SMART BUILDINGS – TECHNOLOGIES THAT WILL DEFINE THE BUILDING OF THE NEXT CENTURY

Marc -Philip Staniszewski
[152118212]

Thesis written under the supervision of André de Almeida Pinho

Dissertation submitted in partial fulfilment of requirements for the MSc in Management with Specialization in Entrepreneurship & Strategy at the Católica Lisbon School of Business and Economics

[4.4.2021]

Abstract

Title: "Smart Buildings – Technologies that will define the building of the next century"

Author: Marc-Philip Staniszewski

Keywords: Smart Buildings, Sustainability, Smart Building Technologies, Smart Cities, Resources, Environment, Architecture,

The nature of real estate is changing. Smart Building Technology has constantly evolved and enabled buildings to develop from being static to becoming reactive and interactive. With the help of Internet of Things technology automated systems are evolving and providing smart building stakeholders with functionalities that allow them to optimize their operations and adapt to their living preferences.

The objective of this dissertation is to investigate how different stakeholders, meaning tenants, homeowners, investors and facility managers, value different smart building technologies. Through a survey of the respective stakeholder groups and selected interviews with experts, the aim is to determine the most promising technologies and evaluate potential improvements that can be achieved when implementing these. The technologies analysed are ranging from the technologies that aim to improve the energy consumption, safety, communication and comfort. The findings were leveraged with the current state of research from academic literature.

The results of the dissertation are that the average of the stakeholders prefer technologies that bring economic and ecological improvements and thus save resources and costs. In addition, preference was given to technologies that provide platforms for other technologies. Technologies such as smart grid/smart meter, building dashboards and photovoltaic technology are among them. Finally, expert interviews and findings from current academic literature testify that not only smart technologies make up a smart building, but that the entire value chain of a building must be considered. Accordingly, a smart building must be economically, ecologically and socially sustainable.

Sumário

Título: "Edifícios inteligentes - Tecnologias que irão definir a construção do próximo século"

Autor: Marc-Philip Staniszewski

Palavras-chave: Edifícios Inteligentes, Sustentabilidade, Tecnologias de construção inteligentes, Cidades Inteligentes, Recursos, Ambiente, Arquitectura,

A natureza dos bens imobiliários está a mudar. A Tecnologia de Construção Inteligente tem evoluído constantemente e permitiu que os edifícios passassem de estáticos a reactivos e interactivos. Com a ajuda da Internet das Coisas, os sistemas automatizados da tecnologia das Coisas estão a evoluir e a fornecer aos interessados em edifícios inteligentes funcionalidades que lhes permitem optimizar as suas operações e adaptar-se às suas preferências de vida.

O objetivo desta dissertação é investigar como os diferentes interessados, ou seja, inquilinos, proprietários de casas, investidores e gestores de instalações, valorizam as diferentes tecnologias de edifícios inteligentes. Através de um inquérito aos respetivos grupos de interessados e entrevistas selecionadas com peritos, o objetivo é determinar as tecnologias mais promissoras e avaliar as potenciais melhorias que podem ser alcançadas ao implementá-las. As tecnologias analisadas vão desde as tecnologias que visam melhorar o consumo de energia, a segurança, a comunicação e o conforto.

Os resultados da tese são que a média dos interessados prefere tecnologias que tragam melhorias económicas e ecológicas e, assim, poupem recursos e custos. Além disso, foi dada preferência a tecnologias que fornecem plataformas para outras tecnologias. Tecnologias como a rede inteligente/medidor inteligente, painéis de instrumentos de construção e tecnologia fotovoltaica estão entre elas. Finalmente, entrevistas de peritos e conclusões da literatura académica atual atestam que não só as tecnologias inteligentes constituem um edifício inteligente, mas que toda a cadeia de valor de um edifício deve ser considerada. Consequentemente, um edifício inteligente deve ser económica, ecológica e socialmente sustentável.

Acknowledgements

I would like to thank everyone who supported me during the preparation of my master thesis.

Special thanks go to my thesis supervisor, André de Almeida Pinho, who accompanied me during the writing process with great dedication and constructive criticism.

My greatest thanks go to my parents, who supported me not only during my master thesis and my studies but in my everyday life.

A big thank you goes to my brother Niklas, for the continuous support and the regular exchange in the field of architecture and civil engineering, which helped me to better understand the subject.

Also, a big thank you goes to my roommates Charly and Luki. who held the fort with me in Lisbon during the pandemic and came through the lockdown with me.

I thank all interview partners for their valuable contribution to this work. I appreciate the time you have invested in me.

Table of Contents

List of Figures

List of Tables

1 Introduction

The future of the building industry is moving towards connected buildings that are equipped with Internet of Things (IoT) technology. IoT devices are using internet communication technologies (ICT) to interact with each other, e.g. sharing, gathering, channelling and evaluating information. Communication will become feasible between different buildings. This includes sharing information about energy usage, safety parameters and other building-related information, e.g. building occupancy. It therefore enables better resource management, information management, increased comfort and new business models within the buildings industry. (King and Perry, 2017)

All these possibilities added resulted in the introduction of the smart city concept. Smart Cities are comprised of interconnected buildings, traffic infrastructure, energy grids and people. Smart buildings are one of the basic units of a smart cities and using IoT- Devices with wireless communication to generate data in various areas that can be used by different stakeholders e.g. tenants, landlords, property managers, service providers and people who interact with the building in any form. (Minoli et al., 2017)

The building industry widely awaits great improvements trough Smart Building Technology (SBT) technology (King and Perry, 2017). Which improvements are able regarding sustainability, living comfort and operability are possible as of today?

1.1 Problem Statement and Relevance

Households in the European Union (EU) accounted for almost 40 % of final energy consumption in 2019 and accounted for around 35% of Greenhouse Gas Emissions (European Commission and Directorate-General for Energy, 2019). If the global population will continue to grow, and buildings will not adapt to more efficient and sustainable energy and infrastructure standards, the worldwide amount of energy consumption consumed by buildings will at least double by 2050 (Berardi, 2017). Especially the fast-economic pace in developing countries, which is complemented by an ongoing urbanisation processes and rising living- and consumption standards is pushing this development (Berardi, 2017).

Apart from environmental reasons there are several other issues that are creating a need for smart building technologies (SBT). One area where SBT could open up new possibilities is regarding security. One prominent example where SBT could prevent greater damage was during the attack of the Pentagon, the headquarters of the United States Department of Defence.

The pentagon was one of the first buildings equipped with SBT. It was able to control heating, ventilation and air-conditioning, and other related functionalities from a central building management control centre. Attacked on the 11th of September 2001 by a hijacked plane, which set a part of the building on fire, the control centre immediately turned down dampers and air ventilation systems in affected areas of the building and thus prevented the spread of fire (Snoonian, 2003). Today, SBT could not only tackle emergencies when they have occurred but also help prevent them before they occur. This includes fire outbreaks, water damages or prevention of any form of irregularities and is achieved by preventive maintenance systems (Cheng et al., 2017).

SBT will eventually change how buildings communicate with its surroundings, primarily with its tenants, homeowners, investors, homeowners and service operators like facility mangers.

On average, people spend 90 percent of their inside buildings (Klepeis et al., 2001). It is therefore a great opportunity to improve the quality of life in buildings through technologies on buildings (Klepeis et al., 2001). SBT as of today is capable of automating processes such as customized climate preferences in rooms, automated doors for authorized areas, and intelligent parking management among others (Suzuki, 2017). Smart building technologies will eventually create a technology platform, where business models of third parties will emerge (Balaji et al., 2018).

1.2 Research Question

The aim of this thesis is to detect the most promising smart building technologies among different stakeholder groups and assess and evaluate their potential.

Buildings are an essential part of our everyday life and are an essential part of the human-made global infrastructure. Therefore, innovations in buildings contribute significantly to improving our everyday life and simultaneously have the potential to reduce human impact on nature and its resources. This thesis will deal with the following research question.

Research Question:

How are different smart building technologies valued by different stakeholder groups?

In the following part, a literature review will provide a basic understanding for the subsequent analysis of the research question.

2 Literature Review

2.1 Digital Transformation applied to buildings

Digital Transformation (DT) describes an approach to use new digital technologies and explore and exploit their beneficial advantages to change key business operations, organisational structures, management concepts as well as products and processes (Matt et al., 2015). Digital technologies facing the building industry are, among others, smart meters, smart grids, building dashboards, intelligent sensors which enable buildings to automate processes, adapt to changing environments and enhance safety standards (Qolomany et al., 2019).

In this thesis digital transformation is applied to buildings and if buildings can be valuably transformed using digital building technology. Current research focuses on different ways to improve efficiency, well-being of occupants, safety and profitability.

2.2 Smart Buildings

Smart buildings differ from intelligent buildings because they act adaptive to the occupant and not reactive (Buckman et al., 2014). Smart buildings "address both intelligence and sustainability issues by utilising computer and intelligent technologies to achieve the optimal combinations of overall comfort level and energy consumption" (Wang et al., 2012). Other definitions state that smart buildings are comprised of different "smart environments" (Mcglinn et al., n.d.), that are "able to acquire and apply knowledge about the environment and its inhabitants in order to improve their experience in that environment" (Cook and Das, 2007). The figure 1 shows different development steps in different categories from the "primitive building" to the "smart building".

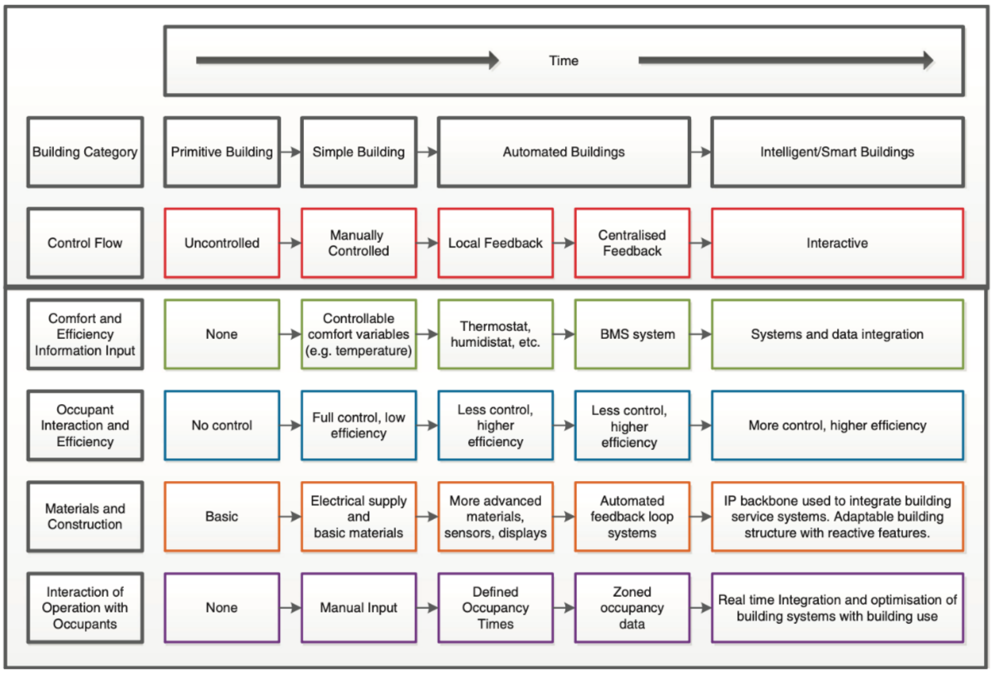

Figure 1: Differentiation of Building Types (Buckman et al., 2014)

Primitive buildings do not interact with its occupants at all. Simple buildings, functionalities can only be operated manually. The figure shows that in different areas, the leap from automated buildings to intelligent or smart buildings is achieved by different systems adapting in real time and immediately to changing environmental conditions. (Buckman et al., 2014)

2.3 Requirements & Enablers

To achieve that buildings become smart and elevate the wellbeing of its occupants it is necessary that enablers support the introduction and establishment of key technologies. The nature of these enablers can be organisational, regulatory, technological, or social. (Suzuki, 2017)

Organisational and regulatory enablers are mainly governments and local municipalities that must work closely together with real estate development companies (Suzuki, 2017). Facing the digital shift of SBT, new regulatory hurdles must be simplified or adapted (Salem, 2016). Legal institutions, politics and think tanks should address the issue of smart buildings technologies and educate the general public on the topic and present potential improvements (Salem, 2016). An implementation strategy for smart building technology must be developed and executed accordingly (Suzuki, 2017).

However, there is already cultural shift towards acceptance of smart technologies. People usage of new technologies like wearable devices, driverless vehicles, virtual reality and virtual home assistants, gives SBT has a solid chance to be accepted by the general population. The increasing awareness about climate change, the appreciation of possible new business models and the desire for security in cities centres will likely support the introduction of SBT. (Suzuki, 2017)

The technological enablers (Socio – technical (Schieweck et al., 2018)) of the Smart Building technologies are based on Internet communication technologies (ICT) and are therefore part of the Internet of Things (IoT). IOT combines diverse technologies ranging from communication protocols and -technologies to sensor networks, sensing technologies, embedded devices and ubiquitous and pervasive computing (Salem, 2016). Innovation in ICT – technologies are increasing and the falling cost on computational power will elevate the distribution of digital devices within the community (Suzuki, 2017). To harvest the most value from SBT and IoT devices it is crucial that intelligent systems have access to different kind of data inputs, coming from both smart sensors and from users (Suzuki, 2017). In this context smart building solutions are driven and enabled by digital technologies but also by social engagement from users (Suzuki, 2017).

Social enablers (Socio – ethical (Schieweck et al., 2018)) are represented through various types of social engagement with the technology (Suzuki, 2017). The occupants will be accountable for the majority of the data created within the building. Occupants data is therefore representing one of the major enablers that can only be harvested with their amicable consent (Suzuki, 2017). Various data can be by today grasped from different sources including mobile phones, automobiles, smart sensors and virtual assistants like “Amazon Alexa” that are integrated in home area networks (Suzuki, 2017). The diversity of devices that are integrated into networks is expected to grow rapidly due to an increase of valuable functionalities in recent times. These devices include smart refrigerators, thermostats and smart meters (Klein and Kaefer, 2008).

In order to guarantee a smooth introduction sufficient security and ethical standards must be adhered. The necessary handling of sensitive data is the primary prerequisite for the general population to accept and appreciate this technology shift. (Suzuki, 2017)

2.4 Challenges

Urbanisation, demographic change and climate change are, among others, major challenges facing society that can be approached by creating Smart environments. Smart building technologies (SBT), sensors and actuators are expected to create smart environments having the potential to tackle these challenges. (Klein and Kaefer, 2008)

Climate change is one of the major challenges currently facing the society (McMichael, 2013). Buildings are responsible for about 40 percent of the global energy usage (D'Oca et al., 2018). With intelligent energy management and intelligent energy distribution in buildings it is possible to improve resource management and eventually protect the environment (Razavi et al., 2019).The challenge therefore is for Economies decreasing environmental strains while maintaining economic growth (Schandl et al., 2016). Buildings and building-related infrastructure represent a large stake affecting the global environment for their entire lifecycle. Significant expectations are therefore placed on companies within the industry, to target environmental issues (Ajenikoko and Olaomi, 2014).

Urbanisation is a challenge to society, because the percentage of people living in cities will rise from 50 % in 2009 to around 70 % in 2050 (Suzuki, 2017). Societal challenges play an important role, as the immigration into western countries and the rural downturn continues. Modern buildings therefore need to be appropriately equipped to meet the needs of a changing society and a city that needs to use space intelligently. To establish a new ecosystem of smart buildings within cities, buildings must be equipped with smart technology (Salem, 2016). The lifetime of a building is ranging from 50 to 150 years (Rauf and Crawford, 2015). One of the most important drivers for the development of buildings in the past was the improvement of the longevity. It should be the hallmark of a smart building today (Buckman et al., 2014). Therefore, buildings need to be designed with a comprehensive strategy over their lifetime. It requires clear pre-defined goals, depending on the specific standards of the occupier and defined actions, if occupants change or if there is a potential conversion of the building (Watson, 2011).

Demographic changes will alter our society. Apart from an increasing world population, the age average in the western countries will increase. In the Member States of the European Union, by 2050, more than a third of the population living in the Union is expected to be over 60 years old and more than a quarter of the population will be over 65 (Crespo Cuaresma et al., 2016). Especially homogeneous societies, such as industrialized countries, which once had strong birth cohorts and now have greatly reduced birth rates, will have problems maintaining their economic and social systems in the near future (Crespo Cuaresma et al., 2016). The introduction of applications that monitor elderly people and support them to live independently for longer or support an effortless housekeeping in their homes, could counteract this problem and relieve the burden on health systems, economies and social security systems (Deen, 2015).

