains the visualization of this structure.

Theme	Group	Code
Social	Personal barriers	Having control vs. Feeling of control
		Acceptance & satisfaction
		Habits
		Time-related hassles
		Unaware of possibilities
		Privacy
	Personal motivations	System feedback
		Interface design
		Clarity
		Transparency
		Flexibility
		Social cohesion
Organization	Design phase challenges	Mismatch design and use
		Design phase error
		Including users in the design phase
		Always start by setting goals
		Importance of primary process
	Stakeholders	Different interests
		Interaction FM and user
		FM is responsible but no time
		FM different goals from HR
		Every company has different targets
	Contextual factors	New way of working
		Automation increases
		Social awareness
		Change comes in small steps
		Being 'smart' is subjective
Technology	Technical hurdles	Technology push
		Error rate in sensors
		Technological integration
		You can't measure everything

		Subjective exp. are hard to measure
	Data management	Understanding what you measure Losing overview due to quantity Data-driven vs individual feelings Data awareness
Next steps	Success factors	Conducting pilots Communication Change management Awareness Stakeholder collaboration Feedback mechanism Aligning organizational objectives
	Obstacles	Large rotation of employees No one-time action Stakeholder communication

Figure 10: Code tree

Figure 10 illustrates the detailed code tree, which serves as a visual representation of the thematic structure. The following sections elaborate on these themes and provide insight into users' experiences with the adoption of smart building technology.

5.1 Social

The primary overarching theme focuses on the experiences associated with the adoption of smart building technology. This theme comprises two distinct groups: personal barriers and personal motivations.

5.1.1 Personal barriers

Within the personal barriers group, the interviews revealed several notable aspects, called "codes" in this context, that contributed significantly to answering the research questions. Three main aspects emerged during the interviews: the dynamics of *control,* the influence of *personal habits* and *time-related hassles,* and a lack of *user awareness.*

In particular, the concept of "control" emerged as a prominent and central aspect. It became clear that a critical distinction could be made between actual control and the perceived sense of control. Having control relates to the actual ability of occupants to directly and actively influence the smart building technology. For example, they can manually adjust temperature settings and lighting levels or access real-time data and feedback on energy consumption. In contrast, the feeling of control emphasizes the psychological aspect of occupant interaction. Even if occupants may not have direct control over certain aspects of the technology, the feeling of control arises when they believe the system is considering their needs and feedback. It is a sense of agency and influence, which can, for example, be derived from transparency and feedback mechanisms of interfaces. This distinction is important since it shows the interaction between the tangible functionality of smart building systems and the psychological factors that influence user satisfaction and acceptance. While providing actual control is essential for the customization of functionalities, the sense of control contributes to their overall experience with and acceptance of the technology.

Other important barriers that were mentioned by participants were the aspects of habits and time-related hassles. Many individuals stated they had established habitual behaviors regarding how they controlled their immediate environment. As described in the literature framework, habits are formed by the consistent repetition of specific interaction patterns between individuals and their environment (Syse and Mueller, 2015). The integration of smart building technology can disrupt these established routines, which may lead to resistance or frustration. As mentioned by one of the interviews: *"Take, for example, someone who has worked at, say, the tax office for 20 years. Who is used to having his own locked room and being able to leave all their stuff in there. Think of that picture frame on the desk idea"(P1).* This quote highlighted the specific habits and routines people develop in their workplace, which often increase the longer people work in one place. These routines may be deeply rooted in their daily work and provide a sense of familiarity and comfort. When smart building technology is introduced, it can disrupt these established routines and practices. This is closely related to time-related hassles, as users need to invest time in understanding how the technology works, setting preferences, or solving problems. Examining hassles in this context is a relatively recent area of study. However, hassles can act as significant stressors that contribute to an undesirable state of well-being (De Vries et al., 2020). Ultimately, this increased stress can lead to avoidance of technology use and, therefore, hinder energy-saving actions in buildings.

Another aspect that came up frequently during the interviews was occupants' limited awareness of the available options and opportunities offered by smart building technology. It is clearly not their job to dive deep into these intricacies. However, the unawareness of technology possibilities often translates to missed opportunities for enhancing comfort and optimizing energy use. Occupants may not realize how the technology could contribute to their well-being, job satisfaction, and broader sustainability goals.

Besides the primary topics, there were several additional elements that emerged during the interviews. Although that were slightly mentioned less often. Privacy emerged as an important aspect, with the interview participants expressing concern about the potential invasiveness of smart building technologies. An interesting note was that smart buildings often use flex spaces to avoid linking specific personal attributes to particular places. However, it was observed that there seemed to be a consistent pattern of individuals tending to sit in the same chair or desk every day. As noted during one of the interviews: "*The situation we have also experienced is that if someone sits at the same workplace every day, then it is very easy to link these insights to an individual person" (P4).* This could call into question the effectiveness of this principle and still highlight the potential privacy issues.

In addition, the balance between acceptance of these systems and user satisfaction was another key discussion point. Participants often indicated that their overall experience depended on how easily they adopted these technologies and how much satisfaction they got out of them. In other words, they wanted to know beforehand how much they could get out of it.

5.1.2 Personal motivations

Moving on to the group of personal motivations to adopt smart building technology. Three main aspects emerged during the interview: *system feedback, transparency, and flexibility*.

Many participants highlighted the importance of feedback from the smart building systems. They emphasized the value of real-time data and insights into energy consumption, indoor climate, and comfort levels. Such feedback not only enabled them to make informed decisions but also ensured that they better understood how these technologies functioned. As an example, the desire for a two-way feedback system emerged prominently in the discussions. Participants expressed their interest in not only receiving information from the system on how it operates but also providing feedback back to the system.

Transparency in system operations was another key motivation that surfaced during the interviews. Participants expressed the desire to have a clear and understandable view of how smart building technology operates. They expect transparency, such as real-time indications of system responses to their actions. For instance, when an occupant adjusts the temperature, the system should promptly indicate this change to prevent unnecessary adjustments by others, thus ensuring optimal comfort and energy efficiency.

The third notable aspect that emerged was creating flexibility and personalization. Occupants emphasized their need for technology that could seamlessly adapt to their unique preferences and changing requirements. Flexibility in this context went beyond just the ability to adjust settings. It was about a level of personalization that accommodates various working styles and individual comfort requirements. As explained by participants, a key aspect of flexibility was the ease of making adjustments. Whether it was changing temperature settings or fine-tuning lighting levels, the technology had to provide a user-friendly interface that allowed quick adjustments in response to users' changing preferences.

Besides the primary topics, there were some other elements that emerged during the interviews. These additional elements encompassed the type of interfaces, clarity of options, and marketing promotions. Participants frequently raised the issue of interface design and usability. They emphasized the importance of having user-friendly interfaces that simplify interactions with smart building systems. For example, there is a difference between digital and physical interfaces. In terms of clarity, it was pointed out that it is important to be clear about the benefits. One participant noted that use cases are particularly effective for the purpose of showing how things would be in practice. Participants also highlighted the significance of effective marketing promotions in motivating individuals to adopt new technology. Additionally, they stressed the importance of clearly presenting the available options right from the beginning rather than requiring users to learn about them over time.

5.2 Organization

The second overarching theme is the organizational context. Within this theme, there are three groups that can be distinguished: *design phase challenges, stakeholders, and contextual factors*. Delving into these components provides invaluable insights into the broader organizational landscape and its influence on integrating smart building technology.

5.2.1 Design phase challenges

These challenges include the hurdles faced during the early stages when transitioning from conventional building systems to smart building systems. A recurring challenge in the application of smart building technology is the mismatch between the original design of the technology and its actual use by users. This challenge underlines the importance of involving end-users, such as building users, during the design phase, as noted during one of the interviews (P7). *"So look at what the user really needs. In doing so, it is crucial that you include a cross-section of that organization in how they work and what they expect from the workplace. It is important to recognize that each organization differs in its approach and priorities (P7)".* This highlights that valuable insights and feedback from occupants are essential to ensure that the technology matches their specific needs, preferences, and daily routines. In this way shows that the alignment between design and actual use is crucial for optimizing the benefits and functionality of smart building technology. If this alignment is not achieved, people may try to override the technology. As indicated in the interviews: *"Examples were shared, such as in our own building where people use tape to hold a ceiling fan in place or attach a piece of paper to prevent a window from moving (P2)."*

In addition, it was mentioned in the interviews that it is crucial to set clear goals and objectives in the early stages of implementing smart building technology. These goals can serve as guiding principles that help direct the entire process. They outline what the organization aims to achieve with the technology and what benefits it intends to deliver. In addition, it was noted during an interview that recognizing the primary process is a fundamental aspect of this phase. It involves understanding the core functions and needs of the organization. By recognizing the primary process, organizations can determine how smart building technology can be integrated to enhance and align these essential functions. This recognition ensures that the technology implementation aligns with the organization's core operations, contributing to more effective and efficient outcomes.

5.2.2 Organizational Stakeholders

One interview noted, "*In practice, facility managers are often seen as people who need to have a good understanding of workplace dynamics. However, the reality often involves that they are dealing with day-to-day challenges, essentially putting out fires and striving to maintain the system's functionality" (P2).* This statement highlighted the gap between the role facility managers play and the practical challenges they face. While facility managers are expected to comprehensively understand building dynamics and occupant satisfaction, the reality is more demanding.

In addition, a prominent theme that emerged from the interviews was the mix of interests between stakeholders within the organizational system. The varying priorities and goals of different stakeholders contribute to the complexity of implementing smart building technology. For example, within the organizational structure, FM focuses on the physical aspects of the workplace by ensuring functionality, safety, and efficiency. HR centers its objectives on the human elements of the workplace. The focus extends beyond the physical infrastructure to prioritize well-being and productivity. IT plays a crucial role in facilitating the integration of technologies and managing the data generated by these systems. However, as the aforementioned practical example shows, this exact alignment of roles is not always the case in reality. These differences can lead to communication gaps, where FM and IT initiatives may not fully align with HR's people-centered objectives.

5.2.3 Contextual factors

In this context, these contextual factors form the framework for smart building technologies. They influence the adoption of these technologies and the pace of their implementation. One critical contextual factor that emerged during the interviews was the shift toward a new way of working. The traditional office setting is evolving, with an increased focus on flexibility, remote work, and collaborative spaces. Smart building technologies are designed to accommodate these changing work dynamics, ensuring that the physical environment aligns with the modern workforce. In addition, as technology continues to evolve, automation becomes more prevalent in day-to-day operations.

Moreover, organizations increasingly recognize the importance of adopting smart building technologies to reduce their carbon footprint and promote eco-friendly practices. This social consciousness extends to the occupants, who, in turn, become more informed and motivated to contribute to these initiatives. This gradual shift often involves occupants adopting these changes in slow, incremental steps. Allowing their understanding and personal motivations to develop.

Another aspect that emerged within the contextual factors is the idea of what it means to be "smart," which varied considerably among the interviewees. *“Being smart is not the same as a smart building”* (P6), as noted by one of the interviews. This interesting quote highlights the contrasting perceptions of being "smart" as an organization and a "smart building." The distinction between these two perspectives is notable because it reflects stakeholders' different objectives and priorities. While some prioritize organizational-level "smartness" that extends beyond the physical infrastructure, others place more emphasis on technological innovations in the building itself.

5.3 Technology

Over the duration of the interviews, the technical dimension of smart building technology emerged as a recurring theme. Although the interviews did not focus primarily on technical details, it became clear that technical challenges can significantly hamper the user experience. Within this theme, two groups can be distinguished: *Technical challenges* and *data management.*

5.3.1 Technical challenges

One recurring challenge highlighted during the interviews is the concept of "technological push." This concept means that the technology is just ‘pushed’ into the building instead of deploying the technology in response to specific requests. *"Implementing as many sensors as possible is not always a good thing" (P4)*, as mentioned during one of the interviews. In addition, another technical challenge that was mentioned was the integration of the new technologies within the organization's existing network. The integration process must be carried out carefully to avoid conflicts or disruptions in the overall technology infrastructure. During several other interviews, it was noted that we should, therefore, make use of already existing technology in the building before introducing new ones. Often, a lot of data is already collected that nothing is currently being done with.

Another prominent issue highlighted was the error rate in sensors. These sensors are integral components of smart building systems, responsible for collecting data on various environmental parameters. However, during an interview, it was noted that sensor errors can cause difficulties: *“For instance, consider a scenario in an office building where sensors are located under the desks of employees to monitor their occupancy. If employees occasionally want to work standing up or for some other reason, the sensors do not register occupancy” (P1).* This situation highlighted the technology's limitations in accurately assessing individuals' actual presence within a workspace.

5.3.2 Data management

Another group of challenges from the interviews is associated with data management and understanding. This is an important aspect as smart building technology increasingly relies on data-driven insights to optimize various aspects of the workspace. One of the primary issues raised during the interviews was the need for a clear comprehension of the collected data. Participants expressed concerns about the significance and purpose of the data gathered by smart systems. Since so much can be measured, the overview can be lost. Collecting data for its own sake does not offer immediate solutions or benefits. Therefore, starting with a clear understanding of what can be achieved with the data before collecting it is essential.

In addition, an interesting contrast that emerged during the interviews was the balance between relying on data and acknowledging occupants' subjective feelings and experiences. Some interviewees noted that while data provides objective measurements, it may not fully reflect subjective aspects of comfort or well-being. One interviewee illustrated this: *"Imagine a scenario where there is a queue at the coffee machine. If you look at this from a data point of view, this can be seen as undesirable, as it is not going as effective as possible. However, the coffee machine is not only there to serve coffee but also to enable spontaneous social interaction among employees. In this context, is the presence of a queue in front of the coffee machine, therefore, necessarily a negative aspect?" (P6).* This highlighted the difference between the quantitative data collection and the qualitative data collection.

5.4. Next steps

The concluding segment of the interviews primarily focused on the next steps and considerations essential to ensuring the occupants' full adoption of smart building technology. So, to see which steps are crucial for achieving the intended objectives for which the technology was designed. While this question may not relate directly to the primary research, it came up frequently in the interviews. Moreover, it adds valuable insights that can guide future research. The first section will elaborate on the recurring success factors, and the second one will focus on the obstacles.

5.4.1 Success factors

Many interviewees emphasized the importance of conducting pilot programs before full-scale implementation. Pilots allow organizations to test and evaluate the technology in a controlled environment. To be able to make adjustments before widespread deployment. In addition, the collaboration between different stakeholders, including FM, IT, and HR, was identified as a critical success factor. Aligning the goals and efforts of these different groups is essential, along with transparent communication between the different stakeholders. Subsequently, this alignment extends to aligning broader organizational objectives with the functionalities of technology. When the functionalities of technology align with broader objectives, it becomes possible to measure the benefits of the technology.

In addition, during the interviews, participants emphasized the effectiveness of integrating use cases. They emphasized that the technology's real-world examples and practical applications contribute significantly to its effectiveness. Moreover, the participants stated that the use cases can help clarify the potential benefit while also making the technology more accessible to the users.

Besides that, the aspect of user feedback emerged as essential. *"This includes not only feedback at the beginning of the project but also seeking feedback after completion of the building. However, the last part is often more difficult" (P7).* This highlighted the misconception that completing the implementation of a building means the end of the process. Establishing a feedback mechanism allows users to share their experiences and make valuable suggestions, promoting continuous development.

5.4.2 Obstacles

In contrast to the success factors, there are also a number of elements that can hinder technology adoption or create obstacles in the long term. It was emphasized during the interviews that implementing technology is not a one-time action where everything runs smoothly afterward. After implementation, consistent monitoring and feedback sessions are essential. This ensures that the system remains well-aligned with the different needs of users. Thereby recognizing that each building is different and has different types of occupants.

Another interesting note during the interviews was that companies with large rotations of employees might experience difficulties. "*This is because new employees do not know about the latest updates. And, during the start-up period, are not concerned with this either*" (P3). Consideration will therefore have to be given to how new employees can be informed about the different features and options available in their working environment.

Finally, effective communication between stakeholders at every stage was considered crucial, as was evident from the interviews. Without shared goals and open communication channels, it becomes challenging to align the functionalities of technology with higher organizational goals. It is necessary to ensure that the technology functionalities of a smart building are aligned with the organization's overarching goals. This alignment not only allows organizations to measure the impact and benefits of the technology but also facilitates the achievement of broader organizational goals.

CHAPTER SUMMARY - Qualitative findings

In this chapter, insights from qualitative interviews were presented, complementing the findings from the literature review. The interviews were conducted using both deductive and inductive approaches. The deductive approach involved applying the interview protocol, including aspects identified during the literature review. The inductive approach embraced an exploratory and open perspective during the interview process. To analyze the interviews, a hierarchical structure of codes, groups, and themes was employed to organize and present insights, as illustrated in Figure 10. A total of nine groups emerged, further categorized into four overarching themes: social (experiences), organization, technology, and next steps. These themes served as guiding threads throughout the text.

The first theme, social, focused on understanding the motivations and barriers that occupants face when adopting smart technology. Several key elements emerged here, including perceived control, acceptance, habits, hassles, and awareness. These factors contributed to shaping how individuals interact with and respond to smart building technology. These findings were consistent with the literature review. Only the addition of the aspect "hassle" element made a new contribution. Additionally, preferences were highlighted, with three preferences standing out the most, as indicated by the respondents: system feedback, transparency, and flexibility. Furthermore, considerations such as the design and clarity of the interface scored significantly. These preferences align with findings in the literature, reinforcing the crucial role these factors play in shaping how users perceive and interact with smart building technology.

The second theme examined the organizational context of smart building technology. One prominent aspect emerged, namely the application of a user-centered approach, which had also surfaced in the literature review (Alavi et al., 2019; Shen et al., 2016). This approach was highlighted as a key strategy to effectively address discrepancies between design and actual use. Additionally, the interviews shed light on a complex landscape of interests between stakeholders within the organizational system. In particular, the diverse perspectives of stakeholders reflected different objectives and priorities, contributing to the overall complexity of the implementation process.

The third theme focused on technical aspects and demonstrated that challenges in this area could significantly impact the user experience. While technical difficulties were commonly noted, it was interesting to observe that they were not always directly linked to user satisfaction. Moreover, there was a risk that the amount of data being collected might lose clarity and overview. Therefore, it showed the importance of clearly understanding the intended applications to avoid collecting data just for the sake of collecting.

The fourth theme examined the next steps. Interviewees underscored the significance of pilot programs for smart building technology, allowing controlled testing and adjustments before full-scale implementation. In addition, aligning the technology functionalities of a smart building with the organization's objectives was essential to enable organizations to measure the impact and benefits of technology in achieving broader organizational goals. Moreover, post-implementation, consistent monitoring, and communication were critical, especially in companies with high employee turnover. In this case, strategies for informing new employees and ongoing communication with stakeholders were crucial. The next chapter will further test the qualitative findings on a larger sample using an online survey.

CHAPTER 6 METHODOLOGY SURVEY

This chapter delves into the quantitative part of the study. This involves a survey sent out among smart building occupants. It is the second phase of the mixed-method approach, as shown in Figure 11. First, the setup will be discussed, followed by the data collection, data operationalization, and data analysis.

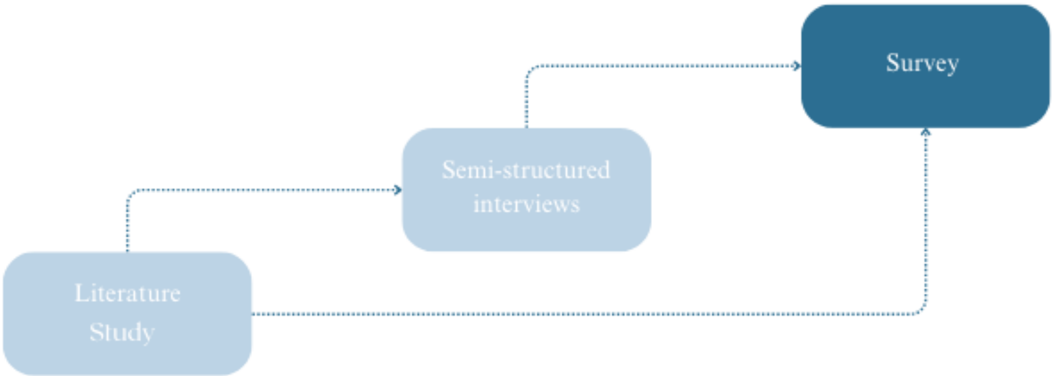

Figure 11: Overview of mixed-method approach

6.1 Quantitative research set up

The quantitative research approach entails the collection and analysis of numerical data to provide explanations for specific phenomena (Goertzen, 2017). This method is utilized to identify behaviors and trends. However, quantitative research does not delve into the underlying motivations behind observed behaviors. Therefore, complementing it with qualitative interviews can offer valuable additional insights into the research (Goertzen, 2017).

The quantitative data for this was collected through a survey that had been distributed among smart building occupants from various office buildings across the Netherlands. Since occupants of different office buildings may have had different experiences and interactions with smart building technology. The survey was intended to validate and extend the insights gained through qualitative research to a broader audience. This made it possible to make more generalized statements regarding the preferences and behavioral mechanisms that occupants experienced in their interaction with smart building technology and specific climate control technology. In this way, sub-question four was addressed:

- *To what extent do smart building occupants in different office environments exhibit common preferences and behavioral* mechanisms *regarding climate control technology?*

6.1.1 Data collection

The study focused on smart building occupants as the population of interest. A sample was drawn from participants from various office types and backgrounds to capture a diverse perspective. This diverse sample aimed to provide a broad understanding of the variations in smart building technology adoption in different work environments. Which is in line with the exploratory research approach. The initial contact with organizations occurred between November 2023 and December 2023, primarily through email or LinkedIn messages. The organizations were selected based on the availability of smart technology in the building. The initial email or LinkedIn message was used to inquire whether the person in question was interested in participating in the study and in sending out the survey within their organization. This was a process in which several companies had been contacted. Because there would also be a high probability that the companies might not want to participate in the survey. After the first companies were contacted separately, this still yielded too few respondents. Accordingly, another separate personal LinkedIn post was made to get more respondents (see Appendix D). This LinkedIn post was asking for people who work in a building that incorporates smart building elements. So, it did not ask about a building that is completely smart in order to get more respondents. The survey was created using the Qualtrics software program. So, once the first contact was made with the participants, they could access the survey via a link. Also, through the LinkedIn post, participants could be led directly to the Qualtrics program.

6.1.2 Data operationalization

As stated above, the survey was designed using the software program Qualtrics. The specific types of questions were formulated right after the completion of the semi-structured interviews. This specific sequencing allowed for testing interview findings on a larger sample. However, modifications were made to the survey as the insights from the interview were mainly drawn from industry experts, while the survey questions were tailored specifically for occupants of the buildings.

To design the constructs for the survey, it was important to understand what to derive from the survey. The study aimed to explore the preferences and behavioral mechanisms of smart building occupants in the context of a smart office building, thereby providing a holistic perspective essential for identifying effective strategies to mitigate hassles and enhance user satisfaction. To reach this objective, the survey needed to provide insights into the smart building occupants' preferences and behavioral mechanisms. As stated in the literature, occupant behavior includes various aspects, such as building occupants' physical movements and control actions (Yang et al., 2021). In essence, it examines how individuals navigate and interact within the built environment, primarily focusing on the choices and actions they make in relation to building systems and technologies. These choices of the occupants depend on their individual preferences for personal comfort (Delzendeh et al., 2017). Therefore, the survey tried to get a grip on the individual preferences for personal comfort. In addition, to explore the behavioral mechanisms, the survey needed to incorporate a set of questions that delved into various aspects of smart building interactions. The overview of the survey questions can be found below in Table 5. The next section elaborates on why each construct was chosen to be included in the study and how it contributes to answering the main research question.