2.5 Sustainability of Buildings

Sustainability, first defined in 1989 by the United Nations of the World Commission on Environment and Development, also aimed at the development of smart buildings with sustainable environment policies (Yılmaz and Bakış, 2015).With their intelligent design and automated systems, smart buildings combine the interests of various stakeholders. Unplanned urbanisation, the increase in the global population, the consumption of limited natural resources and fossil fuels call for a rethink of our consumption habits (Yılmaz and Bakış, 2015). The goal of sustainable policies and a sustainable development model should be to meet the needs of the current generation without endangering future generations. Therefore total development understanding should take environmental mangement, social responsibility and economic solutions further into account while dismanteling the growing consumer society. Buildings, as an important part of the infrastructure, contribute to a large extent to this. The figure 2 is shows the three pillars of sustainability. (Yılmaz and Bakış, 2015)

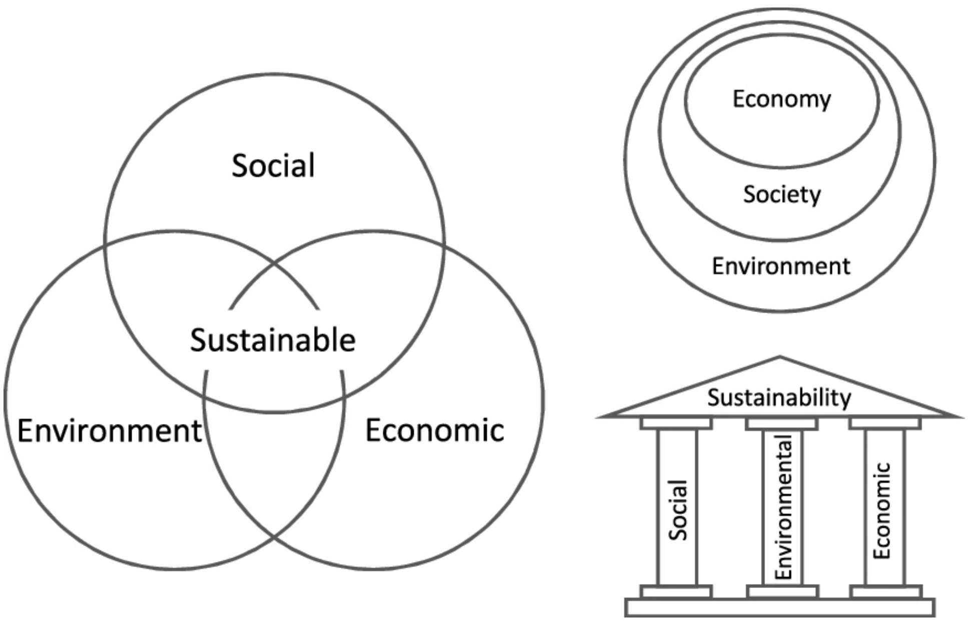

Figure 2: Three Pillars of sustainability (Purvis et al., 2019)

2.5.1 Ecological Sustainability

Ecological sustainability aims at handing over the world to the next generation as good as or even better than the previous generation. It is important to preserve natural habitats and protect them from destruction. The ecological balance between world population and nature plays a decisive role here and calls for a reduction in the consumption of non-renewable resources and a focus on resources which are regularly renewed, and which can also be easily recycled. Care must be taken to ensure that renewable resources are consumed at a rate at which they can be easily replenished. (Yılmaz and Bakış, 2015)

The renewal rate of the raw material must be taken into account (Patel and Chugan, 2013). For example, the extraction of wood for house construction can only be carried out at a rate at which the wood can also grow back in its entirety. A complete clearing of a forest, which also leads to a drying out of the soil, is ecologically unsustainable (Yılmaz and Bakış, 2015).

2.5.2 Economic Sustainability

Currently, the prevailing development model assumes that technological development will increase the quality of life and also increase purchasing power. However, this model assumes that unlimited production and consumption is possible. From an ecologically sustainable perspective, however, this model is not feasible. It is therefore the declared aim of the construction industry to provide buildings that satisfy the greatest possible number of needs with the minimum use of resources. (Yılmaz and Bakış, 2015)

Sustainable economic construction observes the principles of a sustainable life cycle of a building. In this context, the planning, construction, extraction and use of resources, the construction and use of the building, as well as its destruction, must be considered holistically and optimally aligned with sustainability. Ecological, economic and social criteria must be fulfilled. Economic sustainability means encouraging private as well as public investment when it seeks efficient use and management of resources. In addition, the economic efficiency of an investment should be measured by its social improvements rather than the profitability of organisations. (Yılmaz and Bakış, 2015).

2.5.3 Social Sustainability

Social sustainability focuses on fundamental rights and human freedom. Social sustainability is a guarantee of intergenerational equity in resource use. Every generation should have the right to a functioning environment on the basis of which prosperity can be secured. Accordingly, new buildings should be designed to promote social prosperity. Sustainability should be understood as a multidimensional system which has the defined goal of improving the quality of life of all people. Ecosystems such as urban space should be designed in such a way that different generations and social classes can live and interact with each other in a livable way. (Yılmaz and Bakış, 2015)

2.6 Stakeholders of Smart Buildings

There are various stakeholder groups, which are differently connected with a smart building and that have different interests. Major Stakeholder groups are represented by tenants (T), homeowners (HO), investors/landlords (I) but also facility managers (FM). (Menassa and Baer, 2014)

T and HO are referring to residents that are living or working in building. However, HO have different demands on the house they live in, and the majority of them use it as their own private insurance against loss of income or as an old-age provision (Ansell, 2013). I are invested in buildings, need to regularly maintain and renovate them and rent them out to gain a financial return. FM are maintenance service providers that maintain the functionality of the buildings (Menassa and Baer, 2014). However, there is also a human dimension represented by the people. It is difficult to describe a precise relationship with buildings, yet they are influenced by innovations in the building industry (D'Oca et al., 2018).

3 Methodology

3.1 Research design

Both primary research and secondary research were applied to answer the proposed research question.

In order to create a theoretical foundation for the primary research, a literature review based on the latest findings on Smart Buildings and smart building technologies was conducted. Apart from an introduction into the general topic, it outlined upcoming challenges that can be potentially addressed with smart building technologies. Additionally, it defined several requirements that are crucial for the implementation of smart buildings technologies.

The primary research consists of a qualitative and a quantitative component. Within the qualitative research approach, interviews of experts in different areas of the construction industry were conducted. These experts take different points of view and evaluate technologies on a micro and macro level

The qualitative research was comprised by a survey sent out to different stakeholder groups, evaluating smart building technologies, -areas and -properties.

In Secondary research, information from scientific literature as well as different indicators and trends in politics, life style and business was analysed. The secondary research findings were consolidated as the framework of the discussion, thereby providing a foundation for it, further information and limitations.

3.2 Data collection methods

3.2.1 Primary Research – qualitative

Four experts with different points of contact to Smart Buildings were interviewed following a semi structured guideline, enhanced with specific questions depending on the interviewee's area of expertise. The interviewed experts cover different fields of application of Smart Building Technology. The length of the interviews was from 50 min to 70 min. All interviews were recorded by note-taking, one interview got audio recorded. All the interviews got transcribed transcribed in summary form.

The interviewees were:

- Stefan Boetle - CEO Green large-scale Project developer (CIP Architects Stuttgart)

- Marcus Geitlinger a Green Smart buildings developer (Green Architecture AG, Bottighofen (CH))
- Rüdiger Junghans – Business Development Loxone Schweiz (Smart Building Technology OEM; interview got recorded)
- Marion Greiner - interested Customer of Green Homes from Green Architecture

The hypothesis here was that experts with different backgrounds might take different views and opinions on the different technologies, thus enriching the discussion. Furthermore, they represent different layers of macro to micro views on the topic. Stefan Boettle from CIP Architects took the micro view of smart building technologies as an expert working as a CEO for a large project developer. On the other hand, Rüdiger Janghans of the OEM Loxone rather took the macro level, as Loxone is a manufacturer that builds smart building technologies in a wide variety of forms. The analysis of the interviews, three different themes were elaborated. Firstly the general assessment of smart building technologies. Secondly, preferred Smart Building technologies which generate particular value in their point of view. Thirdly, other than IoT-based smart building technology features were elaborated that make buildings smart Each topic was analysed in order to gain an understanding of the assessment, perceptions, motivation and expectations of the different participants on the smart building topic.

3.2.2 Primary Research – quantitative

The second part of the primary research consisted of a survey, where the interviewees were asked to evaluate different smart building technology based on their perceptions. The results of this survey were then compared and discussed with the finding from the expert interviews.

The idea of the design and structure of the survey questions was influenced by the design and structure of the analysis carried out in the paper "A framework to assess the role of stakeholders in sustainable building retrofit decisions" (Menassa and Baer, 2014). Here, and with the help of the interviewed Experts the different stakeholder groups were defined. The groups that were felt most coherent were Tenants (T), Homeowners (H), Investors/ Landlords (I) and Faciltiy Managers (FM).

The survey conducted was structured as following: the first block was comprised of three questions. The respondents firstly had to indicate with which stakeholder group they would most likely identify with. Seven tenants (T), six homeowners (H), four investors/landlords (I) and five facility managers (FM) participated in the survey, totaling 22 respondents

Afterwards the respondents were asked to allocate 100 points to 4 areas of improvements that can be achieved by smart building technologies. These were “economical”, “ecological”, “social” and improvements in “comfort”. The different categories were also used in the paper of Menassa and Bar for the evaluation of retrofittable technologies in the building sector. Furthermore, the pillars of sustainability mentioned in the literature review correspond to the areas of ecological, economical and social. The property "comfort" improvements was added after the survey of the experts, as it represents another important reason for an investment in smart building technologies. The aim of this question was to create a preference of the characteristics of different stakeholders. The allocation of 100 points prevents a possible bias by respondents who tend to give too many or too few points, which is true if any number of points can be awarded.

In the next Question the interviewees were asked to rank 12 different attributes of smart building technologies in the order in which they seem most valuable to them The choice of the different attributes to describe a building technology where taken form the analysis carried out in the paper “A framework to assess the role of stakeholders in sustainable building retrofit decisions” (Menassa and Baer, 2014). The intention was to pick attributes that can be assigned to 4 different areas of improvements namely Economic (blue), Ecologic (green), Social (orange) and Comfort (yellow) improvements, as depicted in Figure 3.

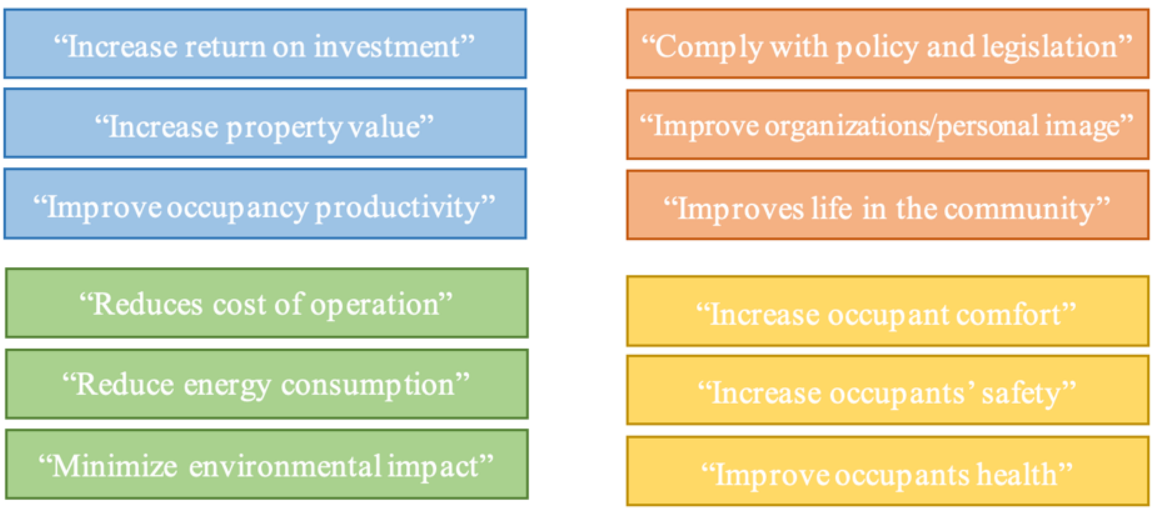

Figure 3: Areas of improvements: Economic (blue), Ecologic (green), Social (orange) and Comfort (yellow) improvements

Afterwards they had to evaluate eleven different smart building technologies that enhance the performance of the building by primarily improving the resource consumption (Ecol - ecologic attributes), efficiency (Econ - economic attributes), the community (Soc - social attributes) and/ or the comfort of the building (Com - comfort attributes).

The range of smart building technologies was provided by the Experts that were previously interviewed as the most promising technologies that would be interesting to investigate further, and were subdivided into several fields:

- 1. Ecology - Technologies improving resource consumption of buildings
    - Smart Grid and Smart Meter
    - Photovoltaic (PV) and Thermosolar systems
    - Battery Storage
    - Heat Pumps (Air Heat Pumps and Geothermal)
- 2. Economy - Technologies improving the efficiency in building
    - Dashboards (Interconnected House Information)
    - Logistics (Mobility)
    - Predictive Maintenance
- 3. Social - Technologies improving security, comfort and healthcare
    - Water, Fire Protection
    - Security of the House
    - Adaptable Roomclimate, Airventilation, Intelligent Shading
    - Healthcare – Technology that enables independent living of old and disabled people

The participants of the survey had to evaluate if the different attributes showed in figure 3 apply to the different smart building technologies. The applicability of the twelve different attributes was based on a seven-point Likert Scale. The participants had to decide if the attributes applied to the smart building technology. They could choose from the following options: 1- strongly disagree, 2 - disagree, 3 - somewhat disagree, 4 - neither agree nor disagree, 5 - somewhat agree, 6 - agree, 7 - strongly agree. Before the analysis of the survey results could be started, the dataset was cleaned. Individual surveys were closely examined and if individual answers were not submitted, adjustments were made accordingly. The survey was analysed and presented graphically with the help of Excel which is shown in Figure 4. For better clarity, the network diagrams were partially adjusted in its axes to better illustrate the results.

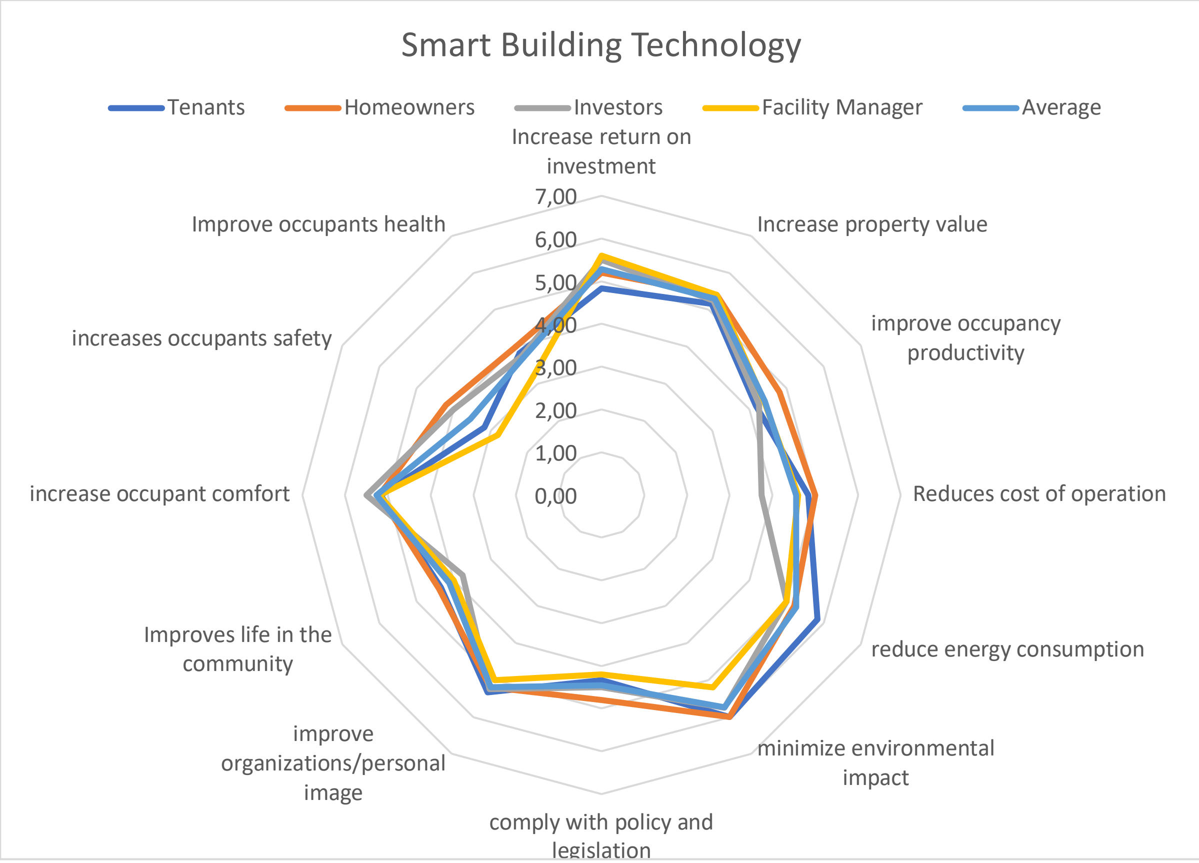

Figure 4: Graphic Example - Different technology evaluations of stakeholders

Afterwards the participants of the survey had to rank the eleven different technologies based on their perception on which technology does bring the most value to them. The aim here was to see a distinction in the decision-making of the different stakeholder groups in the subsequent analysis. The analysis was performed with a first analysis of the different areas preferred by the different stakeholders. Afterwards, a ranking of the different attributes of SBT (Ecol; Econ, Soc, Com) was performed. Subsequently, a ranking of the different technologies was performed and analyzed. Lastly, the best ranked technologies were evaluated and discussed.

3.2.3 Secondary Research

Secondary research was drawn from various information sources from scientific journals to different indicators in trends in politics, lifestyle and business from renowned institutions and publications. The findings in the secondary research were used to scientifically affirm or question the findings of the primary research. The papers were selected according to their relevance to the topic of smart building technologies, but related topics such as climate change, smart logistics and building design were also considered.

4 Findings, Analysis and discussion

4.1 Preferred fields of improvement of Smart Building Technology

The survey showed that the different stakeholders prefer different areas where smart building technologies should bring improvements.