Question	**Response options**	**Contruct**
Section 1: General information 1.1 Please name the organization you work for and describe your role or occupation within the organization	Text field	Organization and occupation
1.2 In which type of office environment do you work? (e.g., private office, shared workspace)	Text field	Office type

1.3 Are you familiar with the smart building technology implemented in your office building? (e.g., smart lighting systems, occupancy sensors or HVAC control systems)	o Yes o No	Familiarity
1.4. To what extent do you think your organization has adopted smart building technology? (Choose one option)	o Fully adopted o Partially adopted o In the process of adoption o Not adopted o Not sure	Adoption
Part 2: User satisfaction 2.1 How satisfied are you with the smart building technologies in your office?	o Very satisfied o Satisfied o Neutral o Dissatisfied o Very dissatisfied	User Satisfaction
Part 3: Motivations and experience 3.1 What motivates you to engage with smart building technologies in your office actively? (Select all that apply or provide specific examples)	o Personal comfort and convenience o Energy conservation and sustainability o Cost savings o Increased productivity o Other (please specify)	Motivations and experience
3.2 What features or benefits are most important to you for improving your office environment? (Select all that apply)	o Transparency and understanding of the system's operations o Feedback and data-driven insights on your energy usage and comfort o Flexibility and customization options o Enhanced control and personalization of your workspace o Greater control over your workspace o Convenience and time-saving benefits o Other (please specify)	Features
Part 4: Barriers and Concerns	o Privacy concerns o Security concerns	Barriers and Concerns

4.1 Do you have any concerns about the (future) use of smart building technology in your office? If yes, list the barriers that apply to you:	o Lack of control o Time-related hassles o Overall work adaptation o Other (please specify) o I have no concerns	
4.2 Have you faced any challenges while using the technology in your office? (Select all that apply or provide specific examples)	o Difficulty in understanding how the technology works o Connectivity issues with smart devices (e.g., thermostat, lighting controls) o Difficulty in adjusting settings or controls o Lack of clarity in user instructions o Technical glitches or malfunctions o Inconvenient user interface o Unwanted or unexpected automation o Other (please specify) o No I have not encountered any difficulties	Challenges
Part 5: climate control and comfort 5.1 How do you typically control the climate (e.g., heating, cooling, ventilation) within your workspace?	o Manual controls (e.g., thermostat) o Automatic controls (e.g., sensors) o I have no control o I don’t know	Climate control
5.2 How important is it for you to have control over the indoor climate in your workspace?	o Very important o Somewhat important o Not very important o Not important at all	Importance of control
5.3 How important is indoor air quality to your overall comfort?	o Very important o Important o Neutral o Not important o Very unimportant	Indoor air quality
Part 6: Behavior and Adaptation 6.1 Has the implementation of smart building technology in	o Yes o No If yes, please briefly describe.	Behavior

your office influenced your behavior or routines?		
6.2 Have you consciously adopted any practices related to energy conservation or comfort optimization in your workspace?	o Yes o No If yes, please briefly describe.	Energy-related practices
Part 7: Feedback and Suggestions 7.1 How important is it for you to have a voice or influence in shaping the technology's functionality within the building?	o Very important o Important o Neutral o Not important o Very unimportant	Having a voice
7.2 Are there any features or functions you believe are missing or could be enhanced in your building?	o Yes o No If yes, please briefly describe.	Missing features
Part 8: Overall Impact 8.1 How has adopting smart building technology influenced your overall experience as an occupant in your office building?	o Significantly improved my experience o Improved my experience o It had no significant impact on my experience o Reduced my experience o Significantly reduced my experience	Overall experience
8.2 Do you believe smart building technology contributes to a more sustainable and energy-efficient workspace?	o Strongly agree o Agree o Neutral o Disagree o Strongly disagree	Sustainable workspace

Table 5: Survey questions

As depicted in Table 5, the survey questions comprised closed-ended items, encompassing multiple-choice questions and dichotomous (yes/no) questions. In addition, respondents were occasionally given the opportunity to explain their chosen answers. These closed-ended question types were selected based on their suitability for quantitative analysis, enabling data quantification and statistical examination. The inclusion of open-text field options allowed respondents the opportunity to articulate their answers. As shown in Table 5, the survey was organized into eight sections. The initial section contained general information, consisting of four questions. The first two questions, relating to the company and office type, were included to identify which organizations the survey participants represented and to understand their working environment. The remaining two questions focused on the participants' familiarity with smart technology in their building and their perception of the technology's adoption level. These questions aimed to investigate the occupants' awareness regarding the smart building technology implemented in their office and whether they perceived their organization to have adopted the smart building technology. The questions were asked specifically from the occupants' perceptions in order to get a better picture of their awareness of the technology implemented in the building. These constructs were included from insights gathered during the literature review and semi-structured interviews. Both highlighted the crucial role of user awareness in the context of smart building technology. In this way, these questions contributed to a better understanding of how users perceived the presence of smart technology in their workplace.

The second section focused on the level of user satisfaction with smart building technology. This, therefore, tied in well with one of the broader goals of increasing user satisfaction. These insights were valuable in understanding the extent to which the technology met occupants' expectations and needs at this time. As shown in the interview results, it was found that participants often indicated that their overall experience depended on how easily they adopted these technologies and how much satisfaction they derived from them.

The third section contained questions about the motivations and experiences of the building occupants. Exploring users' motivations and experiences helped to understand their preferences regarding smart building technology, which is in line with the research goals. The questions in this section were deliberately included to reflect aspects that had been explored in the previous interviews and were also identified in the literature review. So, the multiple-choice answer options from the survey all came from either the literature or the interviews. As a result, multiple-choice answer options could facilitate the validation of specific findings and contribute to answering the main question. The same applied to section four, which examined the barriers and concerns experienced by building occupants. Again, the multiple-choice answer options from the survey all came from either the literature or the interviews. Therefore, this question could facilitate the validation of specific findings. Thus, it contributed to understanding preferences regarding smart building technology, which is important for answering the main research question.

Part five focused on the aspect of climate control and indoor climate. This part was included specifically for additional information on the scope of the research. As explained earlier, within the larger scope of climate control technologies, the scope of this research is on climate control. Within this section, four questions were asked. The first question was to give respondents an initial understanding of the topic. The second question then addressed the crucial aspect of control, an element that came up frequently in both the literature and the interviews. For example, Karjalainen (2013) emphasized in the literature that personal control is widely acknowledged in studies on thermal comfort. Additionally, in the interviews, it was found that there was a critical distinction between actual control and the perceived sense of control. While providing actual control is essential for the customization of functionalities, the sense of control contributes to their overall experience with and acceptance of the technology. Furthermore, the third question in section five examined the aspect of indoor air quality. This construct was included based on its identification in the literature framework as a significant factor contributing to thermal comfort.

Part six looked at the behavior and adaption of the building occupants. This part was included to test whether the technology actually caused changes in energy-related behavior and whether people were aware of this. This is an aspect that did recur in both the literature review and the interviews. As indicated in the literature review, extensive research highlights the central role of occupant behavior in influencing energy consumption in buildings (Xu et al., 2023; Bäcklund et al., 2023). Lack of awareness in this context may act as a significant barrier to adopting energy-saving behavior (Bäcklund et al., 2023).

Then, part seven focused on the aspect of feedback between the building and the occupants. A whole part was devoted to this since it was mentioned during the literature review and most of the interviews. The literature states that providing feedback to users is an effective strategy for promoting behavioral change in energy-related actions (Hu et al., 2020). Furthermore, Nia et al. (2022) showed that feedback between building systems and users can reduce unwanted occupant behaviors. During the interviews, it emerged that feedback should not be one-sided but two-sided. So that occupants could also give this feedback if they wanted to. This showed the importance of having a voice in the decision-making process, which could then be tested in the survey. The second question of this part explored the possible missing features of smart building technology in their building. This was included to see if the suggested elements from the literature or interviews were still missing that users wanted to share.

The last section concluded with two questions on the overall impact. This contributed to understanding the user experience within the smart building. The first question addressed the overall impact on the occupant experience, while the second explored the contribution to creating a more sustainable and energy-efficient workspace. Both concepts were intentionally included because they are highlighted in the literature as important objectives of a smart building.

6.1.3 Data analysis

Statistical analysis was conducted using SPSS (Statistical Package for the Social Sciences), a widely used software for analyzing quantitative data. This tool allows for the identification of significant correlations and patterns within quantitative data. As stated earlier, the data for the analysis was collected through Qualtrics. Using Qualtrics, the data could be directly exported into SPSS. Before any analysis could be done, the data needed to be cleared. The first step to clear the data was to ensure that only respondents who had completed the entire survey were included. The reason for this was that the results of the questionnaire showed that many respondents stopped after the first section on general information and did not proceed to the actual constructs of the survey. Therefore, these respondents had to be removed. This was followed by a detailed examination of the properties of the variables, assessing the appropriateness of data assignment to each variable. Here, consideration was given to their respective types (ordinal, nominal). After the dataset was prepared, the data was ready for analysis. This required determining which type of analysis was suitable for the study. The decision-making process included evaluating the research objectives, the nature of the data, and the desired results. The research aims to explore the preferences and behavioral mechanisms of building occupants. In order to achieve this, the aim of the survey was to test the findings that were found in the literature and the interviews. In addition, it focused on understanding what occupants prefer in a smart building environment and how they interact with and respond to the technology.

Furthermore, a correlation analysis was used to provide insights into possible relationships or patterns within the dataset. This decision aligned with the study's exploratory nature, intending to examine relationships between variables rather than establish cause-and-effect relationships.

CHAPTER SUMMARY - Quantitative methodology

In summary, the quantitative research phase involved collecting data from smart building occupants through an online survey. The survey was meant to validate and extend the insights gained through qualitative research to a broader audience. This made it possible to make more generalized statements regarding the preferences and behavioral mechanisms that occupants experienced in their interaction with smart building technology and specific climate control technology. The survey consisted of closed-ended questions, allowing for numerical data collection. A combination of descriptive statistics, multiple-response analyses, and correlation analysis was chosen to discover relationships between variables rather than establish cause-and-effect relationships.

CHAPTER 7 RESULTS SURVEY

This chapter presents the results of the survey. It is structured according to the different parts of the survey. Where, within each part, the different constructs are discussed. The first part starts with an outline of the sample size and general information. The next stage involves a detailed discussion of the remaining parts of the survey. An overview of the different parts and constructs can be found in Table 5. Once this exploration of individual constructs is complete, the constructs that are suitable for the correlation analysis are identified. The following section presents the findings of the correlation analysis, revealing possible links and relationships between the constructs.

7.1 Part one: General information

The online survey showed 105 respondents. However, after cleaning the dataset, as described in the methodology, a total of 92 respondents were valid for analysis. The survey consisted of eight parts, the first one being about general information. In this section, four questions were asked, the first two questions relating to the company and office type. The remaining two questions focused on the participants' familiarity with smart technology in their building and their perception of the technology's adoption level.

Survey participants were employed by a variety of organizations, reflecting a variety of office types. Most respondents indicated that they often worked in private, shared, or home office environments. Regarding the familiarity of the occupants with smart technology in their building, a total of 66% of the participants were familiar with all the smart technologies implemented in their buildings, while 34% said they were not aware of all the smart technology in the building. Since all respondents were working in a building with (partially) implemented smart technology, a relatively low number of people were aware of all the technological functions. In addition, regarding the level of smart building adoption as perceived by building occupants, figure 12 shows the distribution among the respondents. From this, you can see that the majority of respondents indicated that they are still in the process of adoption. This should be considered when interpreting the results of the other survey questions, as respondents at different stages of adoption may give different answers.

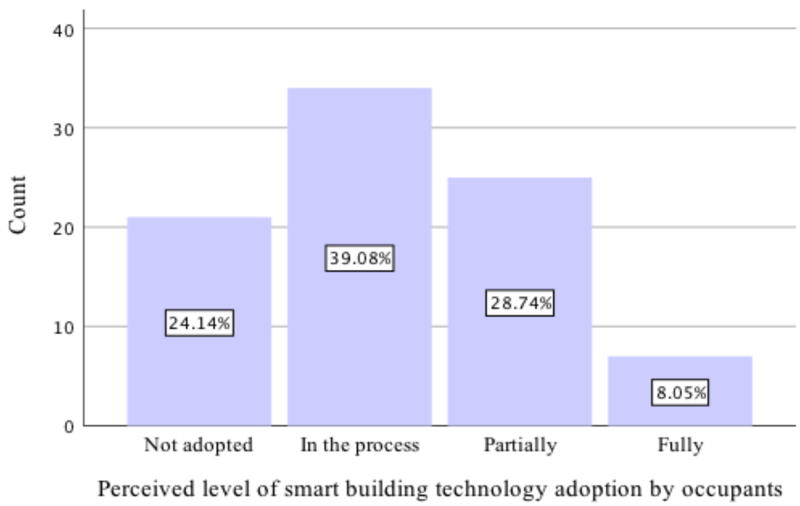

Figure 13: Distribution of responses by occupants highlighting the perceived level of adoption of smart building technology in their office building

7.2 Analysis survey constructs

The remaining seven parts of the survey are discussed below. An overview of the different constructs and the reasons for including them in the study can be found in the methodology. Each part with the different constructs was discussed separately to provide a more focused exploration of the questions asked in the survey. This was aimed at providing a structured overview before delving deeper into the statistical exploration of relationships and connections between variables.