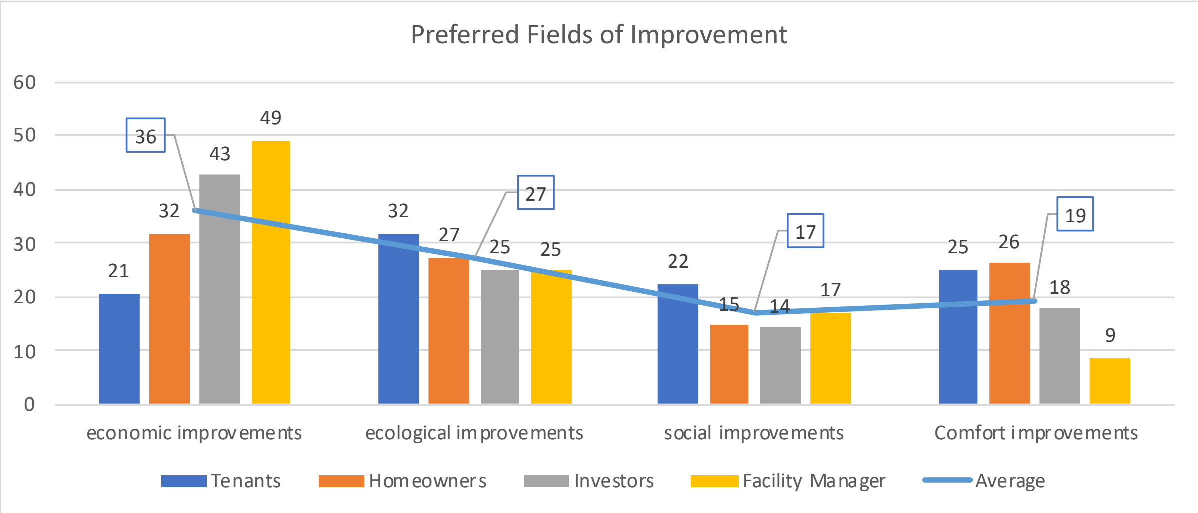

Figure 5: Different Stakeholders allocation of 100 Points to preferred fields of improvements,

Figure 5 shows the preferred fields of improvement of the different stakeholder groups. It shows that on average improvements in the building economics (36) and the building ecology (27) were preferred. Comfort improvements (19) and social improvements (17) through smart building technologies were considered less important. This matches the insights from expert interviews, which highlighted technologies that result in cost savings and sustainability improvements as desirable above all others when planning and retrofitting buildings. Facility managers (FM), Investors (I) and homeowners (HO) favour improvements in building economics. This was to be expected, because they see a building primarily as an investment opportunity and want to save costs. Tenants (T), on the other hand, prefer social and sustainability improvements proportionately more compared to I, H, and FM. Comfort improvements were preferred by H and T rather than I and FM.

Furthermore, it can be observed that the differences in the evaluation in the categories economic improvements and comfort improvements are greater than in the categories ecological improvements and social improvements. The graphical representation in figure 6 depicts these differences.

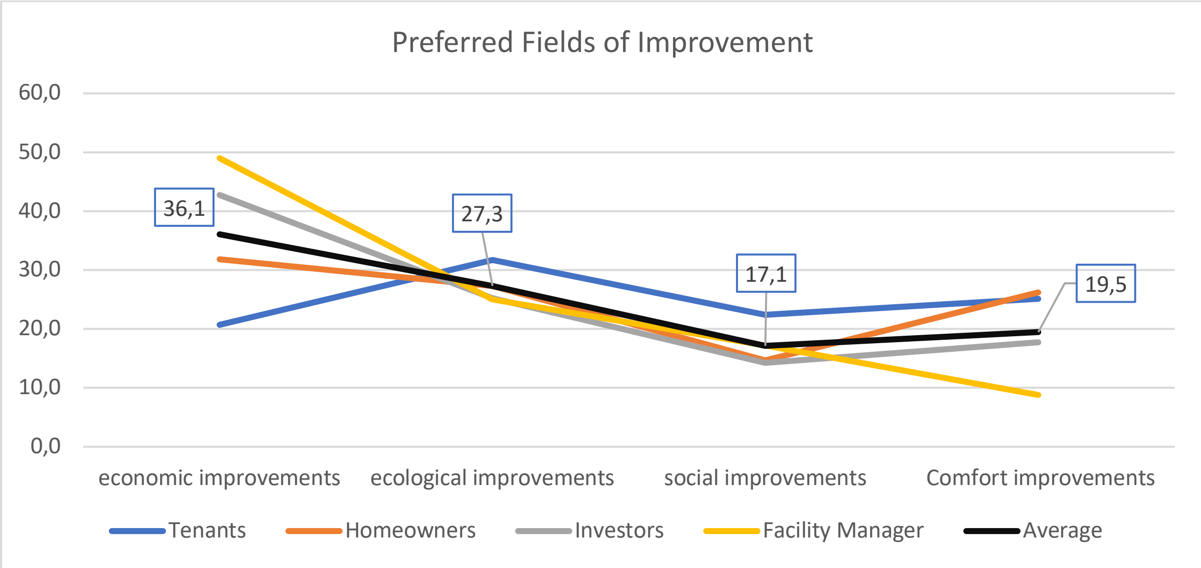

Figure 6: Preferred Fields of improvement of the different Stakeholders (Graph)

Some of the technologies analysed contribute to improvements in primarily one area, while other technologies provide a platform for improvements in multiple areas. The following analysis focused on the different advantages of smart building technologies. According to the experts interviewed, smart building technologies that improve standards in multiple areas should be implemented first. (Boetle, 2020)

4.2 Preferred Attributes of Smart Building Technology

In the following analysis the twelve attributes were again divided into the categories Economic Attributes, Ecologic Attributes, Social Attributes and Comfort Attributes. Similar patterns could be expected for the attributes as they appeared for improvement fields, as one could assume that the different stakeholders would also prefer attributes in the category which they had already rated as more important to them in the part 4.1. Figure 7 is shows that economic attributes and ecologic attributes were again preferred on average to social and comfort attributes. However, figure 7 shows that ecological attributes were preferred to economical attributes.

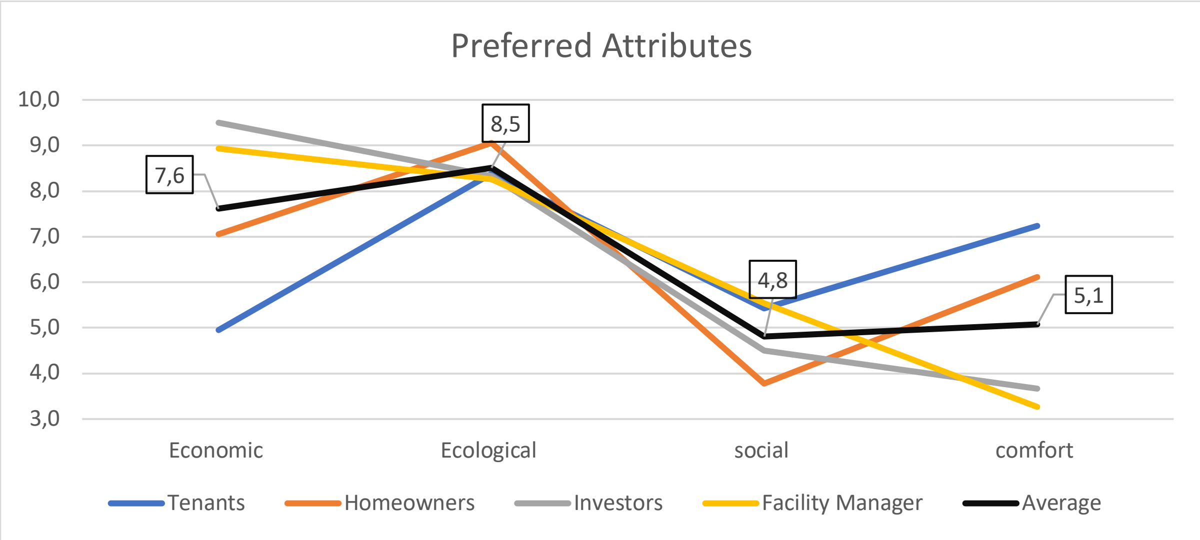

Figure 7: Average Ranking of preferred Attributes Category [0-12; 12 being the best ranking]

In addition, it can again be seen that there are the greatest differences in the ratings between the different stakeholders in the economic and comfort categories. This suggests that in these areas the stakeholders benefit differently from the SBT attributes. The differences in appreciation for environmental improvements and in the area of social attributes were smallest between the stakeholder groups.

It can therefore be concluded that in this category all four stakeholder groups have a similar appreciation. However, the strongest appreciation and support were given for ecological and resource-saving attributes across the different stakeholders.

In figure 14 shows the evaluation of the individual attributes in more detail. The detailed analysis showed that sustainability attributes "Reduce energy consumption" (9,2), "reduces cost of operation" (8,7) and "minimizes environmental impact" (7,6) and the economic attributes "increase return on investment" (8,8) and "increase in property value" (8,4), were rated as being the most important in average. As in the analysis of the preferred fields of improvement, economic and ecological attributes were rated by the average of stakeholders as more important than social and comfort attributes. One of the lowest scoring categories was "improves organisational/personal image". Investors and facility managers in particular rated this poorly.

However, other studies revealed that a majority of facility managers and investors are introducing smart building technologies because of social and brand recognition and to attract new tenants to the building. Furthermore, they realized that an investment towards a sustainable building improves the wellbeing of employees. This eventually results in an increase of productivity, that will it rise 2% equates to a saving in operating cost of 65$ per sqm. (King and

Perry, 2017) Also the experts interviewed also pointed out that investing in smart building technologies increases social recognition. They emphasised that it is important to make a contribution to improving the environment. This would improve personal well-being. (Geitlinger, 2020)

Tenants and homeowners preferred attributes such as "comfort improvements" and "health improvements" over Investors and Facility Managers.

The Attribute "helps to comply with regulations and laws" were generally not considered being important by tenants and homeowners. Here, too, the experts referred to the ever stricter requirements for safety precautions and fire protection that investors and facility managers must be aware of and implement. According to this, the attribute "helps to comply with regulations and laws" were more important to Investors and Facility Managers than tenants and homeowners.

4.3 Ranking of Smart Buildings Technologies according to stakeholders

After evaluating the different smart building technologies, the participants of the survey were asked to rank the smart building technologies according to which of the technologies would bring the most value to them. The table below shows how different stakeholder groups ranked the different technologies and also how the technologies were evaluated in the areas of Economic Improvements (ECN), Ecologic Improvements (ECL), Social Improvements (Soc) and Comfort Improvements (Com). The analysis examines the five best technologies with the three worst technologies chosen by the average.

Ranking			Av. Points	Tenants		Av. Points	Homeowners		Av. Points	Investors		Av. Points	Facility Managers		Av. Points
1	Smart Grid and Smart Meter	ECN	4,77	Smart Grid and Smart Meter	ECN	4,5	Adaptable Roomclimate	ECN	5,5	Smart Grid and Smart Meter	ECN	5,00	Smart Grid and Smart Meter	ECN	4,93
		ECL	6,01		ECL	6,0		ECL	5,9		ECL	6,17		ECL	6,33
		Soc	4,32		Soc	4,4		Soc	4,5		Soc	4,33		Soc	4,33
		Com	2,57		Com	3,6		Com	4,6		Com	3,42		Com	3,53
2	Dashboards	ECN	5,76	Adaptable Roomclimate	ECN	5,6	Photovoltaic	ECN	4,5	Dashboards	ECN	5,8	Predictive Maintenance	ECN	6,0
		ECL	4,89		ECL	6,2		ECL	5,6		ECL	5,6		ECL	5,7
		Soc	5,27		Soc	5,2		Soc	4,5		Soc	5,8		Soc	5,3
		Com	3,89		Com	5,3		Com	2,7		Com	5,3		Com	4,9
3	Photovoltaic	ECN	4,93	Photovoltaic	ECN	4,7	Heat Pumps	ECN	5,1	Photovoltaic	ECN	5,5	Dashboards	ECN	6,1
		ECL	5,67		ECL	5,8		ECL	5,4		ECL	5,5		ECL	5,1
		Soc	4,80		Soc	5,2		Soc	4,8		Soc	4,6		Soc	5,3
		Com	2,39		Com	3,6		Com	4,5		Com	3,1		Com	5,1
		Av. Points	Av. Percent.		Av. Points	Av. Percent.		Av. Points	Av. Percent.		Av. Points	Av. Percent.		Av. Points	Av. Percent.
TOP 3	ECN	5,15	28%	ECN	4,90	24%	ECN	5,04	27%	ECN	5,44	27%	ECN	5,69	27%
	ECL	5,52	30%	ECL	6,02	30%	ECL	5,64	30%	ECL	5,75	29%	ECL	5,71	27%
	Soc	4,80	26%	Soc	4,92	25%	Soc	4,62	24%	Soc	4,89	24%	Soc	4,96	24%
	Com	2,95	16%	Com	4,17	21%	Com	3,93	21%	Com	3,94	20%	Com	4,51	22%
	Sum	**18,42**	**1,00**	-	**20,01**	**1,00**	-	**19,24**	**1,01**	-	**20,03**	**1,00**	-	**20,87**	**100%**
4	Adaptable Roomclimate	ECN	5,53	Battery Storage	ECN	4,8	Smart Grid and Smart Meter	ECN	4,67	Adaptable Roomclimate	ECN	6,2	Battery Storage	ECN	4,8
		ECL	5,93		ECL	5,8		ECL	5,53		ECL	6,0		ECL	5,9
		Soc	4,53		Soc	4,6		Soc	4,20		Soc	5,2		Soc	4,7
		Com	4,60		Com	3,6		Com	3,13		Com	4,3		Com	3,7
5	Predictive Maintenance	ECN	5,82	Healthcare	ECN	4,7	Dashboards	ECN	5,4	Heat Pumps	ECN	5,0	Photovoltaic	ECN	5,1
		ECL	5,29		ECL	2,4		ECL	4,5		ECL	4,8		ECL	5,7
		Soc	5,10		Soc	5,6		Soc	4,7		Soc	4,5		Soc	4,9
		Com	3,72		Com	6,3		Com	5,1		Com	4,4		Com	3,3
		Av. Points	Av. Percent.		Av. Points	Av. Percent.		Av. Points	Av. Percent.		Av. Points	Av. Percent.		Av. Points	Av. Percent.
TOP 5	ECN	5,36	28%	ECN	4,84	25%	ECN	5,04	27%	ECN	5,50	27%	ECN	5,39	27%
	ECL	5,56	29%	ECL	5,24	27%	ECL	5,40	28%	ECL	5,62	28%	ECL	5,76	29%
	Soc	4,81	25%	Soc	4,99	26%	Soc	4,55	24%	Soc	4,87	24%	Soc	4,91	24%
	Com	3,43	18%	Com	4,48	23%	Com	4,01	21%	Com	4,12	20%	Com	4,12	20%
	Sum	**19,16**	**1,00**	-	**19,55**	**1,00**	-	**19,00**	**1,00**	-	**20,10**	**1,00**	-	**20,17**	**100%**
9	Logistics	ECN	5,62	Security of the House	ECN	4,67	Logistics	ECN	5,33	Logistics	ECN	6,08	Water, Fire Protection	ECN	4,33
		ECL	3,92		ECL	2,83		ECL	3,27		ECL	5,17		ECL	2,80
		Soc	5,10		Soc	5,22		Soc	4,80		Soc	5,58		Soc	5,27
		Com	3,66		Com	6,00		Com	4,53		Com	5,25		Com	6,20
10	Security of the House	ECN	4,66	Logistics	ECN	5,39	Security of the House	ECN	4,53	Security of the House	ECN	4,58	Adaptable Roomclimate	ECN	5,87
		ECL	2,78		ECL	3,72		ECL	3,00		ECL	2,83		ECL	5,33
		Soc	5,34		Soc	4,94		Soc	5,27		Soc	5,33		Soc	4,93
		Com	4,56		Com	4,89		Com	5,80		Com	6,33		Com	4,87
11	Water, Fire Protection	ECN	4,35	Water, Fire Protection	ECN	4,44	Water, Fire Protection	ECN	4,20	Water, Fire Protection	ECN	4,42	Security of the House	ECN	4,87
		ECL	2,94		ECL	3,06		ECL	3,33		ECL	2,58		ECL	2,47
		Soc	5,49		Soc	5,33		Soc	5,60		Soc	5,75		Soc	5,53
		Com	4,33		Com	5,50		Com	5,47		Com	5,92		Com	6,20
		Av. Points	Av. Percent.		Av. Points	Av. Percent.		Av. Points	Av. Percent.		Av. Points	Av. Percent.		Av. Points	Av. Percent.
LAST 3	ECN	4,88	28%	ECN	4,83	26%	ECN	4,69	26%	ECN	5,03	25%	ECN	5,02	26%
	ECL	3,22	18%	ECL	3,20	17%	ECL	3,20	17%	ECL	3,53	18%	ECL	3,53	18%
	Soc	5,31	30%	Soc	5,17	28%	Soc	5,22	28%	Soc	5,56	28%	Soc	5,24	27%
	Com	4,18	24%	Com	5,46	29%	Com	5,27	29%	Com	5,83	29%	Com	5,76	29%
	Sum	**17,59**	**100%**	-	**18,67**	**100%**	-	**18,38**	**100%**	-	**19,94**	**100%**	-	**19,56**	**100%**

Figure 8 Detailed Evaluation of Technologies by different Stakeholders

Figure 8 shows that technologies that scored high in terms of economic and ecological improvements were selected for the top positions. Social improvements and comfort improvements are on average less represented among top technologies.

Technologies that occupy the lower ranks were social or comfort improvement attributes. It is noticeable that fewer points were awarded to ecological attributes. On average, 2 points less were awarded to Logistics, Security and Water, Fire Protection. The average score for the economic attributes, however, changed relatively little. It can therefore be assumed that above all ecological attributes of a technology contribute to it being preferred over other technologies.

As was to be expected, on average fewer points were awarded to the lower-ranked technologies. One can therefore deduce that these technologies were not rated as valuable, or that they only generate an advantage in specific areas. Security Technology is scoring predominantly in the social area and barely in economic and ecologic areas. Better rated technologies generate improvements in different areas or form a platform for improvements, such as smart meters/grids or dashboards. Photovoltaics also form a platform that supports various other devices in a smart building.

When analysing individual stakeholders, parallels can be drawn from the previous analyses. Tenants and homeowners place more value on technologies that have comfort attributes. Investors and facility managers prefer economic attributes, whereas homeowners prefer these to a similar extent.

It is noticeable that facility managers have the highest percentage in the category of ecological attributes. This could have arisen from the fact that as technologies with few comfort attributes were preferred. In addition, it can be seen that economic attributes are also associated with ecological attributes, as can be seen in the best-ranked technologies.

In the following analysis, the 5 best technologies are described in more detail and their potential is evaluated.

4.4 Best ranked Smart Building Technologies

In following section, the five technologies that were rated as most valuable by the average of the different stakeholder groups were described in further detail. The technologies chosen were Smart Grid/ Smart Meter (1), Dashboards (2), Photovoltaic (PV) and Thermosolar systems (3), Predictive Maintenance (4) and Adaptable Room climate (5).

As defined in the literature review, sustainable building should focus on 3 areas: ecology, economy and social welfare. It is imperative to consider how improvements in the different areas can be implemented with the minimum effort and with minimal negative externalities, such as energy consumption and resource use. (Yılmaz and Bakış, 2015)

4.4.1 Smart Grid and Smart Meter

Smart Grid and Smart Meters were ranked and perceived as the smart building technology with the most value by the average of stakeholders. Smart meters and smart represent a platform for the integration of different utility systems (Power and heat -generation, Power storage) to increase the overall energy efficiency and sustainability of the building. (Zhang et al., 2013)

Smart grids are capable of optimizing asset allocation, thereby determining load management and scheduling storage times. Additionally, they enable the sale and purchase of power for the next day as hedging measurement or to maximize profits. (Zhang et al., 2013)

An intelligent power grid or smart grid is able to buffer power fluctuations. Smart meters are intelligent electricity meters that can measure the amount of electricity available in the public electricity networks. With the help of smart meters, individual usage patterns can be analysed. Smart meters build a gateway for different energy producing and saving systems within a building and the smart grid (Ajenikoko and Olaomi, 2014). They can indicate when electrical energy is available at low cost and thus provide incentives for appropriately programmed household appliances to be connected to the grid at precisely that time. Therefore, washing machines, dryers or hot water boilers can be programmed to start up selectively when there is a lot of wind and solar power on the grid and electricity prices are low. Furthermore, electric cars could charge their batteries at exactly that time. If the grid is not providing enough power and the electricity prices are rising, energy intense appliances are switched off. (Stefan Boettle, 2020)

Within sustainable building management, these digital power grids can link buildings intelligently and ensure intelligent power distribution between the buildings depending on their demand. Due to a comparably weak degree of efficiency when transporting electrical power over large distances, traditional power grids are being challenged by decentralised smart power grids (Fang et al., 2012).

The aim of future power grids is the integration of different technologies like smart meters, automated distribution and communication systems that will integrate different distributed energy resources (DERs), like solar, wind and geothermal energy. This way traditional consumers of electricity are also able to also supply electricity via smart energy inverters to the main grid and become prosumers. A broad implementation of smart grids would not only result in energy savings that are ranging from up to 12 % but would lead to social benefits with a reduction in Co2, SOx and NOx Emissions, an increase in jobs in the green energy sector as well as securing energy security, because of the decentralised nature of energy production. (European Commission. Joint Research Centre., 2018)

However, the upfront investment to develop a Europe wide smart grid infrastructure is enormous. In order to reduce the greenhouse gas emissions by 40% until 2030 compared to the level of 2005, the European Union will invest from 2011 to 2030 around 600 billion Euro intro the Grid infrastructure to support Smart Grid development. (Nuffel et al., 2017)

Smart Meters deployed in Smart buildings are capable of communicating with the Smart Grid and calculate energy flows. Smart meters are thereby representing the management unit that uses Digital Data Streams to analyse energy demand and supply. Smart meters can provide real-time energy consumption information and communicate this data securely (Depuru et al., 2011).

They are thus capable of bidirectional communication. Smart meters can determine the demand for electricity from the grid and connect decentralised energy sources and storage solutions to optimise billing for customers. The introduction of smart meters is crucial for various reasons that can differ among region (e.g. here Switzerland vs. northern Germany). In most cases the main aim is to successfully integrate and bundle different renewable energy sources with the grid. In other regions it is peak load management, meaning the distribution management of an oversupply and undersupply of electricity. Another driver is the overall reduction for CO_2. (Lawrence et al., 2016)

Europe is planning to install around 300 million Smart Meters until 2020 (Zhang et al., 2017), replacing at least 80% of the traditional meters with smart ones (European Commission. Joint Research Centre., 2018). The maintenance of the network must be ensured and the pace of implementation of smart meter must align with the implementation of distributed energy systems. The basic requirement is that all applications are internet-enabled. (Depuru et al., 2011).

However, a conflict of interest within the utility companies could hinder their introduction. Energy suppliers are motivated to sell as much energy as possible, which is prevented by a decentralised energy supply by the end customer (Depuru et al., 2011). Taking this into account, energy suppliers need to find new ways to stay competitive. It is to be expected that they will look for platform solutions, similar to the way car manufacturers strive to become mobility platforms.(Junghans, 2020)

In addition to saving and controlling energy flows, outages and losses can be prevented. With the introduction of smart grid networks, smart meters are needed to provide demand control, power quality and predictive maintenance services. In addition, smart meters will eliminate the need for manual metering by people, which will lead to cost savings. An increase in electric cars and the rate of renewable technologies will further accelerate the adoption of smart meters. In addition, the industry is hoping for big savings in developing countries, where around $20 billion a year is lost to meter reading errors and electricity theft. (Depuru et al., 2011)

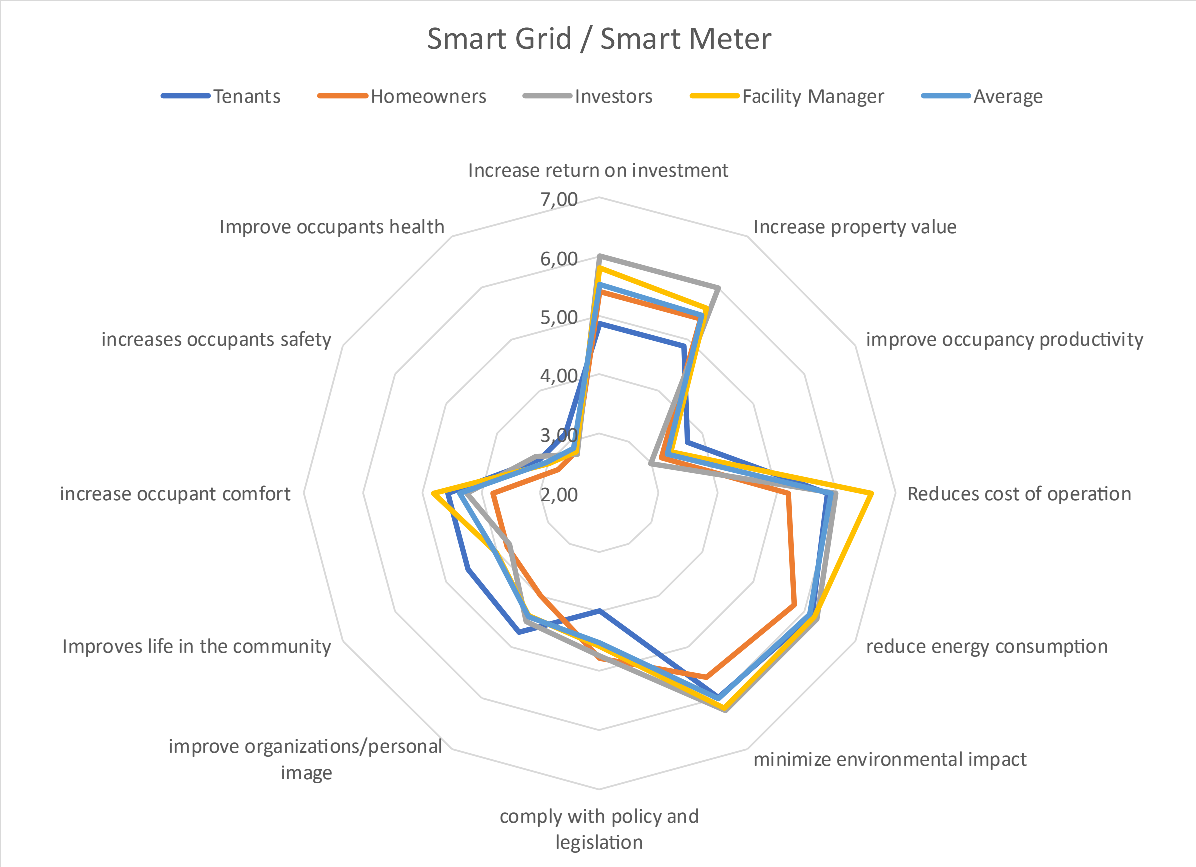

Figure 9: Evaluation of Smart Grid / Smart Meter [0-7 – with 7 applying the most]

Figure 9 shows the technology evaluation of Smart Grid / Smart Meter. The technology assessment reveals that all stakeholders attribute great economic and ecological potential to smart grids and smart meters. Mediocre results were achieved in social sustainability, and safety and health attributes do not apply according to the stakeholders. Overall, the ability to "reduce energy consumption" and to "minimise environmental impact" were rated to apply the most to the technology. Furthermore, attributes like "increases return on investment", " increase property value" and " reduce cost of operation" apply to the technology.

Technology	Final Rank	Tenants	Homeowners	Investors	Facility Managers
Smart Grid / Smart Meter	1	1	3	1	1

Table 1: Ranking Smart Grid / Smart Meter

As mentioned int the methodology 22 respondents to the survey were asked to indicate their relationship with buildings and, after rating each smart building technology, were asked to rank them. Eleven technologies were to be ranked. The technology was ranked in first place by the average of the different stakeholders. This supports the assessment of the interviewed experts, who primarily advocated technologies that reduce costs and protect climate (Jungshans, 2020). In addition, it can be mentioned that smart meters and smart grids are technologies that represent a platform. Technologies of this class are preferred in industry and form a basis for other technologies (Junghans, 2020). In contrast to the homeowners, all other stakeholder groups voted the technology into first place. Homeowners voted "Adaptable Room climate" into first place, which can be explained by the fact that they prefer technologies that improve comfort to those that bring ecological and economic improvements. (Greiner, 2020)

4.4.2 Dashboards

Smart building technologies can create a number of social improvements by enabling people to communicate more efficiently and speed up processes. It can also improve safety by providing maintenance information to prevent equipment failure. Governments, municipalities and associations have to engage with residents within their area in some form. In the past, information was mainly communicated offline with letters or with the help of community meetings. With the help of Dashboards, communication can also be improved in commercial areas. (King and Perry, 2017)

Smart Buildings can use information dashboards to show residents various information. In addition to house-related information such as the energy level available from solar cells and the general energy consumption, environment-related information such as schedules of public transport, waste disposal dates or dates for cultural events, childcare or other services can be displayed. In a housing estate, activities promoting community spirit can be communicated . (King and Perry, 2017)

In an office building, dashboards can show employees and guests how busy the cafeteria is at the moment, which meeting rooms are free and help visitors find their way around the building. In a commercial use, flows of people can be supervised and analysed with the help of other sensors. Predictions about occupancy rates of rooms can be displayed on dashboards (Tilleman, 2018). Employees and facility managers can access the data and can adapt their services to the situation. Investors can analyse with the building's tenants what level of efficiency the building allows and can make changes to the space allocation or layout. By tailoring the building to the needs of the tenant (client), the operation of the building can be made even more profitable for Investors (Boettle, 2020).

Improved efficiency and a pleasant room layout also lead to productivity gains for employees. Room layout can significantly influence how people communicate and work. In fact, different kinds of work tasks require different kinds of room settings. The most efficient and smartest office building, the "Edge" in Amsterdam, is providing their employees access to different kind of rooms, depending on their needs and preferences. Their personal preferences are detected and the surrounding workplace is adapted accordingly. (Tilleman, 2018)

In any case, these productivity gains exceed any savings from potential efficiency gains, e.g. in energy savings, as labour costs are the highest fixed cost in most of the service companies. Therefore, the aim of any company should be to increase the level of productivity of the employees (Boettle, 2020).

Employees and facility managers can access the data and can adapt their services to the situation. This information can be relevant for Predictive Maintenance Services. If there is an increased energy consumption facility manager can maintain the devices and fix the broken parts that cause high energy consumption, before the device breaks down. (Cheng et al., 2020)

The installation IoT based controls and monitoring systems is estimated at around 0.75 cents per square metre. On average, 10-25 per cent of the energy consumption is saved through their use. An office building with 75,000 square metres and an average energy consumption of 2.32 dollars per square metre can expect savings of up to 45,000 dollars. Amortisation times are therefore ranging between 1.5 to 3.2 years. (Rawal, 2016)

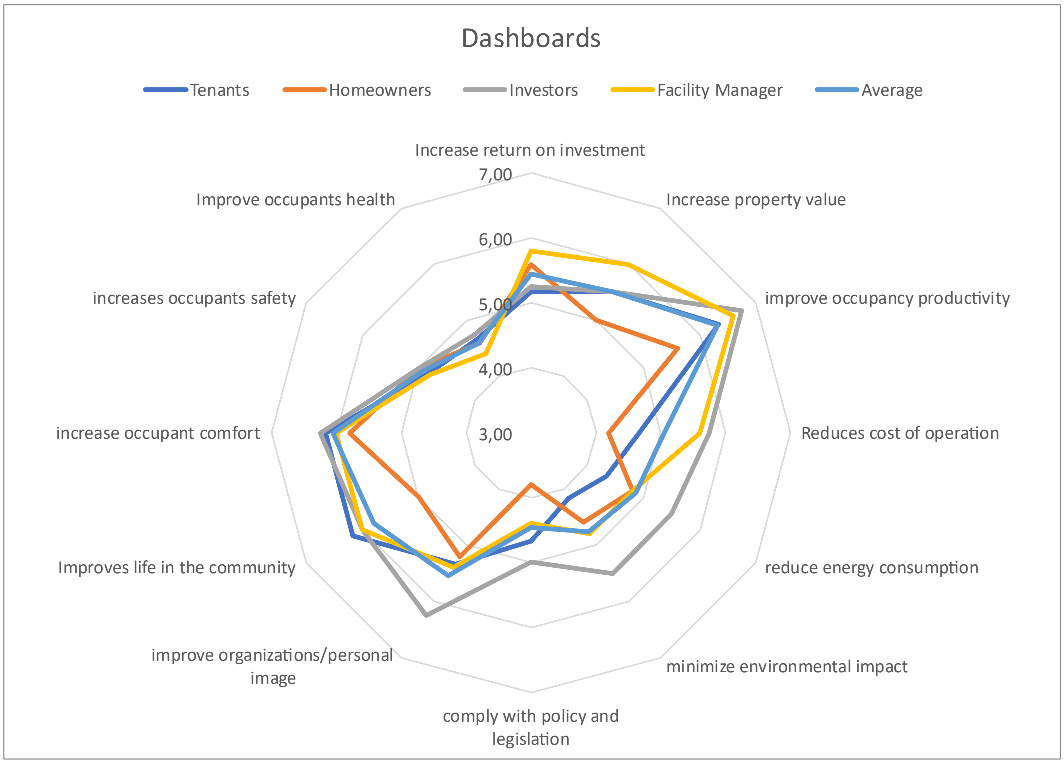

Figure 10: Evaluation of Dashboards [0-7 – with 7 applying the most]

Figure 10 shows the evaluation of dashboards by different stakeholders. In the evaluation of the properties, it can be seen that primarily investors and facility managers have attributed properties such as "improves occupancy productivity" and "reduces cost of operation" to smart building technology. Investors and facility managers are also, as mentioned above, the stakeholders who derive the greatest benefit from the improvement of these properties in a building. Tenants, on the other hand, attributed dashboards primarily to "increases occupancy comfort".

Technology	Final Rank	Tenants	Homeowners	Investors	Facility Managers
Dashboards	2	7	5	2	3

Table 2: Ranking Dashboards

Dashboards as a smart building technology was voted second by the average of stakeholders. A detailed calculation of the final rank is displayed in in table 6. Facility managers (rank 3) and investors (rank 2) were the ones who rated the technology as more valuable than homeowners (rank 5) and tenants (rank 7). This may be due to several factors. On the one hand, facility managers in particular can use dashboards to quickly see where service is needed in the building. For example, a building cleaner might see that there are more people in the building today and therefore the toilets need to be cleaned more regularly. With dashboards and related smart building sensors, Facility Mangers can do their job better, more efficiently and can act faster when conditions change. This increases the well beeing and satisfaction of the occupants or workers and results in an increase in productivity. A building that provides high occupant productivity is also of high interest to an investor, as he can expect higher rental prices. Accordingly, the return per rented square metre increases.

4.4.3 Photovoltaic (PV) and Thermosolar systems

Solar power plants, or photovoltaics, use solar cells to generate electricity directly from the sun's radiation. Solar thermal or photothermic uses the radiation of the sun's rays to heat up water, for example. Both systems make it possible to use the energy of the sun and to generate sustainable power and heat. Both systems make it possible either to be more independent of central power grids or to reduce the consumption of resources for heat generation, that are mostly fossil resources like gas and heating oil (Jurasz and Campana, 2019).