7.2.1 Part two: User satisfaction

This part consisted of only one question, which focused on the construct of user satisfaction with the smart technology in their office environment. Here, the majority, 63%, stated that they were neutral in this manner. In addition, both the satisfied and dissatisfied options received similar responses, 17.4% and 15.2% of the responses each. Interestingly, a modest 3.3% of participants reported being very satisfied with the technology. It suggested a nuanced landscape of user groups, where a significant percentage remained neutral.

7.2.2 Part three: Motivations and experiences

The next part examined the constructs of motivations and experiences of the occupants. The first question asked about what motivated occupants to engage with smart building technology. As stated in the methodology, the question had the option to select 'all that apply.' The answer options reflected the insights gained from the interviews and the literature review.

What motivates you to actively engage with smart building technology in your office?

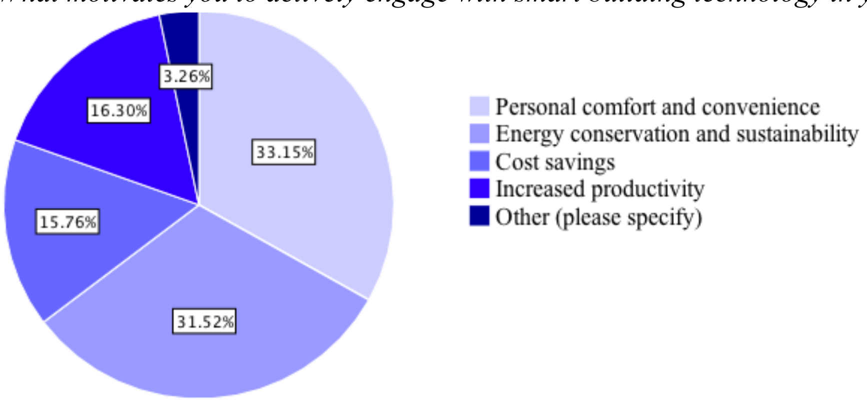

Figure 13: Distribution of responses highlighting the reasons for actively engaging with smart building technology.

As illustrated in Figure 13, responses indicated a notable tendency towards the answers 'personal comfort and convenience' and 'energy saving and sustainability.' This observation aligned with the conclusions drawn from the literature review and interviews. Notably, the lack of responses regarding cost savings as a motivator was consistent with the context of office buildings, where users typically do not bear the cost of the building. As a result, factors such as personal comfort, convenience, and environmental sustainability had more influence on users' motivation to use smart building technology in this research context. Additionally, some respondents selected the 'other' category, providing different insights:

- *"Collaboration."*
- *"Understanding our employee needs."*

- *"Innovation."*
- *"Tailor made services."*
- *"Decision making as a real estate professional."*

The second question of this section explored which features occupants found most crucial when interacting with smart building technology in their office environment. The aim was to discover the specific aspects that occupants considered important in their interaction with this technology.

What features or benefits are most important to you for improving your office environment?

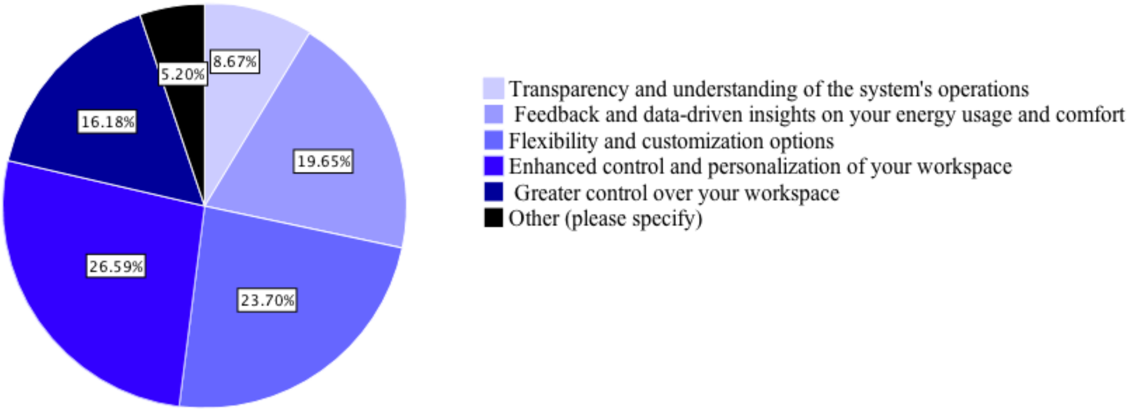

Figure 14: Distribution of responses regarding the features of technology that individuals consider important.

As shown in Figure 14, two options emerged as the most frequently chosen: 'Flexibility and customization' and 'enhanced control and personalization of your workspace.' This indicated a strong preference among survey participants for technology features that provided customizability, personalization, and greater control over personal workspace settings. This thus confirmed these aspects from the literature and interviews. Interestingly, some participants chose 'other.' Their answers were particularly interesting:

- *"Collaboration with colleagues."*
- *"Easy to find suitable working spaces."*
- *"Getting involved, where others just let be and accept not aware of the possibilities to make a difference."*
- *"Employee experience."*
- *"To better understand our employees and their needs."*

These insightful quotes offered a closer look at the different perspectives and motivations that drove participants' choices in addition to the answer options already indicated.

7.2.3 Part four: Barriers and concerns

The following construct delved into the concerns of individuals regarding smart building technology. Again, as can be seen in the charts, these questions offered limited response options, as each option contained findings from the interview and literature.

Do you have any concerns about the (future) use of smart building technology in your office?

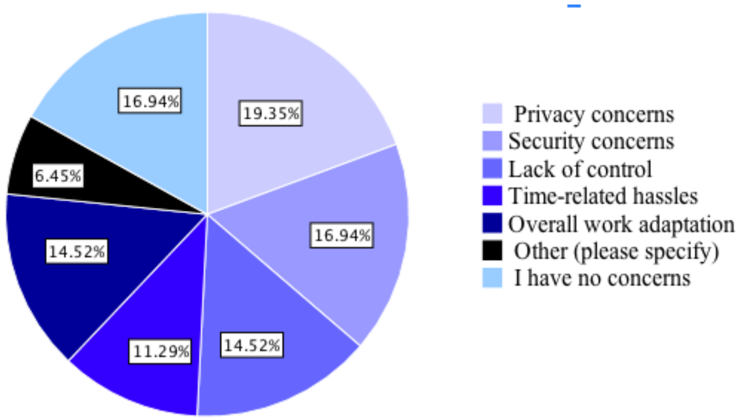

Figure 15: Distribution of responses on smart building technology concerns.

Figure 15 shows the overall distribution of the answers about the concerns about using smart building technology. In particular, the combined percentage of concerns about privacy and security stood out, accounting for 36.9% of all responses. This highlighted the amount of privacy and security concerns among those surveyed. Moreover, it was interesting to note that only 15% said they had no worries. Interestingly, these survey findings differ somewhat from the qualitative interviews, where concerns about privacy and security were not as prominent.

The second question in this part examined the challenges of using smart building technology. This allowed us to see what occupants were encountering when using the technology.

Have you faced any challenges while using the technology in your office?

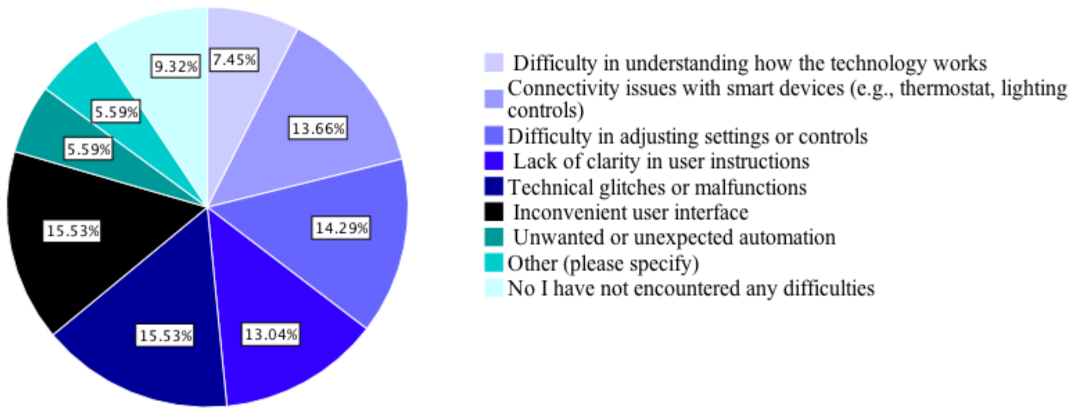

Figure 16: Distribution of responses on challenges in using technology in the office.

Figure 16 depicted a somewhat even distribution of responses, distinguishing it from other questions. However, three challenges emerged as the most prevalent: 'inconvenient user interface,' 'difficulty in adjusting settings,' and 'lack of clarity.' Notably, all these challenges were related to interacting with the interface itself. The findings brought attention to specific usability issues, underscoring the significance of addressing these challenges to enhance the user-friendliness and effectiveness of smart building technology. Moreover, only a relatively small percentage, 9.9%, reported having experienced no difficulties. Additionally, several participants selected the 'other' option:

- *"Adopting external system in our network."*
- *"Compatibility with other systems."*
- *"Integrating issues between several providers/ platforms."*

- *“Lack of manual possible adjustments.”*
- *“Our ambitions are higher than possible.”*
- *“When I come to the office, I just sit.”*

These responses reflected a range of challenges. The last response, *"When I come to the office, I just sit,"* added a funny personal touch, potentially highlighting a sense of disinterest in the technology.

7.2.4 Part five: Climate control and comfort

The first question of part five addressed the importance of the degree of control users have over the climate in their working environment. Interestingly, 59.3% of the participants emphasized the importance of control and ranked it as somewhat important or very important. In contrast, 24.7% considered it not very important or not important at all. The remaining participants took a neutral stance and chose the middle option, 'important.' This highlighted the feeling among the majority of participants, indicating the importance of some degree of control over the climate in their working environment. Therefore, this finding aligned with the literature and interview findings.

The second question of part five examined the impact of indoor air quality on overall comfort within the working environment. A significant 80.2% of participants emphasized the importance of their indoor environment and considered it either very important or somewhat important for their overall comfort. In contrast, only 3.7% of participants indicated that indoor air quality was not very important. The rest of the participants took a neutral position and selected the middle answer option 'important.' This strong preference for a comfortable indoor environment was consistent with the literature on thermal comfort. Also, it corresponded to the earlier question on what motivated people to actively use smart building technology in their offices, where the most frequently chosen answer was personal comfort and convenience.

7.2.5 Part six: Behavior and routines

The next construct examined the influence of smart technology on occupants' behavior and routines. Surprisingly, only 12,5% of participants reported experiencing an influence. This finding suggested that the current implementation of smart building technology, in this case, may not have had a significant effect on the daily activities and habits of occupants within the office environment. This outcome raised questions about the effectiveness of the existing smart building features in promoting desired behaviors. Below are some examples provided by the occupants who did say they experienced some influence in behavior and routines:

- *“Booking a meeting room in advance or my parking spot.”*
- *“I am able to find available spaces more easily, and I can control the environment I work in from my device.”*
- *“I work more from home.”*
- *“We use WSM tools for meeting room reservations. Once this was updated, everything was much easier.”*
- *“When wireless connectivity with, for example, a screen doesn’t work, I will stop trying and use a hardline bypass by default.”*

These examples underlined the variety of options with the technology. Ranging from greater convenience in booking facilities to greater flexibility in work arrangements. In addition, a participant also noted technical challenges, which suggested a reduction in the impact of changing behavior and routines.