Depending on the environmental conditions the power supply varies. A big challenge for solar power is the prevention of current peaks (Jurasz and Campana, 2019). Since solar electricity is primarily produced when residential demand is low, meaning during lunch time. Here, demand is generally highest in the morning and evening, but solar power is strongest at midday. However, oversupply of electricity can be redirected and collected in Energy Storage Systems (batteries) implemented within the smart grid. Alternatively, electrical oversupply can be transmitted to batteries of electrical vehicles that can be regarded as mobile energy storage units. (Thomas et al., 2018)

Solar pannels can be easily integrated into existing buildings and are particularly interesting in urban areas, as they do not generate any noise during energy production. They are also durable, as they do not contain any moving parts (Jurasz and Campana, 2019). Furthermore, photovoltaic systems are interesting in areas where there is a high electricity demand during the day due to air conditioning. This energy demand can be cushioned decentrally by PV systems (Jurasz and Campana, 2019).

The costs of solar systems have been reduced by about 75% since 2009 due to advances in production (King and Perry, 2017). There are many ways to implement solar energy systems. They can be placed on the roof or integrated into the building itself. There are applications where solar panels are integrated directly into external glass surfaces and are therefore particularly suitable for office towers. Solar power is able to reduce the energy consumption a building by 14%, when operated with a storage system (e.g. batteries). When adding a smart inverter to feed electricity into the main net the savings in energy resulted in another 14% return. (King and Perry, 2017)

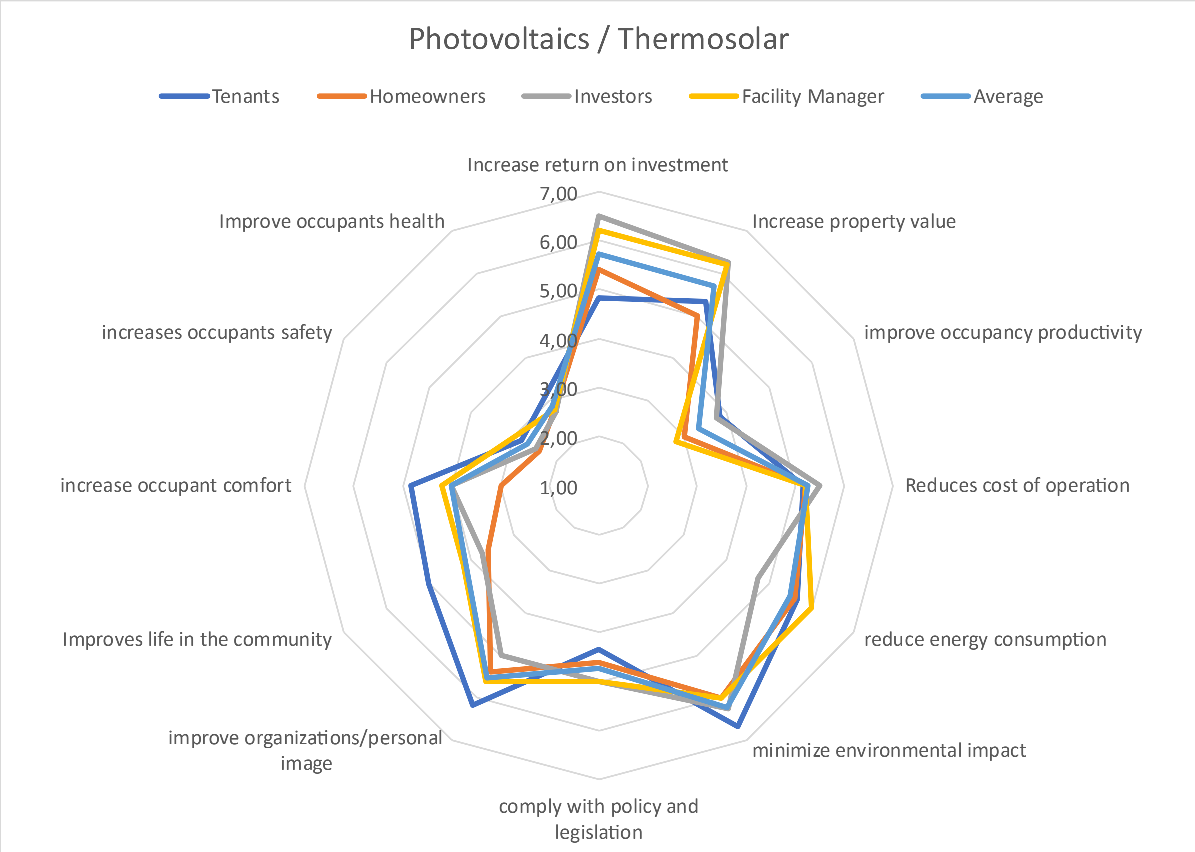

Figure 11: Evaluation of Photovoltaics/ Thermosolar [0-7 – with 7 applying the most]

Figure 11 shows the Evaluation of Photovoltaics/ Thermosolar. The technology convinced with strong ratings in the economic and ecological areas. In the rubric of comfort properties, the rating was the worst compared to the other top 5 technologies. Solar power technology was evaluated similarly to smart meters/smart grids, namely with great potential in the areas of "return on investment" and "increase in property value". It should be noted that, compared to tenants, primarily investors and facility managers see potential in this area. Tenants, on the other hand, see in solar energy systems primarily properties such as "increase of occumpants comfort", and social properties such as "improves life in the community" and "improves organisational/personal image". The property "reduces energy consumption" was of least interest to investors, probably because energy costs can be passed on to tenants and therefore have no direct influence on their return. Among all stakeholders, photovoltaics was ranked highest by home owners.

Technology	Average	Tenants	Homeowners	Investors	Facility Managers
Photovoltaic/ Thermosolar	3	3	2	3	5

Table 3: Ranking / Photovoltaic / Thermosolar

Table 3 shows the ranking of Photovoltaics / Thermosolar. The technology was ranked third in average. Homeowners gave the technology a better placement. Tenants and investors remained on average with their rating. All 3 stakeholder groups can save costs, increase efficiency and increase property value through the use of photovoltaic systems. Facility managers, on the other hand, scored lower. As mentioned earlier, photovoltaic systems are low maintenance due to fewer moving parts. FMs preferred technologies such as predictive maintenance, dashboards over photovoltaics. These technologies offer FM a multiplier, as these technologies in turn offer a platform through which facility managers can offer and enhance their services.

4.4.4 Adaptable Room climate, Air ventilation, Intelligent Shading

An intelligent heating and cooling control can always produce the desired temperature in every room, fully automating the building's heating plan and adapting preferences of occupants. To achieve this, intelligent heating, ventilation and air conditioning (HVAC) systems use several sensor genes for control and monitoring (King and Perry, 2017). Pattern recognition calculates the exact heating requirements to increase the comfort and recognises when occupants are at home or not. Furthermore, energy consumption can be reduced by limiting HVAC in unused rooms and turning it off when the general electricity consumption and therefore electricity prices are increased (King and Perry, 2017). By intelligently switching the HVAC system according to the occupants' needs, up to 50% of energy costs can be saved (King and Perry, 2017).

Heating and cooling the house can be influenced through intelligent shadings. Modern buildings often come with large windows, light entering through them is heating up the living area. This light can be used to heat up rooms, however intelligent shading can counteract and can support cooling. A pleasant indoor climate also supports a more productive way of working, which is essential for companies or for working in a home office. In commercial buildings up to 40% of the cooling demand is due to solar heat gain through windows. (Bahadori-Jahromi et al., 2017)

Automated system optimization, replacing traditional building management systems which followed a default schedule, reacts in real time and based on changing external factors like weather, occupancy patterns and utility rate. (King and Perry, 2017)

Through automated systems and optimised processes, smart buildings save a substantial part of energy costs. The installation of an integrated system of different technologies often leads to savings of more than 50% (HVAC controls, intelligent shading, dashboards), while the introduction of individual components such as smart thermostats in HVAC only saves around 15% of the energy demand. (King and Perry, 2017)

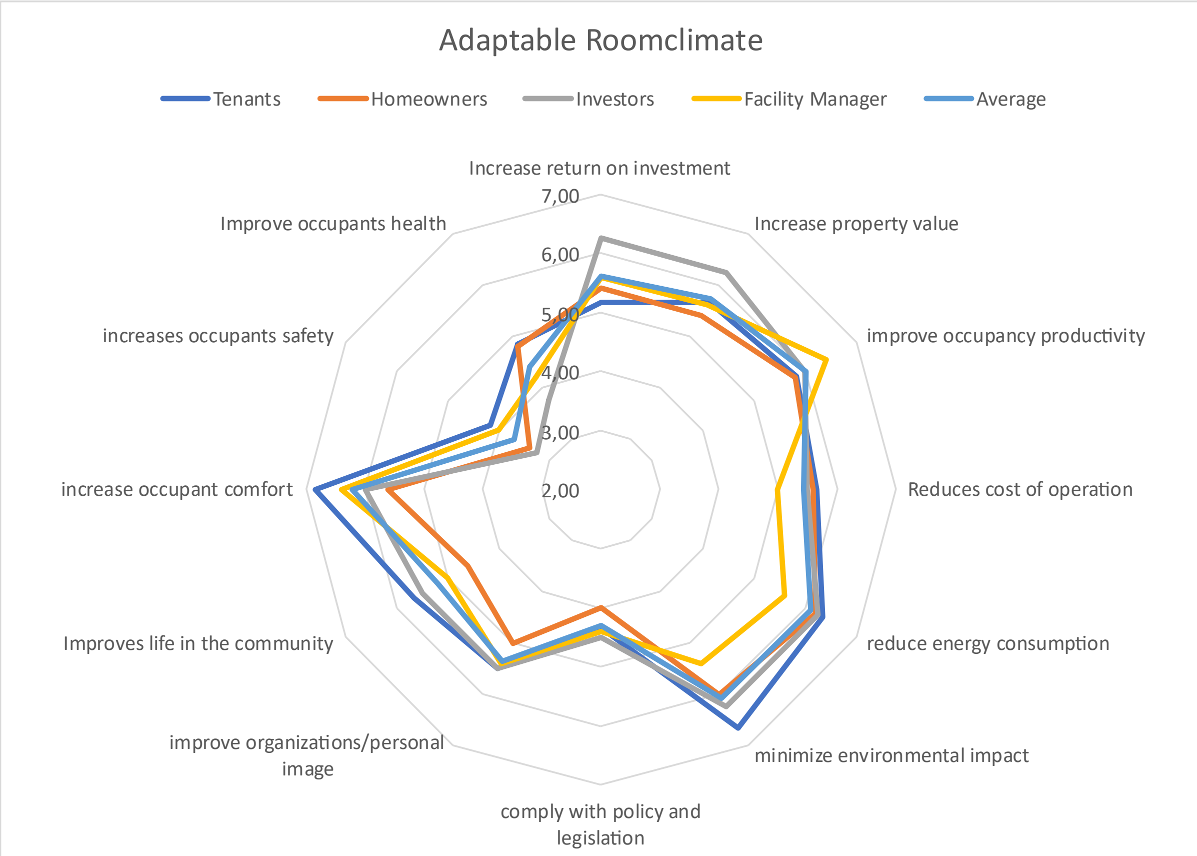

Figure 12: Evaluation of Adaptable Room climate [0-7 – with 7 applying the most]

Figure 12 shows the technology evaluation of the technology Adaptable Room climate. It shows that the different stakeholders attribute the technology with "increase occupants' comfort", "minimizes environmental impact" and "reduces energy consumptions". On the other hand, social attributes such as "complies with policy and legislation" were not rated as applicable.

Technology	Average	Tenants	Homeowners	Investors	Facility Managers
Adaptable Roomclimate	4	2	1	4	10

Table 4: Ranking Adaptable Roomclimate

Adaptable room climate, airventilaltion and shading was voted 4th out of 11 Smart Building Technologies. Homeowners (1) and tenants (2) in particular gave good rankings. Investors (4) and facility managers (10), on the other hand did not value this technology too highly. Among other things, this can be explained by the fact that comfort improvements are more likely to be perceived with this technology than cost savings. Comfort improvements through an improved indoor climate are particularly valued by tenants and homeowners. Investors appreciate a pleasant climate for the additional reason that higher rents can potentially be charged and thus the return on the property can be increased.

However, facility managers do not see any value and would value other technologies over Adaptable room climate. Even if the technology achieves cost savings through a reduction in energy demand, facility managers gave it a low rating and considered other technologies to be more valuable.

4.4.5 Predictive Maintenance

In the field of facility management, predictive maintenance can significantly reduce maintenance costs and the frequency of repairs. During the life cycle of a building, the largest share, about 60 % of the total costs, is incurred as maintenance costs (Marmo et al., 2020). Smart meters can detect increased power consumption and sensors can detect faulty operations in various systems. Especially in office buildings, failures of elevators or air conditioning systems can be the cause of high costs. If lifts are breaking down people cannot move within the building and if rooms cannot be heated or ventilated, business can potentially stop (Wu et al., 2021). Predictive maintenance systems are particularly important in buildings where a functioning ventilation system is urgently needed and a failure would have serious consequences, such as in hospitals. Predictive maintenance can save up to 20% of maintenance and energy costs per year while extending the projected life time of the building by several years (Hemmerdinger, 2010). In office buildings as well as in multi-storey residential buildings, predictive maintenance measurements can ensure reduced downtime, reduced maintenance cost, increased transparency over building operations and the opportunity for value-adding services for facility managers (Cheng et al., 2020). In order to service lifts, large heating systems and air-conditioning systems, various sensors are installed, such as pressure, environmental, magnetic and vibrations sensors. These IoT enabled sensors help to create an ecosystem for predictive services and buildings intelligence.

Predictive Maintenance measurements can increase the lifetime return on investment 10 times more than reactive maintenance (Hemmerdinger, 2010). However, the upfront investment in these systems is substantial, especially when companies do not face breakdowns of systems often. This means that the corporate culture, the staff and the occupants of the building must be made aware of this data and the fact that predictive maintenance can lead to cost savings in the long term.

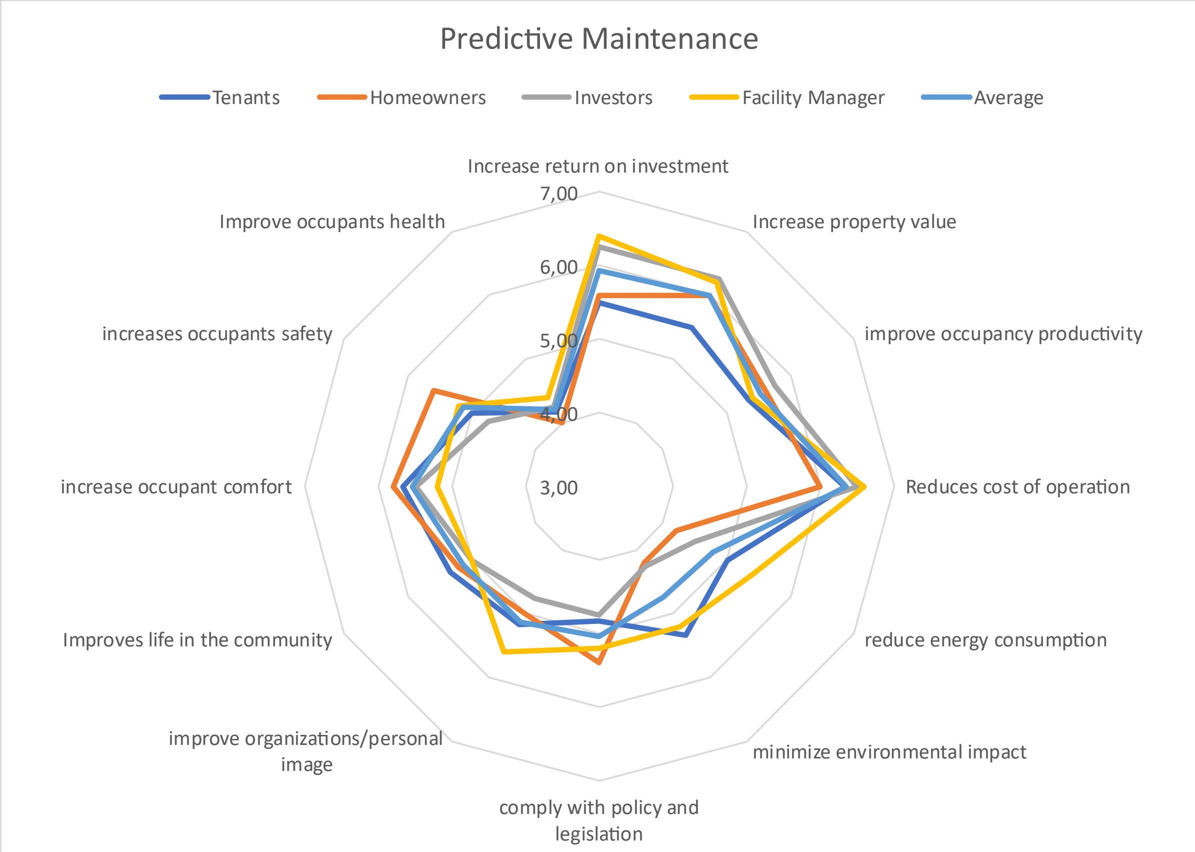

Figure 13: Evaluation of Predictive Maintenance [0-7 – with 7 applying the most]

Figure 13 shows that facility managers attributed "Increases return on investment" and "Increases property value" to the technology. Otherwise, the ratings are relatively uniform. However, the properties "Reduces energy consumption" and "Minimises environmental impact" are rated differently. Here, homeowners and investors differ from facility managers and investors.

Technologie	Average	Tenants	Homeowners	Investors	Facility Managers
Predictive Maintenance	5	8	7	6	2

Table 5: Ranking Predictive Maintenance

Predictive Maintenance (PM) was ranked as the 5th most valuable smart building technology. Predictive maintenance systems were primarily rated as particularly valuable by facility managers. Investors, tenants and homeowners, on the other hand, did not place the technology so far ahead in their preference order. This was the largest difference made by stakeholders among all technologies analysed. The different perceptions of the technology can be explained by various factors. PM systems can open up new service opportunities for facility managers. Maintenance work can be adapted to the building in a targeted manner through data evaluation.

Therefore, Facility Managers tend to rank this technology better. Additionally, because of their profession facility managers know which savings can be realised through the implementation of PM. For tenants and homeowners as well as investors, savings potentials are therefore difficult to comprehend. This may be true for many other technologies, but especially for PM, as potential savings are difficult to grasp.

4.4.6 Less value-adding smart building technologies

Water, Fire Protection, Security of the House, Logistics, and Healthcare were rated the worst among all technologies. This was attributed to the fact that these technologies had poor scores on economic and environmental characteristics. Technologies that improved in these areas were generally preferred.

Logistics technologies, which had good economic attributes, but a lack of environmental attributes was among the least ranked technologies. The analysis of the preferred areas, the preferred attributes and the preferred technologies also reflects today's trends, which above all strives for an improvement in the use of resources. A technology that brings about ecological and economic improvements should be preferred. This is also reflected in the assessment of the interviewed experts.

4.5 Challenges, Concerns and Risks of Smart Building Technology

The adaptation of smart building technologies is often very slow. Upfront investments are significant (King and Perry, 2017). Additionally, new technologies seem to be too complex for homeowners or investors, the added value is not immediately apparent, and they are not able to maintain or operate the new technologies. An increasing digitalisation of buildings increases the dependence on service providers, as repairs become more complex. (Junghans, 2020) In addition, the cycles in which smart building technology is introduced or old devices are replaced are long and mostly devices are only replaced when they break(King and Perry, 2017).

In addition, there are challenges with interoperability between devices and different communication protocols. Therefore, standardised protocols that can be used across devices are steadily introduced (Junghans, 2020). Technological change and digitalisation are certainly bringing value to the building industry. However, by digitalizing processes and enabling data communication, smart grids and smart meters are at risk of cyber-attacks from outside. (King and Perry, 2017)

Less than ten percent of currently installed smart devices are adequately protected against cyber-attacks with IoT security (Minoli et al., 2017). Hence, the protection of data integrity will be crucial for the industry. Current smart grid systems are vulnerable for attacks. (Junghans, 2020) Due to the decentralised nature of smart grid systems, potential attackers have multiple entry points to attack. Reliable and secure tools to prevent cyber-attacks are therefore crucial and need to be developed in coordination with various smart building technology manufacturers (Junghans, 2020).

The majority of residents feel uncomfortable with the installation of web-based home surveillance cameras like Google’s “nest” or Amazon’s “ring” products, that are also installed indoors. (Junghans, 2020). The analysis of the survey revealed that 71% of the respondents said local storage of data was preferable to cloud solutions that are broadly common in smart home products.

Alternative security systems can replace security cameras in various ways. When residents are absent, the smart building function can be set so that networked elements in the house, such as venetian blinds or lighting, behave as if the house were normally occupied, depending on the time of day. (Junghans, 2020)

5 Discussion

The aim of the dissertation was to explore how different stakeholders evaluate different smart building technologies. The analysis revealed that in general, smart building technologies (SBT) were preferred, which produce economic and ecological improvements. Especially, ecological improvements convinced different stakeholders seeing technologies as valuable. However, it could also be observed that for some SBTs in energy production, management and distribution, economic attributes and ecological attributes are interdependent. One example is that the use of photovoltaics reduces the consumption of fossil fuels and makes the household's energy supply less dependent on electricity providers.

Tenants and homeowners prefer technologies that generate comfort improvements over investors and facility managers. Investors and Facility Managers prefer technologies with an economic character over Tenants and homeowners. Thus, the main distinction between stakeholders was in the areas of economic attributes and comfort attributes. However, on average across all stakeholders, the most important attributes are "reduce energy consumption", "reduce cost of operation" and "increase return on investment". The least relevant attributes were "Improves organisational/ personal image", "Increase occupants’ safety" and "Improves life in the community". However, it should be noted that perhaps these attributes were not considered important because they were already automatically associated with other attributes.

For example, organisational or personal image increases with an investment in a resource-efficient technology even if one did not acquire it for the reason of improving the personal image. The top ranked technologies were “Smart Grid/Smart Meter”, “Dashboards”, “Photovoltaics”, “adaptable room climate” and “Predictive Maintenance”.

The expert interviews revealed from the micro-view (Stephan Boettle) as well as from the macro-view (Rüdiger Junghans), that both in larger project planning and in the consumer sector, smart building technologies that lead to cost savings are preferred. In most cases, these technologies - smart meters, photovoltaics and adaptive climate systems - are the ones that also save resources. The decisions in favour of sustainable technologies are also supported by subsidies from the European Union, which has committed itself to support private investments in sustainable technologies with the goal of climate protection. What also stood out was that the analysis of the technologies confirmed what the experts Boettle and Junghans had indicated. Technologies that improve in different areas are preferred. Technologies such as smart grid/smart meter, photovoltaics, dashboards and predictive maintenance systems are representing platform technologies (Junghans, 2020). Other technologies and business models are using these platforms to emerge in the area of smart buildings (Junghans, 2020). For example, smart grid/smart meter is connecting different decentralised energy systems, and dashboards can be used to view security, energy and predictive maintenance systems. The theory of the "pillars of sustainability" mentioned in the literature review, which consists of ecological, economic and social sustainability, also suggests that technologies that address all three pillars are preferred (Yılmaz and Bakış, 2015)

The expectations of the analysis were therefore largely fulfilled. The analysis confirmed that technologies that save on costs and resources are preferred overall and could therefore be used in the buildings of the future.

Furthermore, when talking about sustainable and smart buildings, the entire value chain of the building must be included. A building should not be considered sustainable only because of the technologies it contains. The theory of the three pillars of sustainability also refers to the way buildings are built, who builds the buildings, how the buildings are used, how they can be changed and how they are demolished. Accordingly, care must be taken to use sustainable resources already during construction, as long as the building statics allow it.

The production of cement is currently responsible for 5% of the world's CO2 pollution and the consumption of sand for its production is also considerable (Hasanbeigi et al., 2012). New timber construction methods make it possible to build in a more environmentally friendly way and to recycle raw materials, such as biological building materials, even if the building is demolished. The term "Cradle to Cradle" (C2C) describes the theory of a circular economy in which as little waste as possible is produced during the entire value creation process (Silvestre et al., 2014).

A social pillar refers to the way the building is constructed. Care must be taken to ensure that workers are employed under appropriate conditions. Buildings in the United Arab Emirates and Qatar are under pressure in this respect. Even when new types of buildings are constructed and modern technologies are used, working conditions and human rights are violated here on a large scale (Ewers et al., 2020).

A smart building should also be measured by whether it represents an added social value during construction. A building also creates social added value through flexible usage possibilities. This including providing space for different demographic groups. Urbanisation demands a rethink in many cities and calls for multiple uses of buildings. Smart buildings must therefore meet the needs of different personas, which can change in the course of use.

6 Conclusion

The objective of this dissertation was to investigate how different stakeholders, meaning tenants, homeowners, investors and facility managers, value different smart building technologies.

The results of the dissertation are that the average of the stakeholders prefer technologies that bring economic and ecological improvements and thus save resources and costs. In addition, preference was given to technologies that provide platforms for other technologies. Technologies such as smart grid/smart meter, building dashboards and photovoltaic technology are among them. Finally, expert interviews and findings from current academic literature validate that not only smart technologies make up a smart building, but that the entire value chain of a building must be considered. Hereby, a smart building must be economically, ecologically and socially sustainable.

What does the building of the next century look like? Which smart buildings technologies are preferred by different stakeholders and perceived as having value? IoT-based technology is fundamentally changing the way we interact with buildings, and since people spend about 90% of their time indoors, it makes sense to look at how to make that time more efficient and how smart buildings can serve and even promote sustainable purposes. This analysis has found that at its core, 3 aspects are fundamentally important for the building of the next century. The analysis of which technologies are preferred by different stakeholders showed that technologies must primarily achieve economic and ecological improvements before comfort and social improvements. Furthermore, when selecting the preferred technologies, it became apparent that technology platforms are preferred. Smart grid/smart meters, dashboards and photovoltaic technology are required to integrate more specialised technologies into the building system. The literature revealed that it is not only the use of technologies that makes a building smart, but that the three areas of sustainability should be addressed throughout the life of the building.

It has analysed which technologies are preferred by different stakeholder groups and can be used as a guideline for the integration of smart building technologies. Furthermore, it which aspects of smart building must be fulfilled in order to comply with holistic sustainability.

6.1 Limitations and potential for further research

The ambition of this dissertation was to define the different technology trends that are most promising and should be implemented into smart buildings of the future. It is challenging to determine the exact value of a technology, as there are different definitions of value. Perhaps the value of a technology could be based purely on its economic potential, as it is best expressed in numbers. However, the value of a technology should not be measured in purely economic terms. (Boetle, 2020)

The results of the attribute assessment partly led to contrary results compared to the previous analyses of the domain assessment. In addition, the results in the values differed only by a small margin. Therefore, the unambiguousness of the results can be questioned. Contrary results also occurred, e.g. figure 8 showed that among the best 3 technologies, facility managers (22%) achieved a higher rating in the comfort area than tenants (20%) and homeowners (20%).

Further research in the field of sustainable buildings could have different approaches. Sustainability is concerned with the effective use of resources. Buildings use space, so further research could focus on whether modern buildings could dynamically adapt their spatial layout to the needs of the occupants. Movable walls and smart furniture could help to further improve the efficient use of space. Also, given that work is changin in general, new space concepts will be needed for home offices, especially in urban areas.

Reference List

Ajenikoko, G.A., Olaomi, A.A., 2014. Hardware design of a smart meter. Int J. Eng. Res. Appl. 4, 115–119.

Ansell, B., 2013. The Political Economy of Ownership: Housing Markets and the Welfare State. Working Paper.

Bahadori-Jahromi, A., Rotimi, A., Mylona, A., Godfrey, P., Cook, D., 2017. Impact of Window Films on the Overall Energy Consumption of Existing UK Hotel Buildings. Sustainability 9, 731. https://doi.org/10.3390/su9050731

Balaji, B., Bhattacharya, A., Fierro, G., Gao, J., Gluck, J., Hong, D., Johansen, A., Koh, J., Ploennigs, J., Agarwal, Y., 2018. Brick: Metadata schema for portable smart building applications. Appl. Energy 226, 1273–1292.

Behrends, S., 2016. Recent Developments in Urban Logistics Research – A Review of the Proceedings of the International Conference on City Logistics 2009 – 2013. Transp. Res. Procedia 12, 278–287. https://doi.org/10.1016/j.trpro.2016.02.065

Berardi, U., 2017. A cross-country comparison of the building energy consumptions and their trends. Resour. Conserv. Recycl. 123, 230–241. https://doi.org/10.1016/j.resconrec.2016.03.014

Boetle, Stefan, 2020 - Expert Interview

Buckman, A.H., Mayfield, M., B.M. Beck, S., 2014. What is a Smart Building? Smart Sustain. Built Environ. 3, 92–109. https://doi.org/10.1108/SASBE-01-2014-0003

Buldeo Rai, H., Verlinde, S., Macharis, C., 2019. Unlocking the failed delivery problem? Opportunities and challenges for smart locks from a consumer perspective. Res. Transp. Econ. 100753. https://doi.org/10.1016/j.retrec.2019.100753

Cheng, J.C.P., Chen, W., Chen, K., Wang, Q., 2020. Data-driven predictive maintenance planning framework for MEP components based on BIM and IoT using machine learning algorithms. Autom. Constr. 112, 103087. https://doi.org/10.1016/j.autcon.2020.103087

Cheng, M.-Y., Chiu, K.-C., Hsieh, Y.-M., Yang, I.-T., Chou, J.-S., Wu, Y.-W., 2017. BIM integrated smart monitoring technique for building fire prevention and disaster relief. Autom. Constr. 84, 14–30. https://doi.org/10.1016/j.autcon.2017.08.027

Cook, D.J., Das, S.K., 2007. How smart are our environments? An updated look at the state of the art. Pervasive Mob. Comput. 3, 53–73. https://doi.org/10.1016/j.pmcj.2006.12.001

Crespo Cuaresma, J., Loichinger, E., Vincelette, G.A., 2016. Aging and income convergence in Europe: A survey of the literature and insights from a demographic projection exercise. Econ. Syst. 40, 4–17. https://doi.org/10.1016/j.ecosys.2015.07.003

Deen, M.J., 2015. Information and communications technologies for elderly ubiquitous healthcare in a smart home. Pers. Ubiquitous Comput. 19, 573–599. https://doi.org/10.1007/s00779-015-0856-x

Depuru, S.S.S.R., Wang, L., Devabhaktuni, V., 2011. Smart meters for power grid: Challenges, issues, advantages and status. Renew. Sustain. Energy Rev. 15, 2736–2742. https://doi.org/10.1016/j.rser.2011.02.039

D'Oca, S., Hong, T., Langevin, J., 2018. The human dimensions of energy use in buildings: A review. Renew. Sustain. Energy Rev. 81, 731–742. https://doi.org/10.1016/j.rser.2017.08.019

Electric, S., Hemmerdinger, R., 2010. Predictive Maintenance Strategy for Building Operations: A Better Approach 10.

European Commission, Directorate-General for Energy, 2019. Clean energy for all Europeans.

European Commission. Joint Research Centre., 2018. Cost-benefit analysis of Smart Grid projects: Isernia : costs and benefits of Smart Grid pilot installations and scalability options. Publications Office, LU.

Ewers, M.C., Diop, A., Le, K.T., Bader, L., 2020. Migrant Worker Well-Being and Its Determinants: The Case of Qatar. Soc. Indic. Res. 152, 137–163. https://doi.org/10.1007/s11205-020-02427-3

Fang, X., Misra, S., Xue, G., Yang, D., 2012. Smart Grid — The New and Improved Power Grid: A Survey. IEEE Commun. Surv. Tutor. 14, 944–980. https://doi.org/10.1109/SURV.2011.101911.00087

Geitlinger, Markus, 2020 - Expert Interview

Giuffrè, T., Siniscalchi, S.M., Tesoriere, G., 2012. A Novel Architecture of Parking Management for Smart Cities. Procedia - Soc. Behav. Sci. 53, 16–28. https://doi.org/10.1016/j.sbspro.2012.09.856

Greiner, Marion, 2020 - Expert Interview

Hasanbeigi, A., Price, L., Lin, E., n.d. Emerging Energy-efficiency and CO2 Emission-reduction Technologies for Cement and Concrete Production 58.

Junghans, Rüdiger, 2020 - Expert Inverview

Jurasz, J., Campana, P.E., 2019. The potential of photovoltaic systems to reduce energy costs for office buildings in time-dependent and peak-load-dependent tariffs. Sustain. Cities Soc. 44, 871–879. https://doi.org/10.1016/j.scs.2018.10.048

King, J., Perry, C., 2017. Smart buildings: Using smart technology to save energy in existing buildings. Amercian Council for an Energy-Efficient Economy.

Klein, C., Kaefer, G., 2008. From Smart Homes to Smart Cities: Opportunities and Challenges from an Industrial Perspective, in: Balandin, S., Moltchanov, D., Koucheryavy, Y. (Eds.), Next Generation Teletraffic and Wired/Wireless Advanced Networking. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 260–260.

Klepeis, N.E., Nelson, W.C., Ott, W.R., Robinson, J.P., Tsang, A.M., Switzer, P., Behar, J.V., Hern, S.C., Engelmann, W.H., 2001. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. J. Expo. Sci. Environ. Epidemiol. 11, 231–252. https://doi.org/10.1038/sj.jea.7500165

Lawrence, T.M., Boudreau, M.-C., Helsen, L., Henze, G., Mohammadpour, J., Noonan, D., Patteeuw, D., Pless, S., Watson, R.T., 2016. Ten questions concerning integrating smart buildings into the smart grid. Build. Environ. 108, 273–283. https://doi.org/10.1016/j.buildenv.2016.08.022

Lynggaard, P., Skouby, K., 2016. Complex IoT Systems as Enablers for Smart Homes in a Smart City Vision. Sensors 16, 1840. https://doi.org/10.3390/s16111840

Mahmud, K., Hossain, M.J., Town, G.E., 2018. Peak-Load Reduction by Coordinated Response of Photovoltaics, Battery Storage, and Electric Vehicles. IEEE Access 6, 29353–29365. https://doi.org/10.1109/ACCESS.2018.2837144

Marmo, R., Polverino, F., Nicolella, M., Tibaut, A., 2020. Building performance and maintenance information model based on IFC schema. Autom. Constr. 118, 103275. https://doi.org/10.1016/j.autcon.2020.103275

Matt, C., Hess, T., Benlian, A., 2015. Digital Transformation Strategies. Bus. Inf. Syst. Eng. 57, 339–343. https://doi.org/10.1007/s12599-015-0401-5

Mcglinn, K., Gibney, A., Lewis, D., n.d. SimCon: A Tool to Support Rapid Evaluation of Smart Building Application Design using Context Simulation and Virtual Reality.