The second question of part six looked at whether the participants consciously adopted any energy-related practices in their working environment. A select group of 16% of participants acknowledged engaging in such practices. Explanations provided by this group include:

- *“Adjust clothing in winter due to lower temperature settings.”*
- *“Always take 5 minutes to manually adjust the screen height, screen brightness and color, desk height, and chair height. An automated selection per employee through some sort of app would be nice for the digital screen settings, for example.”*
- *“Dress warm.”*
- *“Balance control and providing insights in climate per area.”*
- *“Tempering the operations of the system.”*
- *“We have an application for manual control of lighting and temperature overwrite.”*
- *“When leaving, reduce temperature settings.”*
- *“Domotica is energy-consuming to a large extent. E.g., the Edge building in Amsterdam. Over-designed and a lot of issues, including energy consumption.”*

These findings indicated that some of the participants were actively engaged in promoting energy-related practices. This reflected a level of awareness towards sustainable behavior in the workplace. Particularly interesting was the fact that some participants mentioned adjusting their clothing, a practice that was not explicitly addressed in the survey but emerged as a notable behavior.

7.2.6 Part seven: Feedback and suggestions

In part seven, the first question examined whether participants considered it important to have a voice in shaping the functionalities of the technology used in their workplace. Notably, 42.0% of respondents indicated that they considered this aspect very important or somewhat important. Similarly, exactly 42.0% considered participation in shaping technology functionalities not very important or not important at all. The remaining participants took a neutral position. This suggested an even split in opinions. Remarkably, these results did not quite reflect the insights from the interviews, in which feedback was considered important during each interview. This suggested that the assumption that all employees were willing to engage with technology by receiving or giving feedback might not have held true.

Since personal comfort is different for everyone, the second question of part seven explored which features of a smart building were missing, according to occupants. Interestingly, 56.8% said that some features were missing. Below are the features they felt were missing, categorized by improved comfort, improved convenience, more insights/ transparency, more control, more automation, and improved system integration.

Improved comfort	“Very modern (perhaps unrealistically modern) workspaces with automatically customizable settings. Like modern cars where you can set your preferred mirror settings, chair settings, etc. It would be nice if we could hold our employee card against a workplace sensor and have all settings automatically adjusted.”

	“Ventilation based on the real needs in specific parts of the office.”
	“Lighting and better heating.”
	“Working spaces where you can adjust the sizing of the space and generalized ways of connectivity throughout the building.”
	“Better air quality, better ventilation.”
	“Temperature and sun protection.”
Improved convenience	“Desk booking room.”
	“Wayfinding, colleague finding, free room finding, automatic suggestions like parking and working cabins.”
	“Workspace availability.”
	“Use of desks, activity-based usage.”
	“Parking space.”
More insights/ transparency	“Dashboard for energy use.”
	“Better insights in occupancy of restaurants.”
	“Intuitive workspace booking and having insights into technological resources.”
	“Measuring occupancy rate and advising on workspace solutions.”
	“Sensors on soft seat places to better understand usage.”
	“People counting with relation to airflow.”
	“Up-to-date controls and systems.”
	“Utilization sensors.”
More control	“Better access control.”
	“Climate control.”
	“Control of temperature at my desk.”

	“Easier control of temperature.”
	“Better control.”
More automation	“Automatic solar operation, light sensors.”
	“Automated lights in restrooms.”
Improved system integration	“Connection security management systems with building systems.”
	“Data needs to be stored in one central place so that we can draw cross-system insights into what makes our environment ‘better’ or ‘worse’ for employees.”
	“A more streamlined occupancy in our spaces, sensing.”

Table 6: Missing features of the smart building, as indicated by respondents.

Table 6 illustrates the occupants' expectations regarding the applications of a smart building. In terms of preferences for comfort and personal convenience, it became clear that users of smart buildings looked beyond basic features and sought an attractive and technologically advanced working environment. In addition, the emphasis on 'insights and transparency' reflected a desire for a data-driven understanding of their environment. Moreover, the importance placed on 'control and automation' indicated a preference for a personalized and adaptive working environment. The recognition of 'systems integration' as crucial underlined the need for interconnected building systems.

7.2.7 Part eight: Overall experience

The last part of the survey examined whether the adoption of smart building technology had affected the overall experience within the office building. Accordingly, 31.7% of respondents claimed it had improved or significantly improved their experience, while only 2.6% stated their overall experience had decreased or significantly decreased. Interestingly, almost 65.8% took a neutral position on this. It should be noted again that the majority of the respondents were still in the process of adoption, as indicated in part one.

This part’s second question addressed the smart building's perceived contribution to creating a more sustainable and energy-efficient working environment. Interestingly, an overwhelming 91.4% of respondents agreed or strongly agreed with this construct. In contrast, a minimal 8.6% took a neutral position or strongly disagreed. The large majority of positive responses indicated a positive perception of the role of the smart building in promoting a more energy-conscious working environment among the survey participants.

7.3 Correlation analysis

In addition to examining each construct individually, this section elaborates on the correlation between the constructs. As described in the methodology, a correlation analysis proved particularly useful for identifying associations between two or more variables, offering insights into potential relationships or patterns within the dataset. However, not all questions were included in the correlation analysis. This choice was based on the fact that the analysis is most effective when it is applied to ordinal or continuous variables (Leard Statistics, z.d.). In the context of this survey, this criterion included questions with a 5-point scale. Therefore, the questions with only a binary choice (yes/no) or question categories with no inherent order were considered unsuitable. Consequently, the analysis included the following constructs: Adoption, user satisfaction, control, indoor air quality, having a voice, overall experience, and sustainability. An overview of the corresponding questions can be found in the methodology.

Moreover, a Spearman correlation analysis was chosen over Pearson, the most common correlation analysis. Like the Pearson test, the Spearman correlation test evaluates whether two variables are correlated. However, the crucial difference lies in the methodology: the Spearman test uses ranks instead of assuming normality. This choice was particularly relevant in this case because participants' responses did not exhibit a normal distribution. In a normal distribution, you usually see the answers evenly distributed, with most respondents choosing options in the middle and fewer respondents at the extremes. However, responses were occasionally high at the extremes, while at other times, they were more apparent at the options in the middle. Therefore, the Spearman test seemed more appropriate.

The next step involved including all relevant constructs for analysis in SPSS. Given the study's exploratory nature and the absence of predetermined hypotheses, it was decided to include all identified constructs in the analysis. Testing all constructs allowed the possible relationships found in the literature or interviews to be tested by a larger sample. The results, displayed in Figure 17, compared the constructs against each other. This revealed two key components: the correlation coefficient, indicating the strength of relationships, and the significance level, determining if these relationships were statistically meaningful. Regarding the correlation coefficient, the closer the coefficient was to +1 or -1, the stronger the correlation. As for the significance level, if the p-value was lower than the significance level (0.01 or 0.05), the null hypothesis that there is no correlation could be rejected.

Construct	Mean (SD)		Adoption	User satisfaction	Control	Indoor air quality	Having a voice	Overall exp.
Adoption	2.2069	Coefficient						
	(0.90397)	Sig.						
User satis.	3.0879	Coefficient	**0.413****					
	(0.67739)	Sig.	<0.001					
Control	3.5432	Coefficient	-0.002	0.016				
	(1.20467)	Sig.	0.984	0.889				
Indoor air	4.3827	Coefficient	0.010	0.127	**0.403****			
	(0.88837)	Sig.	0.933	0.261	<0.001			
Having a voice	3.1728	Coefficient	**0.276***	0.038	**0.246***	0.198		
	(1.22260)	Sig.	0.015	0.740	0.028	0.078		
Overall exp.	3.2911	Coefficient	**0.289****	**0.508****	0.068	0.175	**0.252***	
	(0.58071)	Sig.	0.012	<0.001	0.554	0.125	0.026	
Sustainability	4.2469	Coefficient	**0.264***	0.194	-0.071	0.064	0.068	**0.319****
	(0.69876)	Sig.	0.021	0.084	0.533	0.574	0.549	0.004

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 17: Correlation analysis SPSS

In Figure 17, the SPSS output illustrates the correlations between the constructs. Notably, several significant correlations were observed. However, it is crucial to note that correlations of 0.3 are considered weak, 0.5 medium, and 0.7 or higher somewhat stronger. Moreover, it is important to note that correlation does not imply causation. The observed relationship only indicates a statistical association between these variables. The following sections discuss the observed correlations, followed by a brief summary highlighting key findings from the correlation analysis.

Firstly, a positive correlation was identified between user satisfaction and the perceived level of technology adoption ($r = 0.413$, $p < 0.001$), indicating that higher levels of technology adoption tended to correlate with higher user satisfaction. In addition, individuals who found it important to have a voice in shaping technology showed a positive correlation with the perceived adoption of smart building solutions ($r = 0.276$, $p < 0.05$). Moreover, the perceived level of technology adoption also showed a positive correlation to the overall user experience of occupants ($r = 0.289$, $p < 0.05$). This suggested that a positive overall experience with technology was associated with a higher likelihood of its adoption. In addition, the perceived level of technology adoption showed a positive correlation with the perception of a smart workplace's contribution to sustainability ($r = 0.264$ $p < 0.05$).

Then, participants reporting positive overall experiences also expressed higher levels of satisfaction ($r = 0.508$, $p < 0.001$). This correlation highlighted the connection between positive user experiences and the user satisfaction that is derived from technology use. In addition, the importance of having control over the working environment highlighted a positive correlation with the importance of good indoor air quality ($r = 0.403$, $p < 0.05$). Moreover, the importance of having control over the working environment showed a positive correlation with individuals who value having a voice ($r = 0.246$, $p < 0.05$). This correlation suggested that there was a relationship between the desire for an active role in decision-making (having a voice) and the need for control over their working environment. Furthermore, a positive correlation was observed between overall experience and the significance placed on having a voice in shaping technology ($r = 0.252$, $p < 0.01$). This indicated that a positive overall experience is associated with the likelihood of individuals considering it important to influence and contribute to technological decisions. Lastly, a positive correlation was found between the overall experiences and the perception of the smart workspace as sustainable and energy efficient ($r = 0.319$, $p < 0.05$).

In summary, as shown in Figure 17, quite a few correlations were found between the constructs. However, it's noteworthy that these correlations, though statistically significant, are relatively weak, ranging between r = 0.246 and r = 0.413. This suggests that while there is some association between the variables, their relationship lacks substantial strength. This could be attributed to the complexity of the variables involved and the potential influence of additional factors not considered in this study. As highlighted in the literature review, occupant behavior is influenced by numerous factors, some of which were not addressed in this study. The only exception was a significant correlation between the constructs of user satisfaction and overall experience, which was $r = 0.508$, which showed a stronger relationship (p < 0.001). Indicating a relationship between the satisfaction of users with the smart building technology and the influence of smart building technology on the overall satisfaction in the office building. This underscores the importance of emphasizing and improving user satisfaction with smart building technology as an important factor affecting building users' overall satisfaction and well-being.

CHAPTER SUMMARY - Findings survey

This chapter presented the findings of the online survey, which was distributed among individuals working in a (partially) smart building environment. The survey consisted of eight sections and aimed at validating and broadening the qualitative research insights. This allowed for more general statements about users' preferences and behavioral mechanisms in their interaction with smart building technology. The survey received 105 responses. However, after cleaning the dataset, as described in the methodology, a total of 92 respondents were valid for analysis.

When looking at each construct individually, what stood out were the parts on the various motivations, features, barriers, and concerns of smart building occupants. These parts consisted of questions with the option to select all that apply. The answer options reflected the insights from the literature and interview findings. This allowed to confirm specific findings. Concerning motivations, there was a notable tendency towards the answers 'personal comfort and convenience' and 'energy saving and sustainability.' As for the crucial features of the technology, two options were most frequently selected: ‘flexibility and customization’ and ‘increased control and personalization.’ In terms of concerns about smart building technology, a significant percentage was devoted to combined concerns about privacy and security, accounting for 36.9% of all responses. In addition, it is noteworthy that only 15% said they had no concerns about technology. Furthermore, in terms of challenges, three issues emerged prominently: ‘an inconvenient user interface,’ ‘difficulty adjusting settings,’ and ‘lack of clarity.’ Remarkably, all these challenges have to do with interacting with the interface itself.

In terms of control and comfort, the survey results were in line with both the literature and the interviews, with the majority of participants indicating that they considered it important to have some degree of control over the climate in their working environment. Moreover, 80.2% of respondents underlined the importance of the quality of their indoor environment, which they considered either very important or somewhat important for overall comfort, aligning with the findings in the literature. Regarding behavior and routines, the broader impact of smart technology on behavior and routines seemed limited. However, a significant proportion of participants showed a conscious effort to engage in energy-related practices. This indicated a positive trend towards sustainability awareness in the workplace.

For the question related to feedback and suggestions, results showed that occupants' expectations regarding the applications of a smart building looked beyond basic features and sought an engaging and technologically advanced working environment. In addition, regarding the importance of having a voice in shaping the functionalities of the technology used in their workplace, the findings showed a rather even distribution. This suggested that the assumption that all employees were willing to engage with technology by receiving or giving feedback may not have held true. Thereby indicating that a one-size-fits-all approach to user engagement may not have been effective.

Besides looking into each construct individually, the second section elaborated on the correlation analysis between the constructs. Correlation analysis can be particularly useful to find the association between two or more variables. However, what was found is that the significant correlations were quite low (between $r = 0.246$ and $r = 0.413$). The only exception was a significant correlation between the constructs of user satisfaction and overall experience, which was $r = 0.508$, which showed a stronger relationship ($p < 0.001$).

CHAPTER 8 DISCUSSION

This chapter discusses the findings of the mixed methodology, comparing qualitative and quantitative insights with the literature framework and research questions. It begins with an overview of the research questions, followed by a thematic discussion of the findings and related recommendations. The chapter concludes with an exploration of the limitations of the study and suggestions for future research.

8.1 Overview research (sub)questions

The research focused on addressing the following question:

- *What are building occupants' key preferences and behavioral mechanisms that are contributing to the adoption of climate control technology in smart buildings?*

To answer the research question, an exploratory research approach was used, aiming to gain initial insights into how users adapt to smart building environments, which cannot be found in the literature so far. Moreover, a mixed methodology was used, combining both qualitative and quantitative methods. Through semi-structured interviews, a deeper understanding of the motivations, barriers, and other aspects of occupant behavior and interactions with smart building technology was explored. In addition, insights from interviews with industry experts shed light on key factors contributing to the increased adoption of smart building technology. These qualitative findings were complemented by quantitative data collected through an online survey, which allowed trends and preferences to be identified from a larger group of participants.

8.2 Discussion and recommendations per theme

Several key themes emerged from the findings that are discussed in previous chapters. The following sections discuss these various themes, along with their implications and recommendations per theme.

8.2.1 User-centric design

When comparing the interview and survey results with the theoretical framework, it became clear that the HBI approach, which uses user-centered design, stood out as a crucial strategy for aligning technology with users' needs. As explained in the literature framework, this user-centric approach emphasizes understanding human preferences and needs when engaging with the environment. It offers valuable insights into the underlying mechanisms influencing users' engagement with the building and technologies (Shen et al., 2016). Moreover, the literature suggested that delving into motivations and preferences helps explain the decision-making process that drives individuals' interactions with the indoor environment (D'Oca et al., 2018).

When exploring user preferences during the interviews, participants emphasized the importance of system feedback, transparency, and flexibility as key factors. Furthermore, considerations such as the design and clarity of the interface scored significantly. These preferences aligned with findings in the literature, reinforcing the crucial role these factors play in shaping how users perceive and interact with smart building technology.

Moreover, the survey supported these perceptions, with respondents putting forward "flexibility and customization" and "greater control and personalization" as the most prioritized features in their workspace. In addition, the survey highlighted different preferences through examples given by respondents regarding the elements they felt were missing from their current workplace. For instance, respondents expressed a desire for control over temperature settings in their desk areas, while others indicated a preference for more customizable settings. These preferences reflected the user-centric approach, where the technology is tailored to accommodate the specific needs and comfort levels of each occupant.

However, as noted during the interviews: *"It is crucial that you include a cross-section of that organization in how they work and what they expect from the workplace. It is important to recognize that each organization differs in its approach and priorities* (P7)". This underscored the importance of taking into account the different preferences and expectations of the users in each building. Consequently, it indicated that gathering user preferences and feedback is essential to ensure that technology matches the specific needs and daily routines of the diverse users in a given office building.

In summary, the recurring theme of user-centered design in the literature, interviews, and surveys underscored its significant importance in the context of this research. In particular, the study's findings on occupant preferences highlighted the central role of users in achieving the goals of smart building technology.

Recommendation:
Consequently, a key recommendation is to prioritize user-centered design throughout the life cycle of smart building technology, from development to implementation. This recommendation is not just a technical consideration but more a strategic imperative. It implies that user experience should be at the forefront of decisions made. This can be especially insightful for stakeholders actively involved in creating and implementing smart building solutions, such as designers, developers, and facility managers. It involves prioritizing features and functionalities that meet the diverse needs of building users. In essence, it is about ensuring that the user experience is prioritized at every stage of smart building technology, thereby increasing the overall success and effectiveness of these initiatives.

8.2.2 Hassle factor

In addition, in exploring the behavior of occupants during the interviews, several elements emerged that could either shape these behaviors or act as barriers. These factors include perceived control, acceptance, habits, hassles, and awareness. These findings are consistent with the literature review. Only the addition of the aspect "hassle" element makes a new contribution. Examining hassles in this context is a relatively recent area of study. However, hassles can act as significant stressors that contribute to an undesirable state of well-being (De Vries et al., 2020).

Moreover, there is a noteworthy link between hassles and convenience, an aspect previously highlighted in the study. Identifying and mitigating potential hassles can enhance the convenience of smart building technologies for occupants. Accordingly, reducing hassles for users becomes critical to increasing user satisfaction.

Recommendation:
Therefore, it is recommended to incorporate the element of 'hassle' into the user-centered design, where potential sources of discomfort can be recognized and systematically addressed. This research shows that the identification of hassle can be achieved through methods such as interviews, surveys,

or observational studies, thereby revealing specific challenges and barriers faced by individuals. This insight is particularly relevant to developers because it allows them to proactively address these identified issues during the design phase. By doing so, developers can minimize stressors that might otherwise hinder users' well-being and better tailor smart building technologies to users' needs and comfort.

By comparison, Ebrahimigharehbaghi et al. (2021) examined behavioral factors that influence individual decisions about energy-efficient renovations. The study found that although the literature review touched on the aspect of hassles, empirical data was lacking, so the aspect of hassle could not be integrated into the study. This highlights the novelty of introducing hassle as an important and empirically unexplored factor in the decision-making process.

8.2.3 Awareness

Related to the hassle factor is another important element: awareness. Interview participants noted that a lot of employees don't know what the possibilities are and, therefore, may limit themselves in the options available. This lack of awareness may be closely related to the hassle factor, as occupants may find investing time in exploring the available options to be a hassle if they are unaware of the potential benefits.

To address this, proactive initiatives, such as communication and education programs during technology integration, emerge as effective strategies. This insight became clear during an interview with a participant (P6) who has experience in implementing smart building technology initiatives in multiple organizations. An illustrative example from the interview (P4) underscored the importance of these initiatives. As such, P4 emphasized the crucial role of a "kick-off program" in introducing smart building technology to the office. They formed a special team with the providers of the technology, known as the "digital adoption team," tasked with actively demonstrating the tangible benefits of the technology. P4 emphasized that merely providing a space for questions is insufficient; a proactive approach is essential. Actively demonstrating the benefits, answering questions, and engaging users are crucial steps to overcoming the challenge of ignorance and unawareness. According to P4, this direct approach is essential to raise awareness, making users more responsive to the possibilities and benefits of smart building technology and reducing the associated hassles.

Moreover, the interview emphasized the importance of use cases in these educational initiatives. Both P4 and P6 emphasized the effectiveness of showing real-world examples and practical applications of the technology. Use cases not only clarify the potential benefits but also make the technology more relatable and accessible to users.

Recommendation:
In short, to improve awareness regarding the potential of smart building technologies, proactive initiatives are essential. These initiatives serve as an essential bridge between the design of smart building solutions and their implementation in practice. By actively engaging users through demonstrations, use cases, and direct engagement, these initiatives ensure that end users gain a practical understanding of the technology's benefits.

8.2.4 Control

Moreover, the aspect of control, which had been found in the literature, had emerged as one of the most discussed topics during the interviews. And scored as very important by the majority of the respondents in the survey. In particular, the interviews delved deeper into the differences between perceived control and actual control. Having control relates to the actual ability of occupants to directly and actively influence the smart building technology. In contrast, the feeling of control emphasizes the psychological aspect of having control. Even if occupants may not have direct control over certain aspects of the technology, the feeling of control arises when they believe the system is considering their needs and feedback. Interpreting this difference between actual and perceived control showed the critical relationship between two key aspects of smart building systems: the tangible functionalities and the psychological factors influencing user satisfaction and acceptance. On the one hand, providing actual control is essential for the customization of functionalities. This tangible control ensures that users have the ability to actively interact with the system according to their preferences and needs. On the other hand, the sense of control showed a contribution to their overall experience of occupants with and acceptance of the technology. Thus, both dimensions of control underscored their importance and emphasized that the aspects should be considered when designing and implementing smart building systems.

However, this raises questions about the feasibility and limitations of giving control to building users. While providing (perceived) control has benefits, as highlighted above, it also brings concerns such as potential abuse, possible human errors, and conflicting preferences. This raised the question: How much control should be given to people? Karjalainen (2013), who examined the attitude of occupants towards different control systems, revealed that the balance between control and automation of building systems should be maintained carefully. He emphasized in his research that the suitable level of automation is not constant between different systems and users. Thereby indicating the differences in building systems and the preferences of different users. Consequently, finding the right balance between giving building users control and implementing automation is a critical consideration for achieving overall effectiveness.

Recommendation:
As a suggestion, this balance might be accomplished by integrating control functions into the user interface, complemented by clearly defined permissions. For example, this involves assigning varying levels of access or control to different users within the smart building system. Then, individual employees may have control over specific elements such as lighting and temperature in their personal workspaces. In contrast, facility managers could be granted broader access, enabling control over the entire building system. Further details on this aspect are explored in the section on future research. Additionally, the subsequent text will delve into the significance of interface design.

8.2.5 Interface design

Furthermore, the findings from both the interviews and the survey underscored the central role of user-friendly interfaces. It became clear that interfaces served as the primary means for users to interact with building systems, thus, the point where technology and users came together. This became particularly evident in the interviews, where questions about interacting with the technology consistently focused on elements of the interface. During the interviews, the importance of a user-friendly interface was reflected in the mentioned motivations and barriers. For example, respondents expressed their preference for the interface to be transparent about real-time data and insights into energy consumption, indoor climate, and comfort levels. Moreover, be transparent in system responses to their actions and be flexible to adjustments.

In addition, the survey highlighted the importance of the user-friendly interface, in that most of the challenges mentioned about smart building technology had to do with interacting with the interface itself. Specifically, respondents highlighted challenges such as *"inconvenient user interface,"* "*difficulty adjusting settings*," and "*lack of clarity,"* all of which addressed difficulties with interface interaction. Therefore, the findings of the interviews and survey together showed the importance of designing interfaces that were not only technologically advanced but also user-friendly.

Moreover, this underscores the importance of addressing the 'hassle' factor, where a user-friendly interface can play a pivotal role in reducing challenges and enhancing the overall convenience of interacting with smart building technologies. Prioritizing ease-of-use in interface design can effectively minimize barriers to adoption and promote greater user engagement with smart building solutions.

Recommendation:
In light of these insights, designers are advised to prioritize the user-friendly interfaces in smart buildings. This involves incorporating user preferences and addressing missing features to develop interfaces that are more intuitive and user-friendly. As shown in the result section, a diversity of preferences and missing features were found, highlighting the diversity of opinions regarding personal comfort. As an example, one of the primary preferences that emerged during the interviews was the preference for system feedback. As such, interview participants highlighted the value of real-time data and insights into energy consumption, indoor climate, and comfort levels. Such feedback not only can enable occupants to make informed decisions but also enhance their understanding of how these technologies function.

Furthermore, the survey showed that a majority of the participants (56.8%) expressed that some features were missing. Examples of features that were missing were related to improved comfort, improved convenience, more insights/ transparency, more control, more automation, and improved system integration. This underscored the importance of addressing these specific needs to ensure that smart building interfaces meet users' diverse preferences and expectations.