McMichael, A.J., 2013. Globalization, Climate Change, and Human Health. N. Engl. J. Med. 368, 1335–1343. https://doi.org/10.1056/NEJMra1109341

Menassa, C.C., Baer, B., 2014. A framework to assess the role of stakeholders in sustainable building retrofit decisions. Sustain. Cities Soc. 10, 207–221. https://doi.org/10.1016/j.scs.2013.09.002

Minoli, D., Sohraby, K., Occhiogrosso, B., 2017. IoT Considerations, Requirements, and Architectures for Smart Buildings—Energy Optimization and Next-Generation Building Management Systems. IEEE Internet Things J. 4, 269–283. https://doi.org/10.1109/JIOT.2017.2647881

Nuffel, L.V., Rademaekers, K., Yearwood, J., Graichen, V., n.d. European Energy Industry Investments 180.

Patel, C., Chugan, P.K., 2013. Measuring Awareness and Preferences of Real Estate Developers for Green Buildings over Conventional Buildings (SSRN Scholarly Paper No. ID 2208409). Social Science Research Network, Rochester, NY.

Purvis, B., Mao, Y., Robinson, D., 2019. Three pillars of sustainability: in search of conceptual origins. Sustain. Sci. 14, 681–695. https://doi.org/10.1007/s11625-018-0627-5

Qolomany, B., Al-Fuqaha, A., Gupta, A., Benhaddou, D., Alwajidi, S., Qadir, J., Fong, A.C., 2019. Leveraging Machine Learning and Big Data for Smart Buildings: A Comprehensive Survey. IEEE Access 7, 90316–90356. https://doi.org/10.1109/ACCESS.2019.2926642

Rathore, M.M., Ahmad, A., Paul, A., Rho, S., 2016. Urban planning and building smart cities based on the Internet of Things using Big Data analytics. Comput. Netw. 101, 63–80. https://doi.org/10.1016/j.comnet.2015.12.023

Rauf, A., Crawford, R.H., 2015. Building service life and its effect on the life cycle embodied energy of buildings. Energy 79, 140–148. https://doi.org/10.1016/j.energy.2014.10.093

Rawal, A.G., 2016. Costs, Savings, and ROI for Smart Building Implementation [WWW Document]. IoT@Intel. URL https://blogs.intel.com/iot/2016/06/20/costs-savings-roi-smart-building-implementation/ (accessed 3.26.21).

Razavi, R., Gharipour, A., Fleury, M., Akpan, I.J., 2019. Occupancy detection of residential buildings using smart meter data: A large-scale study. Energy Build. 183, 195–208. https://doi.org/10.1016/j.enbuild.2018.11.025

Salem, F., 2016. A Smart City for Public Value: Digital Transformation Through Agile Governance-The Case of'Smart Dubai'. World Gov. Summit Publ. Forthcom.

Schandl, H., Hatfield-Dodds, S., Wiedmann, T., Geschke, A., Cai, Y., West, J., Newth, D., Baynes, T., Lenzen, M., Owen, A., 2016. Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions. J. Clean. Prod. 132, 45–56. https://doi.org/10.1016/j.jclepro.2015.06.100

Schieweck, A., Uhde, E., Salthammer, T., Salthammer, L.C., Morawska, L., Mazaheri, M., Kumar, P., 2018. Smart homes and the control of indoor air quality. Renew. Sustain. Energy Rev. 94, 705–718. https://doi.org/10.1016/j.rser.2018.05.057

Sechilariu, M., Wang, B., Locment, F., 2013. Building Integrated Photovoltaic System With Energy Storage and Smart Grid Communication. IEEE Trans. Ind. Electron. 60, 1607–1618. https://doi.org/10.1109/TIE.2012.2222852

Silvestre, J.D., de Brito, J., Pinheiro, M.D., 2014. Environmental impacts and benefits of the end-of-life of building materials – calculation rules, results and contribution to a “cradle to cradle” life cycle. J. Clean. Prod. 66, 37–45. https://doi.org/10.1016/j.jclepro.2013.10.028

Snoonian, D., 2003. Smart buildings. IEEE Spectr. 40, 18–23.

Suzuki, L.R., 2017. Smart Cities IoT: Enablers and Technology Road Map, in: Rassia, S.Th., Pardalos, P.M. (Eds.), Smart City Networks, Springer Optimization and Its Applications. Springer International Publishing, Cham, pp. 167–190. https://doi.org/10.1007/978-3-319-61313-0_10

Thomas, D., Deblecker, O., Ioakimidis, C.S., 2018. Optimal operation of an energy management system for a grid-connected smart building considering photovoltaics’ uncertainty and stochastic electric vehicles’ driving schedule. Appl. Energy 210, 1188–1206. https://doi.org/10.1016/j.apenergy.2017.07.035

Tilleman, R., n.d. Cover illustration: PLP Architecture 22.

Tseloni, A., Farrell, G., Thompson, R., Evans, E., Tilley, N., 2017. Domestic burglary drop and the security hypothesis. Crime Sci. 6, 3. https://doi.org/10.1186/s40163-017-0064-2

Wang, Z., Wang, L., Dounis, A.I., Yang, R., 2012. Integration of plug-in hybrid electric vehicles into energy and comfort management for smart building. Energy Build. 47, 260–266. https://doi.org/10.1016/j.enbuild.2011.11.048

Watson, A., 2011. Digital buildings – Challenges and opportunities. Adv. Eng. Inform. 25, 573–581. https://doi.org/10.1016/j.aei.2011.07.003

Wu, Y., Maravelias, C.T., Wenzel, M.J., ElBsat, M.N., Turney, R.T., 2021. Predictive maintenance scheduling optimization of building heating, ventilation, and air conditioning systems. Energy Build. 231, 110487. https://doi.org/10.1016/j.enbuild.2020.110487

Yassine, A., Singh, S., Alamri, A., 2017. Mining Human Activity Patterns From Smart Home Big Data for Health Care Applications. IEEE Access 5, 13131–13141. https://doi.org/10.1109/ACCESS.2017.2719921

Yılmaz, M., Bakış, A., 2015. Sustainability in Construction Sector. Procedia - Soc. Behav. Sci., World Conference on Technology, Innovation and Entrepreneurship 195, 2253–2262. https://doi.org/10.1016/j.sbspro.2015.06.312

Zhang, D., Shah, N., Papageorgiou, L.G., 2013. Efficient energy consumption and operation management in a smart building with microgrid. Energy Convers. Manag. 74, 209–222. https://doi.org/10.1016/j.enconman.2013.04.038

Zhang, Y., Chen, W., Gao, W., 2017. A survey on the development status and challenges of smart grids in main driver countries. Renew. Sustain. Energy Rev. 79, 137–147. https://doi.org/10.1016/j.rser.2017.05.032

Appendices

Appendix 1: Further details on attribute evaluation and technology ranking

Figure 14: Preferred Attributes in Detail

Final Ranking	Average Ranking (A.R)	Technology	Ranking Tenants	(A.R.) Tenants	Ranking Homeowners	(A.R) Homeowners	Ranking Investors	(A.R) Investors	Ranking Facility Managers	(A.R) Facility Managers
1	3,0	Smart Grid and Smart Meter	1	3,9	3	5,0	1	1,5	1	1,6
2	4,3	Dashboards	7	5,6	5	5,0	2	3,3	3	3,4
3	5,1	Photovoltaic	3	4,9	2	4,0	3	4,8	5	6,6
4	5,3	Adaptable Roomclimate	2	4,1	1	3,6	4	5,3	10	8,2
5	5,5	Predictive Maintenance	8	7,0	7	6,0	6	6,3	2	2,6
6	5,9	Battery Storage	4	4,9	8	6,8	7	6,8	4	5,0
7	6,0	Heat Pumps	6	5,4	3	4,4	5	6,0	8	8,0
8	6,4	Healthcare	5	5,3	6	5,4	8	7,3	7	7,6
9	7,7	Logistics	10	8,4	9	8,0	9	7,8	6	6,6
10	8,2	Security of the House	9	7,9	10	8,4	10	8,3	11	8,4
11	8,8	Water, Fire Protection	11	8,7	11	9,4	11	9,0	9	8,0

Table 6: Detailed Calcualtion of Ranking

Appendix 2: Assessment of the lower ranked Smart Building Technologies

Battery Storage

The technology battery storage was rated at place 6. The battery storage unit is used to store the solar power that could not be used directly in the household. Without the storage unit, the generated solar power must be directly consumed or fed into the public grid. Direct use is only partially possible since PV produces most of the electricity during the day. Demand is typically highest in the morning and towards evening. However, the feed-in tariff for solar power is significantly lower than the purchase price. Therefore, it does not make sense to feed electricity into the grid during the day and draw it from the grid in the evening. A storage solution can capture the generated power and safe it for later use therefore increasing the efficiency photovoltaic system. A car battery can perform a similar function here if it is not moved during the day, as is the case with commuters, for example. (Mahmud et al., 2018)

The efficiency of solar systems increases considerably in combination with a battery storage system. The driver for battery storage is the contribution to the energy transition, the protection against electricity prices and the independence from energy suppliers. Due to falling production costs, battery prices will continue to fall and lead to further dissemination. (Sechilariu et al., 2013)

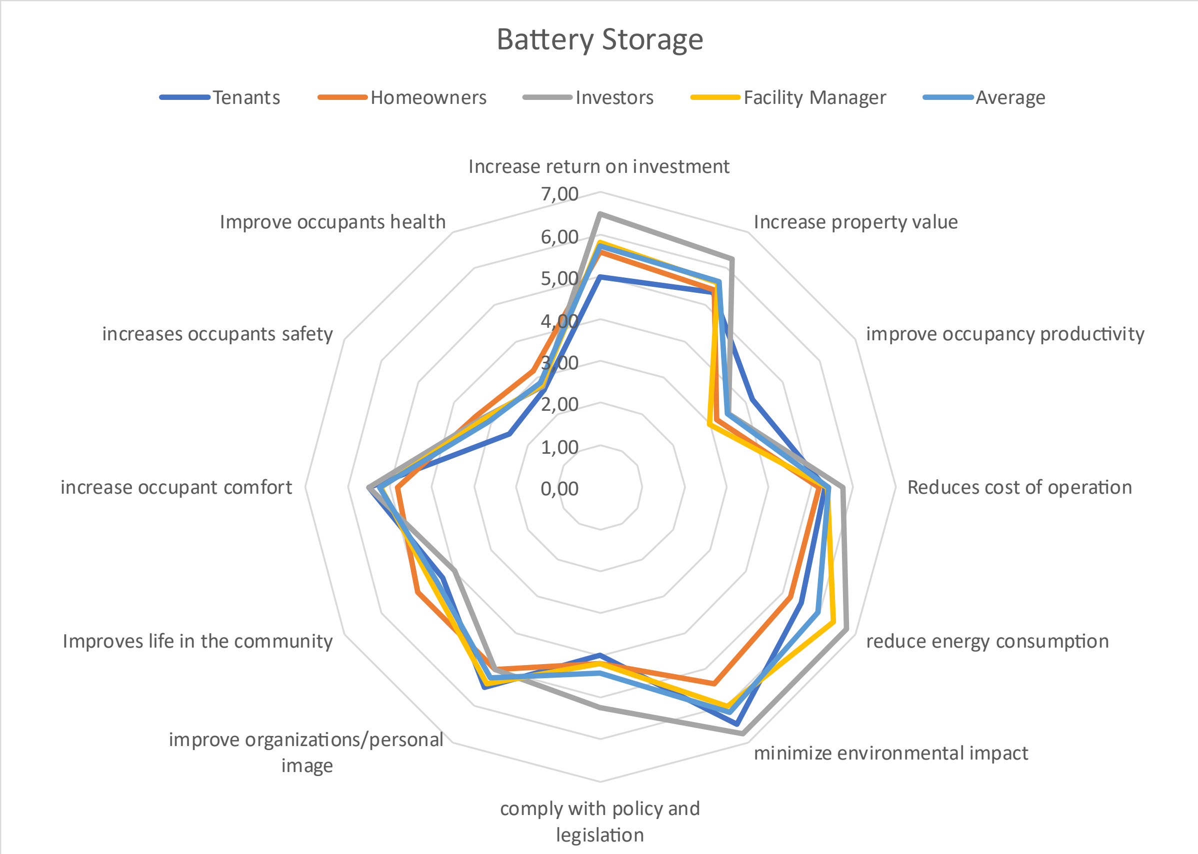

Figure 15: Evaluation of Battery Storage [0-7 – with 7 applying the most]

Technology	Average	Tenants	Homeowners	Investors	Facility Managers
Battery Storage	6	4	8	7	4

Table 7: Ranking Battery Storage

Tenants and Faciltiy Managers rated Battery Storage as more valueable compared to Investors and Homeowners. This assessment could be based on the fact that tenants have to pay less electricity costs due to the reduction in electricity consumption and facility managers can manage a wider area by adding technology to the building. On the other hand, homeowners and investors have to incur investment costs and pay for maintenance. Of course, investment costs can be passed on to the tenant, but in many regions with rent caps this is restricted by policy.

Heat Pumps

The technology heat pumps was rated at place 7. A solution for the production of heat or cold (Air-conditioning) without the use of fossil energy are "Power-to-Heat" or "Power-to-Cold" solutions like the heat-pump system. Here, electricity is used to transfer heat from a heat-source (ambient air, geothermal heat) to the heat sink, here the interior area of the smart building. The devices are working with a mechanism similar to refrigerators. The exchange of ambient with used air from the building provides the building with a fresh air supply. Geothermal solutions can also be used for cooling during summer. However, for the heat-pump system to create heat electricity is needed. This electricity can either be taken from alternative energy sources within the local grid or form the main grid. Fossil resources that are commonly used for heat generation like gas or oil can be are saved.

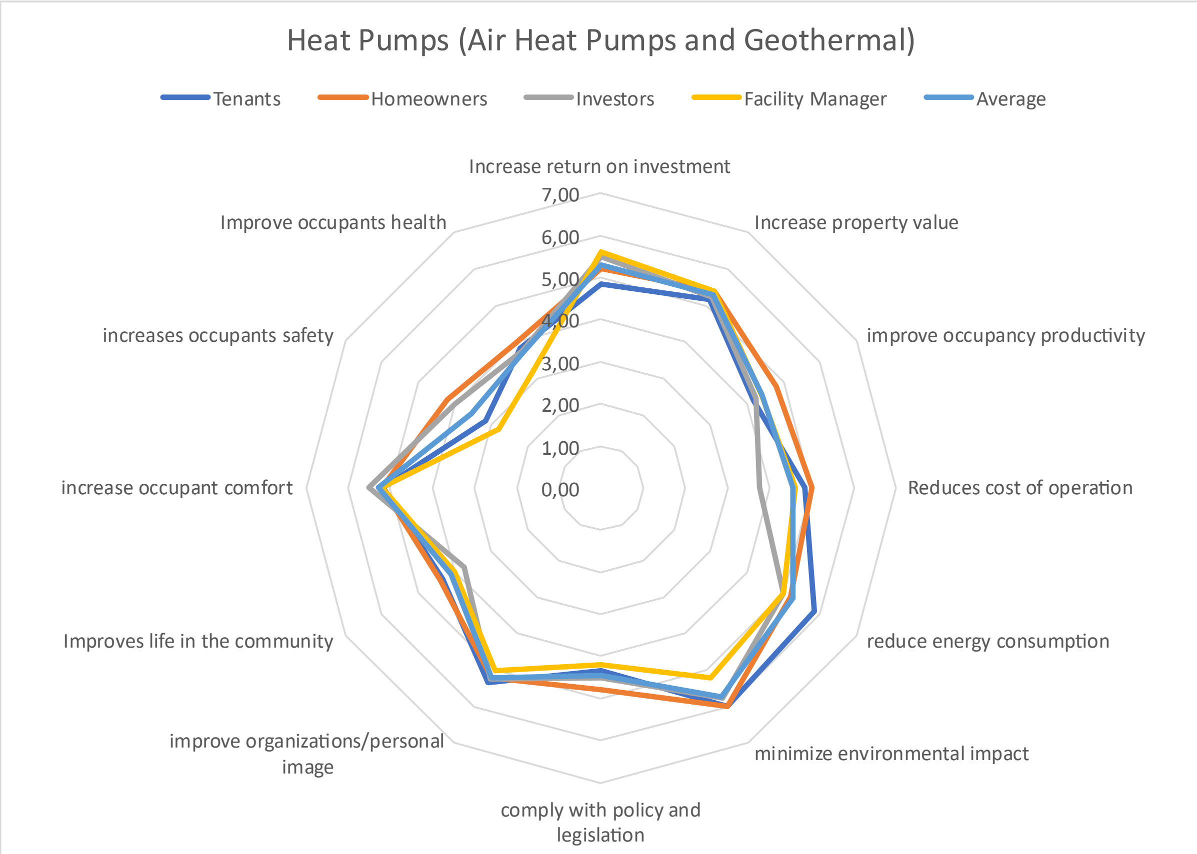

Figure 16: Evaluation of Heat Pumps [0-7 – with 7 applying the most]

Ranking:

Technology	Average	Tenants	Homeowners	Investors	Facility Managers
Heat Pumps	7	6	3	5	8

Table 8: Ranking Heat Pumps

Healthcare Services

The technology healthcare services was rated at place 8. The older generation in particular can be monitored and supplied in a targeted manner using smart devices. Here applications are used which represent an interface between smart home and IOT wearables. The increased use of these applications could mean a considerable relief for the health care systems, which are currently under great strain or overburdened by the demographic change. External supply can reduce personnel costs and space occupation in nursing homes and hospitals. The costs saved can be used more effectively in the health system. (Deen, 2015) Smart Buildings can supervise and help elderly people with a need of care. Sensors detect unusual behaviour, e.g. if the person of has fallen on the ground and is in the need for help, thereby informing nursing services or ambulance. (Lynggaard and Skouby, 2016) Additionally, it is possible for Smart Meters to create activity patterns of residents, supervising general routines and the usage of energy and water. The mapping of routines, which consequently develop into habits allows the SM to recognise a change in behaviour. Healthcare applications utilize this data and possibly detect a health problem and give personal recommendations or an emergency and consult assistance. As services like these develop it will reduce the burden of healthcare systems and will elevate the living quality of people with self-limiting conditions or disabilities. (Yassine et al., 2017)