Considering these diverse preferences, it showed the essence of establishing consistent feedback loops with users. This recommendation emerged during an interview in which a participant emphasized, *"Implementing technology for smart buildings is not a one-time action: you have to keep collecting feedback, people change, times change, and technology changes (P3).*" Hence, these feedback loops could play a crucial role in addressing user concerns or challenges and facilitating the continuous optimization of smart building interfaces based on real-time user experiences. As demonstrated in this study, surveys served as a practical means of facilitating these feedback loops. By gathering insights through surveys, designers could systematically collect user feedback and gather valuable information about preferences, challenges, and missing features. Moreover, including a 'suggestion box' feature directly in the interfaces could provide another way to gather feedback. This concept emerged during the interviews, where the discussion revolved around a two-way feedback mechanism. Participants underscored the significance of a two-sided feature, highlighting that it could empower occupants to proactively contribute suggestions if they wanted to do so.

8.2.6 Privacy and security

The exploration of privacy and security within the context of smart building technology was noteworthy. This theme initially emerged in the literature as a barrier to the adoption of smart building technology. Subsequently, I explored this further by asking about barriers during the interviews. Surprisingly, privacy concerns did not come up prominently in the discussions during the interviews. Nevertheless, given its importance in the literature, this aspect was included as one of the options in the subsequent survey. Interestingly, the survey findings showed that during the survey, the aspect of privacy and security emerged as the most important concern. Specifically, respondents expressed significant combined concerns related to privacy and security, accounting for 36.9% of all responses to the question addressing concerns about smart building technology.

Recommendation:
The significant role of privacy and security in the survey responses underscored their substantial influence on users' perceptions and attitudes toward smart building solutions. This observation highlighted the need to address and mitigate privacy and security concerns during the implementation of smart building solutions to ensure trust and user engagement. This notion was also reflected in the paper of Al-Turjman et al. (2019), who studied security and privacy issues in IoT communications within smart cities. They emphasized the critical importance of accounting for security and privacy threats in the design and implementation of new smart systems. This aligned well with user-centered design, which emerged as the primary theme in this discussion. In the section on future research, this is further discussed.

8.2.7 Alignment of technical functionalities and organizational objectives

Furthermore, the interview participants mentioned the strategic alignment of the smart building's functionalities with the organization's objectives. Interestingly, this aspect has not been found in the existing literature so far as a crucial element for the adoption of smart building technology. The interviews underscored that alignment was essential to enable organizations to measure the impact and benefits of technology in achieving broader organizational goals. Although it did not directly address the research question, focusing on the occupant's point of view, this insight contributed to understanding the overall adoption of smart building technology, aligning with the broader goals of the research.

Recommendation:
Hence, it is advisable to ensure that the functionalities of the smart building are in alignment with the organization's goals. This can be beneficial for organizations that are seeking to implement smart building technology. This can involve evaluating how technology aligns with various organizational goals, including operational efficiency, environmental sustainability, employee well-being, and the organization's overall mission. For example, if we take the objective of employee well-being and productivity, this involves incorporating features that contribute to a healthier and more productive work environment for occupants. This can, for example, be achieved by integrating elements such as optimal lighting, indoor air quality monitoring, and personalized comfort controls.

8.2.8 Balance quantitative and qualitative research

Also, a finding emerged in the interviews that underscored the balance between relying on quantitative data and acknowledging occupants' subjective feelings and experiences. This was in line with the principles of mixed methodology used in this study. It emphasized the importance of not relying solely on quantitative data but also including qualitative findings. On the one hand, the use of quantitative data proved to be crucial for gaining objective insights into various aspects of smart building performance and user behavior. On the other hand, acknowledging occupants' subjective feelings and experiences allowed for adding depth to the evaluation that cannot be identified with data alone.

Recommendation:
Therefore, it is recommended to establish an approach that integrates quantitative metrics and qualitative insights to maintain a balance in understanding occupant dynamics in smart buildings. This recommendation holds value for key stakeholders involved in the trajectory of smart building development, including researchers, developers, and facility managers. For example, the qualitative side can be established through interviews or user feedback mechanisms. On the quantitative side, it showed the importance of approaching data collection with a clear understanding of its intended applications to avoid the collection of data solely for the sake of data collection. Contrary to the misconception that more data is always better, it was emphasized that too much focus on quantity could lead to a loss of overview. Moreover, it was highlighted that a critical starting point was to examine the systems already present within the organization. Introducing additional systems could complicate the amount of data, making it, again, challenging to maintain a clear overview.

8.3 Overview of key recommendations

In summary, the findings from the interviews, coupled with those from the literature review and survey, emphasized users' diverse preferences and motivations. Moreover, findings showed that as each organization differs in its approach and priorities, it is crucial to understand how people work and what they expect from their workplace. This suggested that there is *no one-size-fits-all approach* to implementing smart building technology. It emphasized the importance of recognizing and addressing the unique factors and preferences within each organization or case.

Nevertheless, the key themes of the study, as outlined in the previous sections, offered valuable recommendations tailored to specific stakeholders to guide the implementation of the smart building technology. The following table provides a brief overview of these recommendations.

Stakeholder	Theme	Finding	Recommendation
Developers/ designers/ researchers/ organizations	User-centric design	The user-centered design stands out as a crucial strategy for aligning technology with users' needs. It offers valuable insights into the underlying mechanisms influencing users' engagement with the building and technologies.	Prioritize user-centered design throughout the life cycle of smart building technology, from development to implementation. This involves prioritizing features and functionalities that meet the diverse needs of building users. So, it is about ensuring that the user experience is prioritized at every stage of smart building technology.
Developers/ designers/res earchers	Hassle-factor	During the interviews, several elements emerged that influence occupants' behavior, such as perceived control,	Eliminate the 'hassles' of occupants by integrating this element into user-centered design. This means identifying potential

		acceptance, habits, hassle, and awareness. Most correspond to the literature, except for the element "hassle," which constitutes a new contribution.	sources of discomfort early on in the design phase and addressing them proactively to improve user well-being and ensure a positive and user-friendly experience.
Organization s/technology providers	Awareness	Interview participants noted that a lot of employees don’t know what the possibilities are and, therefore, may limit themselves in the options available.	Take proactive initiatives to bridge the gap between technical design and practical implementation. Engage users through demonstrations, use cases, and direct interaction to ensure a practical understanding of the technology's benefits.
Developers/ designers/res earchers	Control	The difference between actual and perceived control showed the critical relationship between two key aspects of smart building systems: the tangible functionalities and the psychological factors influencing user satisfaction and acceptance.	It is crucial to consider both dimensions of control in the design and implementation of smart building systems. One way to achieve this balance is to seamlessly integrate control functions into the user interface while ensuring explicit permissions to prevent potential misuse.
Developers/ Designers	User-friendly interfaces	The findings of the interviews and survey together showed the importance of designing interfaces that are not only technologically advanced but also user-friendly.	Enhance smart building interfaces by incorporating user preferences and addressing missing features. Considering the diversity of preferences in different buildings and changing user needs over time, it is essential to establish consistent feedback loops with users.
Developers/ designers/ researchers	Privacy and security	The significant role of privacy and security in the survey responses underscored the significant influence on users' perceptions and attitudes toward smart building solutions.	Develop and implement strategies to address and mitigate privacy and security concerns. Findings highlighted the need to address and mitigate these concerns during the implementation of smart building solutions to ensure trust and user engagement.
Organization s	Alignment of Technical functionalitie	The interviews underscored that alignment of technological functionalities with the	Evaluate how smart technology aligns with various organizational goals, including operational

	s and organizational objectives	organization's objectives is essential to enable organizations to measure the impact and benefits of technology in achieving broader organizational goals.	efficiency, environmental sustainability, employee well-being, and the overall mission of the organization. In order to measure the overall impact and benefits.
Researchers/ organizations /developers/ designers	Balance quantitative and qualitative research	Interviews underscored the importance of the balance between relying on quantitative data and acknowledging occupants' subjective feelings and experiences.	Establish an approach that integrates quantitative metrics and qualitative insights, for example, with surveys, interviews, or observation methods, to maintain a balance in understanding occupant dynamics in smart buildings.

Table 7: Overview recommendations

8.4 Strengths and limitations

First of all, one of the strengths of this study lies in its methodology. It employed a mixed-method approach, combining both qualitative and quantitative methodologies. This integrated approach facilitated a more comprehensive understanding of the research problem compared to relying solely on qualitative or quantitative methods. An important contributing factor to the study's strength was the deliberate sequencing of its components. The qualitative phase preceded the quantitative phase so that the insights from the in-depth qualitative research could be used to design the quantitative survey. This ensured that findings from the interviews could be tested across a larger sample.

Another strength was the richness of perspectives provided by various interview respondents and the substantial number of survey participants. The diverse range of interviewees presented multiple viewpoints, resulting in a thorough exploration of the research topic.

In addition to the strengths, several limitations were identified. First of all, a notable limitation had to do with the multifaceted nature of factors affecting user behavior in smart buildings. As indicated in the literature review, occupant behavior is complex and shaped by a large number of interrelated factors. It is important to note that this study deliberately focused on personal factors influencing behavior. The decision to limit the focus to personal factors was driven by the intention to delve deeply into the personal aspects that determine behavior within smart buildings. While this ensured a nuanced understanding of the personal dimensions, it inherently limited the ability of the study to consider external factors such as environmental, technological, or organizational influences.

Besides that, the research encountered a challenge in delineating the study to climate control technology within the broader spectrum of smart building technologies. Although, in the beginning, this looked like the right way to delineate the study better, this led to some practical limitations. During the interviews, the open-ended questions focused on exploring different aspects of interactions with smart buildings, focusing on climate control. The interviews showed that the interactions with climate control technology were primarily associated with interactions through the interface. However, it should be noted that the interface serves as a connection point for various smart building technologies not limited to climate control. In other words, the interactions are relevant to various smart building technologies. Therefore, the conversations often shifted to other smart building technologies as well. Although the exploratory nature of the research allowed for this expansion, this was not the original intention. While this expanded the scope of the research, it also introduced the possibility that not enough depth was achieved in exploring the specifics of climate control. On the other hand, it improved a broader understanding of interactions with different types of smart building technologies.

Moreover, the qualitative part of the study also showed some limitations. The design of the interview questions attempted to strike a balance between incorporating elements from existing literature while being open to the emergence of new constructs, which was consistent with the exploratory nature of the study. As a result, interviews often diverged quickly to different topics. Looking back, I recognize that it might have been better to have followed the interview protocol more closely. For example, the aspect of privacy came up prominently in the survey, while it was not discussed much in the interviews. This might indicate a missed opportunity to delve deeper into this aspect during the qualitative phase. Reflecting on this, although the approach of using protocols as guidelines seemed logical in theory, practical application revealed that discussions in several interviews diverged from the intended direction. This led to many new insights but compromised the consistency because these insights could not be confirmed by all interviewees.

There were also some limitations in the survey design. The first limitation emerged due to the difference in set-up between the interview protocol and the questions from the survey. In the interviews, the discussion was guided by an interview protocol. This used topics from the literature, as well as open-ended questions, to explore participants' broader views. However, when translating these qualitative insights into the quantitative format of the survey, the questions used a closed structure. This change in approach might have unintentionally influenced respondents, encouraging them to select answers from a predetermined set of options, potentially limiting the diversity of their responses. Consequently, the closed-ended survey questions may not have fully reflected the depth and variability of participants' thoughts and experiences.

Additionally, the survey had another limitation. When the survey was designed, the main focus was on the different constructs that were found in the literature and interviews to be included. However, due to the focus on these constructs, the possible statistical analyses were less considered at that point. For example, not all constructs that were made in the survey had a 5-point scale and, therefore, could not be included in the analysis. This oversight affected the feasibility of analyses with the data that was collected. Although analyzing the different constructs gave interesting findings, the limitation restricted the potential for more complex statistical methods, which may have acted as a barrier to obtaining more in-depth results.

Furthermore, there was a limitation to the different respondents of the survey. Despite the exploratory nature of the study, where the intention was to cover a wide range of companies and perspectives, it resulted in a concentration of respondents from a specific organization, namely RHDHV. This concentration introduced a possible bias, as the findings may be more reflective of experiences and views within RHDHV.

8.5 Suggestions for future research

This study had an exploratory nature and delved into the interaction between climate control technology and occupants. The insights came from interviews and surveys conducted among occupants of (partially) smart buildings. Yet it is crucial to recognize that these were one-time measurements, providing a snapshot of the occupants' perspectives. Moreover, in assessing the impact of smart building technology on behaviors and routines, the survey found that only a small percentage of participants reported having any impact on their daily routines and activities. Therefore, for future studies, it would be interesting to extend monitoring over a longer period of time. Conducting a long-term case study would allow researchers to observe how occupants adapt to smart building technologies and how their behavior evolves over time. A different approach might be to ask about specific actions in different time frames so that behavioral changes can be observed more clearly. For example, a mixed method approach could again be used at different phases of the study. In this way, the findings can be compared between the initial and final phases.

In addition, the current research concentrates on the occupant as the central element in the building. However, as noted in the limitations, it does not consider the impact of external factors influencing the behavior of occupants and their subsequent impact on technology adoption. For future research, I suggest extending the analysis to external influences, such as organizational culture, socio-economic factors, and external policy environments. This would provide a more broad understanding of the dynamics that determine occupant behavior in the context of smart building technology adoption.

Moreover, for future research endeavors, I recommend delving deeper into the dynamics of privacy and security within the context of smart building technology. The survey results highlighted the prominence of these concerns among users. However, the current study did not address specific aspects, such as the decision-making processes related to security and privacy and the subsequent impact on behavior. A more detailed examination of these dimensions could provide valuable insights into the choices and behavior of occupants. This thereby contributes to a better understanding of the implications of smart building technology.

Finally, a more in-depth exploration of levels of control in smart buildings is recommended. Although the research acknowledges the importance of both perceived and direct control, it does not specify the optimal balance and mechanisms for providing such control to users. Too much control could possibly lead to potential misuse or human errors. Future research in this direction can help refine the design and implementation of smart building systems for improved effectiveness and user satisfaction.

CHAPTER 9 CONCLUSION

This research focused on improving our understanding of the interaction between climate control technology and occupant behavior, with an emphasis on matching technology to user needs in smart buildings.

The study's findings showed that the successful implementation of smart building technology extends beyond technological details, requiring a balance between quantitative data and recognition of users' subjective experiences. Additionally, the study revealed diverse user preferences and motivations, emphasizing the absence of a one-size-fits-all approach. As a result, it highlighted the importance of recognizing and addressing the unique factors and preferences within each organization or case.

Moreover, the findings underscored the crucial role of users in achieving the goals of smart building technology and argued for a user-centered design approach in smart building initiatives. This user-centric design approach emerged as a critical strategy to better align technology with occupants' needs. The approach places central importance on understanding human preferences and needs, highlighting that insights and feedback from occupants are crucial to ensuring technology matches their specific preferences and daily routines.

So, to answer the central question of the title of this thesis, *"Who is 'smarter,' humans or buildings?"* the conclusion emphasizes that achieving a balance is the key. The findings indicated that neither humans nor buildings alone are the definitive solution. While data and technology are crucial components, their effectiveness is ultimately enhanced by human involvement.

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APPENDIX A: Informed consent form for survey

Informed consent form provided to survey participants

You are being invited to participate in a research study titled *"Who is smarter, buildings or humans?"* This study investigates the interplay between smart building technology and human behaviour. The research is being conducted by Piene Burgers of TU Delft, under the supervision of Dr Gerdien de Vries, in collaboration with RoyalHaskoningDHV.

The purpose of this research study is to explore human preferences and behavioural patterns of building occupants regarding smart building technology. The smart building technologies have significant potentials such as enhanced energy efficiency, occupants' satisfaction, and work performance within buildings. However, realizing these benefits hinges on the effective understanding and adoption of these solutions by the occupants. To realize the full potential of smart building technology, it is therefore crucial to bridge this gap between the technical innovations and the building occupants.

The survey will take you approximately *10* minutes to complete. The data will be used to write a master's thesis. Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. In the survey, we will be asking you to express your preferences and hassles regarding smart building technologies.

Like any online activity, there is always a potential risk of a breach. It's important to note that all data collected during this research will be securely stored at TU Delft, with access restricted to the research team exclusively for the duration of the research project. The survey is carefully designed to ensure the anonymity of participants. We refrain from requesting any personal information that could be used to identify you. At the conclusion of the study, the aggregated answers from all participants, including yours, will be made publicly available. However, it's essential to clarify that any free-text or open-ended responses will not be included in this public release. Furthermore, the final master thesis resulting from this research will be archived in the public repository of TU Delft. This archiving is necessary for examination purposes and potential future research. Importantly, this thesis will not contain any personal data, thus ensuring the protection of your privacy.

By clicking 'next', we assume you have been sufficiently informed and agree to the above. \

APPENDIX B: Informed consent form for interview

Informed consent form, provided to interview participants

You are being invited to participate in a research study titled *"Who is smarter, buildings or humans?"* This study investigates the interplay between smart building technology and human behaviour. The research is being conducted by Piene Burgers of TU Delft, under the supervision of Dr Gerdien de Vries, in collaboration with RoyalHaskoningDHV.

The purpose of this research study is to explore human preferences and behavioural patterns of building occupants regarding smart building technology. The smart building technologies have significant potentials such as enhanced energy efficiency, occupants' satisfaction, and work performance within buildings. However, realizing these benefits hinges on the effective understanding and adoption of these solutions by the occupants. To realize the full potential of smart building technology, it is therefore crucial to bridge this gap between the technical innovations and the building occupants.

The online interview will take you approximately *30* minutes of your time. The data will be used to write a master's thesis. Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. During the interview we will ask you to express your preferences and hassles regarding smart building technologies.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will therefore keep your answers as confidential as possible. Moreover, any information you provide will be anonymised, i.e. your name will not be mentioned in quotes or in transcripts, among other things. The audio of the interview will be recorded solely for subsequent transcription of the information in the form of text. This audio recording will only be accessible to the master student, Piene Burgers, conducting the interview, and the TU Delft supervisor, and will not be shared further. After completion of the master's thesis, the recording will be permanently deleted. The final master thesis will be stored in the public archive of TU Delft, required for inspection and possible further research, but will not contain any personal data.

Please complete the rest of this form if you agree to participate under the above conditions. For further information, questions or comments, please contact p.w.burgers@student.tudelft.nl or g.devries-2@tudelft.nl.

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
1. I have read and understood the study information dated [*03/10/2023*], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐

2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that participation in this study involves an audio-recorded interview, so the recording can be transcribed and analysed. I understand that the audio recording and transcript will be deleted at the latest one month after the final result (the thesis) is completed.	☐	☐

Signatures

__________________________ _________________________ ________

Name of participant Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

________________________ __________________ _______

Researcher name Signature Date

APPENDIX C: Survey questions

Survey questions set-up occupants

Section 1: General information
1.1. Organization and occupation: Please name the organization you work for and describe your role or occupation within the organization.
1.2. Office type: In which type of office environment do you work? (e.g., private office, shared workspace)
1.3 Are you familiar with the smart building technology implemented in your office building? (e.g., smart lighting systems, occupancy sensors or HVAC control systems)
- Yes
- No

1.4. To what extent do you think your organization has adopted smart building technology? (Choose one option)
- Fully adopted
- Partially adopted
- In the process of adoption
- Not adopted
- Not sure

Part 2: User Satisfaction
2.1 How satisfied are you with the smart building technologies in your office?
- Very satisfied
- Satisfied
- Neutral
- Dissatisfied
- Very dissatisfied

Part 3. Motivations and experience
3.1 What motivates you to engage with smart building technologies in your office actively? (Select all that apply or provide specific examples)
- Personal comfort and convenience
- Energy conservation and sustainability
- Cost savings
- Increased productivity
- Other (please specify)

3.2 What features or benefits are most important to you for improving your office environment? (Select all that apply)
- Transparency and understanding of the system's operations
- Feedback and data-driven insights on your energy usage and comfort
- Flexibility and customization options
- Enhanced control and personalization of your workspace
- Greater control over your workspace
- Convenience and time-saving benefits
- Other (please specify)

Part 4: Barriers and Concerns

4.1 Do you have any concerns about the (future) use of smart building technology in your office? If yes, list the barriers that apply to you:

- Privacy concerns
- Security concerns
- Lack of control
- Time-related hassles
- Overall work adaptation
- Other (please specify)
- I have no concerns

4.2 Have you faced any challenges while using the technology in your office? (Select all that apply or provide specific examples)

- Difficulty in understanding how the technology works
- Connectivity issues with smart devices (e.g., thermostat, lighting controls)
- Difficulty in adjusting settings or controls
- Lack of clarity in user instructions
- Technical glitches or malfunctions
- Inconvenient user interface
- Unwanted or unexpected automation
- Other (please specify)
- No I have not encountered any difficulties

Part 5: Climate control and comfort

5.1 How do you typically control the climate (e.g., heating, cooling, ventilation) within your workspace?

- Manual controls (e.g., thermostat)
- Automatic controls (e.g., sensors)
- I have no control
- I don't know

5.2 How important is it for you to have control over the indoor climate in your workspace?

- Very important
- Somewhat important
- Not very important
- Not important at all

5.3 How important is indoor air quality to your overall comfort?

- Very important
- Important
- Neutral
- Not important
- Very unimportant

5.4 What do you prioritize when setting the indoor temperature?

- Personal comfort
- Energy conservation
- Company policies
- Other (please specify)

Part 6: Behavior and Adaptation

6.1 Has the implementation of smart building technology in your office influenced your behavior or routines?

- Yes
- No

If yes, please briefly describe.

6.2 Have you consciously adopted any practices related to energy conservation or comfort optimization in your workspace?

- Yes
- No

If yes, please briefly describe.

Part 7: Feedback and Suggestions

7.1 How important is it for you to have a voice or influence in shaping the technology's functionality within the building?

- Very important
- Important
- Neutral
- Not important
- Very unimportant

7.2 Are there any features or functions you believe are missing or could be enhanced in your building?

- Yes
- No

If yes, please briefly describe.

Part 8: Overall Impact

8.1 How has adopting smart building technology influenced your overall experience as an occupant in your office building?

- Significantly improved my experience
- Improved my experience
- It had no significant impact on my experience
- Reduced my experience
- Significantly reduced my experience

8.2 Do you believe smart building technology contributes to a more sustainable and energy-efficient workspace?

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

APPENDIX D: LinkedIn post

Hoe 'smart' is jouw werkplek? Voor mijn afstudeeronderzoek aan de TU Delft binnen de master Complex Systems Engineering and Management, verdiep ik mij in het onderwerp #smartbuildings. Ik ben op zoek naar werknemers die hun ervaringen met het werken in een slim gebouw willen delen via een korte vragenlijst. Of je werkomgeving nu slechts enkele elementen heeft van een smart building of volledig is geoptimaliseerd, alle ervaringen zijn waardevol!

Wat is een smart building? 🏢 Dit is een gebouw dat gebruik maakt van verschillende technische componenten zoals #sensoren, #automatiseringssystemen en #communicatienetwerken om prestaties te optimaliseren. Denk bijvoorbeeld aan sensoren die de bezettingsgraad van vergaderruimtes meten of lichtsystemen die zich aanpassen aan de aanwezigheid van mensen.

Past dit bij jouw werkomgeving? Vul dan de vragenlijst in via deze link, het kost maar 5 minuten: https://lnkd.in/e6TEFx9v. Deelname wordt zeer gewaardeerd!

Translation:

How 'smart' is your workplace? For my graduation research at TU Delft in the Master's program of Complex Systems Engineering and Management, I am delving into the topic of #smartbuildings. I am seeking employees willing to share their experiences of working in a smart building through a brief questionnaire. Whether your work environment has only a few elements of a smart building or is fully optimized, all experiences are valuable!

What is a smart building? 🏢 It is a building that utilizes various technical components such as #sensors, #automation systems, and #communication networks to optimize performance. Think, for example, of sensors measuring the occupancy of meeting rooms or lighting systems adapting to the presence of people.

Does this resonate with your work environment? If so, please complete the questionnaire via this link, it only takes 5 minutes: https://lnkd.in/e6TEFx9v. Your participation is highly appreciated!