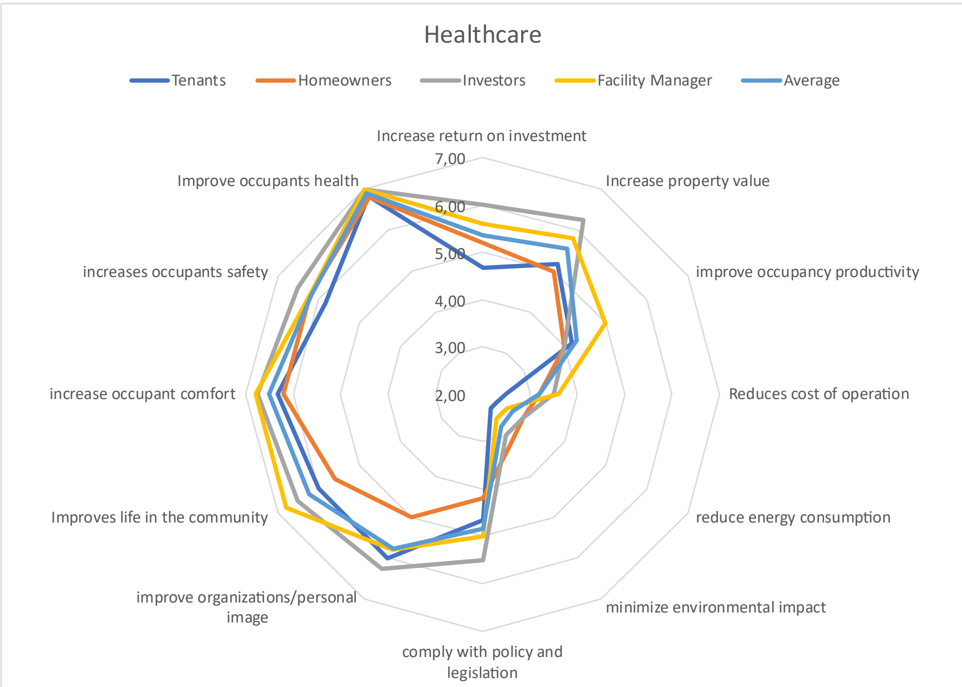

Figure 17: Evaluation of Healthcare [0-7 – with 7 applying the most]

Technologie	Average	Tenants	Homeowners	Investors	Facility Managers
Healthcare	8	5	6	8	7

Table 9: Ranking Healthcare

Logistics (Mobility and other business Services)

The technology logistics services was rated at place 9. Smart buildings can offer technologies that support modern logistics. The density in Cities is rising. Smart buildings can offer parking space more effectively using digital technologies. Smart Sensors in the parking areas can communicate free parking spaces dynamically. A parking management system can offer parking spots to residents and to commuters, simultaneously. Smart Sensors in the Parking area and the smart building management systems can communicate with third party apps on the basis of behavioural data of the parking spot owner. (Giuffrè et al., 2012) This will eventually lead to an improved parking situation on the Roadside. Specially tendered parking spaces for logistic vehicles can thus be introduced on more justified grounds and will eventually reduce double parking, which in the past has led to increased congestion and accidents (Giuffrè et al., 2012). With an enhanced parking situation in cities, the conditions for online and food delivery services (e.g Amazon Prime, Uber eats) are improving (Behrends, 2016). Online Shopping, grocery services and other digital logistic services get increasingly popular. With up to 60 % failed home deliveries the current situation is in need of improvement. Smart buildings offer unattended acceptance of parcels and groceries with smart lock technologies. (Buldeo Rai et al., 2019). Electric vehicles parked in smart buildings, are charged and connected to the smart grid. Car batteries of electric vehicles help to support the load management of the grid. This leads to cost savings and will enhance the reliability of the grid (Mahmud et al., 2018). These and other related services are automatizing processes, increasing living comforts and can go hand in hand with sustainability goals.

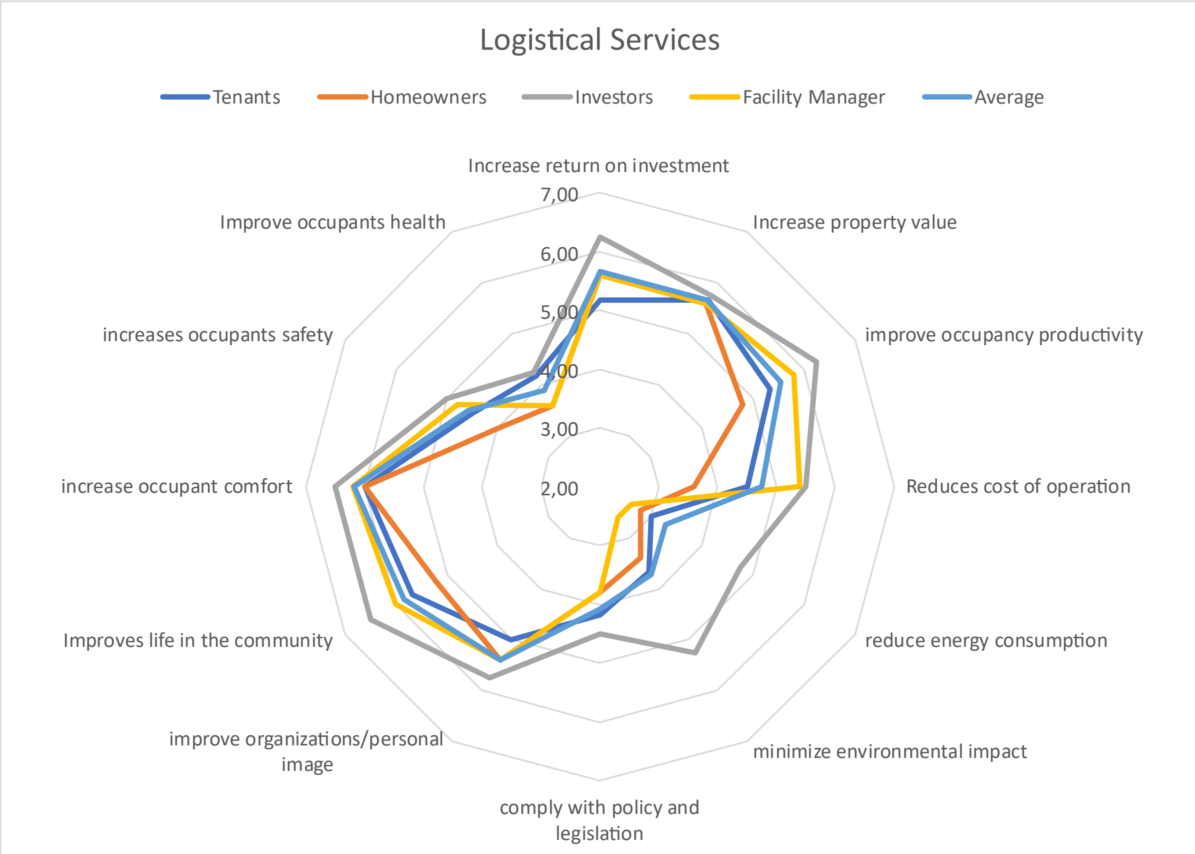

Figure 18: Evaluation of Logistical Services [0-7 – with 7 applying the most]

Technology	Average	Tenants	Homeowners	Investors	Facility Managers
Logistics	9	10	9	9	6

Table 10:Ranking Logistics

Security of the House

The technology security services was rated at place 10. Smart Building Technology can support the security of properties by installing gateway systems that can be supported by cameras, Smartphone, Smartwatch and other ICT devices that can grant access authorisations. IoT based access systems furthermore can be controlled remotely, by tenants. Postman, friends and family members can be granted access to the building via mobile. (Minoli et al., 2017) Domestic burglaries are still present in criminal statistics (Tseloni et al., 2017). Smart building technology could prevent domestic burglaries, not only by introducing surveillance cameras, but also with the help other smart devices within the network to improve security (Rathore et al., 2016).) If irregularities are detected, the alarm system can contact the resident with a call on his Phone. In case of a burglary, the alarm can play loud music, flicker the lights or the shades. (Jungshans, 2020)

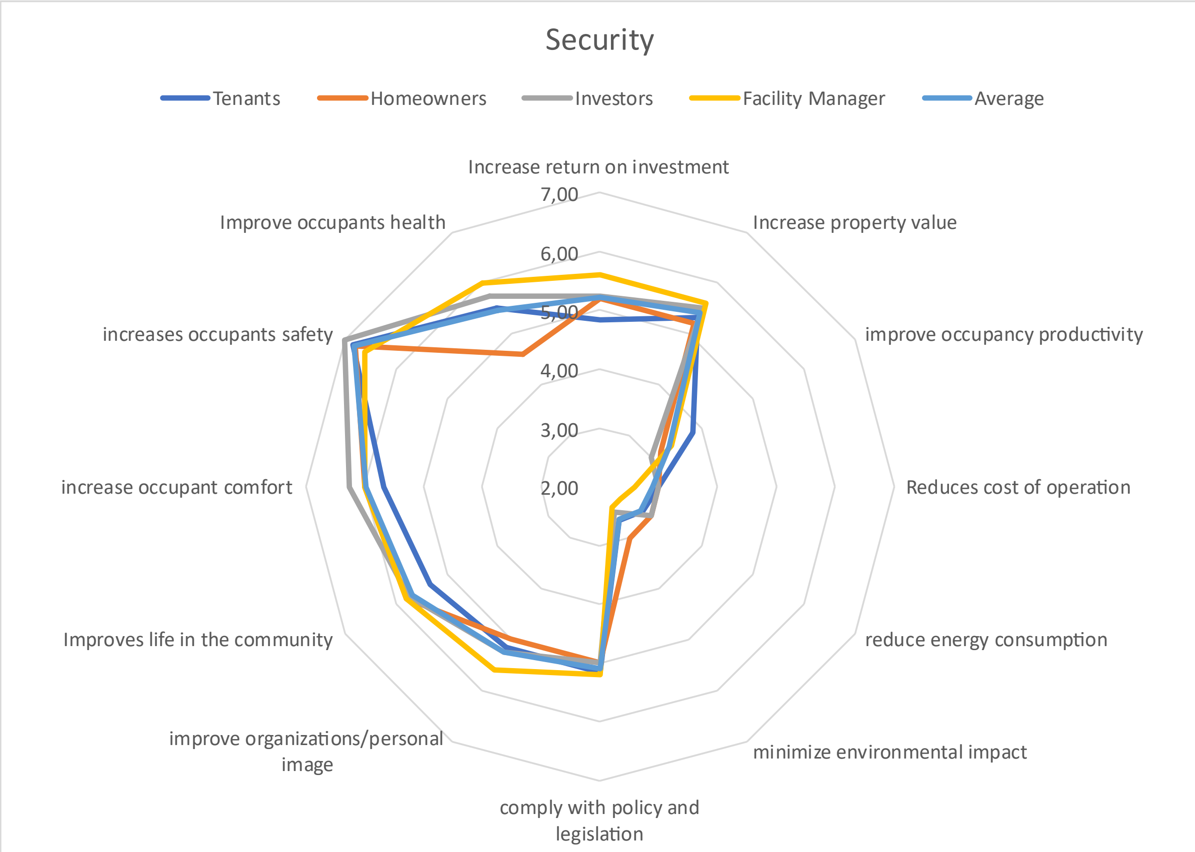

Figure 19: Evaluation of Security Technologies [0-7 – with 7 applying the most]

Technology	Average	Tenants	Homeowners	Investors	Facility Managers
Security of the House	10	9	10	10	11

Table 11: Ranking Security

Water and Fire Protection

The technology water and fire protection was rated at place 11. Water leakage sensors can detect water that is coming from broken pipes, the floor heating or household appliances and warn residents or maintenance services to prevent severe damages to the building. Smoke and fire detectors warn residents to prevent fire development early and inform rescue services. Rescue services should be put on special alert if buildings are equipped with solar panels or battery storage systems. Solar panels and lithium-ion batteries require advanced techniques to prevent the release of toxic substances.

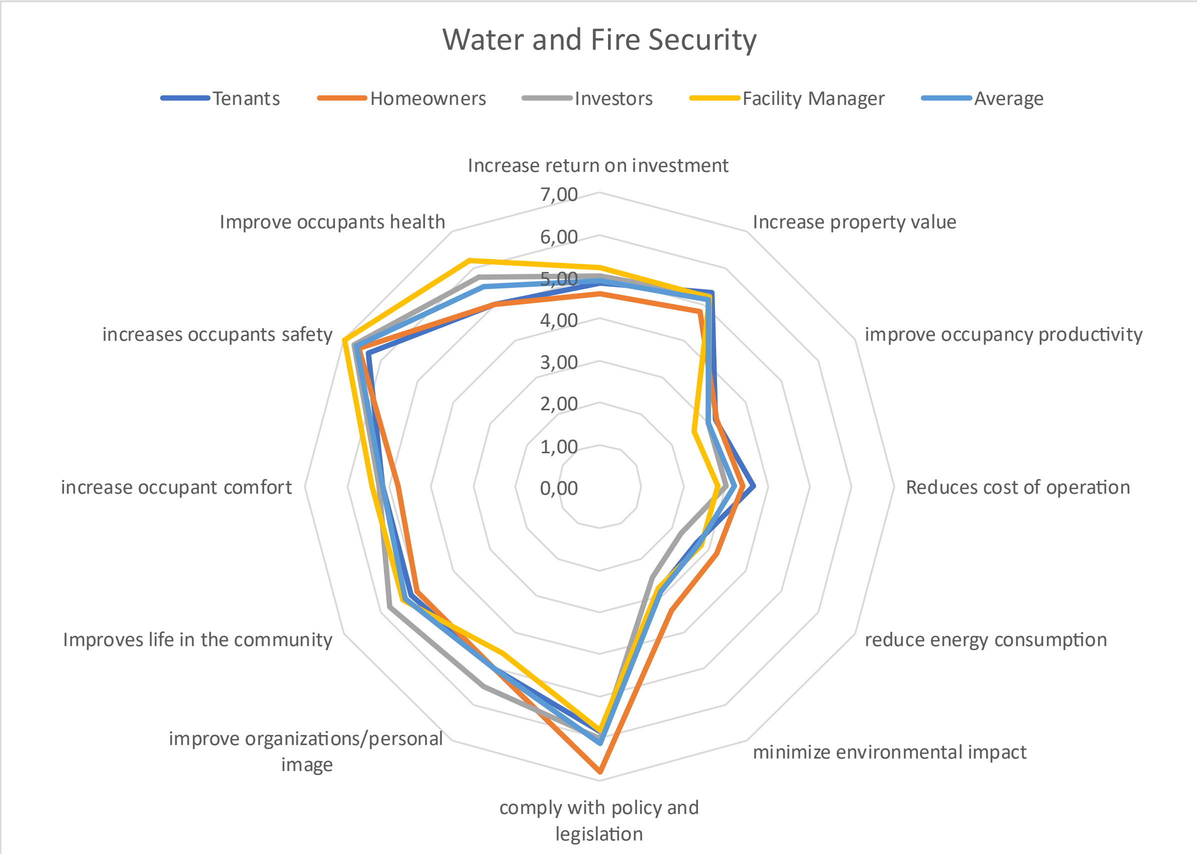

Figure 20: Evaluation of Water and Fire Security [0-7 – with 7 applying the most]

Ranking:

Technology	Average	Tenants	Homeowners	Investors	Facility Managers
Water, Fire Protection	11	11	11	11	9

Table 12: Ranking Water, Fire Protection

Appendix 3: Interview Guidelines and transcribed Interviews

General

Briefly describe yourself, your role in the industry and your occupation.

Digital Buildings

How important has become smart building technology and building automation and for the digitalisation of the building?

Environmental Issues

Would you say buildings have a great steak in the global energy consumption?

Does smart building technology has a great steak in making buildings more efficient?

How Important are smart building technologies to improve the efficiency of buildings?

Stakeholder Value

Which are the most common used smart building technologies (tenants, office buildings)?

Which technologies are most useful for the user?

Which smart building technologies are overrated?

Challenges & Outlook

How does the building look like in 10 to 20 years?

What challenges will the real estate industry face in the next 20 years?

Individual Interview questions

Stefan Boetle

How will the way we live in our houses change, especially in urban space?

Markus Geitlinger

Does a smart building also pay off because of a higher resale value?

Rüdiger Junghans

Loxone products take off exemplary 50k handles. What costs does building automation save in the different application areas?

In times of "Nest" and "Amazon Alexa" - How is Loxone positioned against American technology companies that are pushing into the market, what is the USP of Loxone?

Especially in urban areas, buildings are increasingly developing into multifunctional objects (mixed use - living, working, living, local supply, doctor) - Does Loxone see potential here and has a corresponding business model for this scenario?

API's enable third-party collaboration via the Loxone technology platform - How important is openness/flexibility in the smart building area?

Marion Greiner

How important are smart technologies for your future home. what expectations do you have?

Interview Marcus Geitlinger

Marcus Geitlinger is Co - CEO of Green Architecture Bottighofen GmbH. Green Architecture plans and realizes environmentally friendly buildings with smart building technology. He works with smart building concepts on a daily basis and therefore has a good insight into trends around smart buildings. (Date/Time: (24.4.2020; 44:43 min))

Digital Buildings

The digitalization of buildings is an advancing process. Buildings begin to communicate with their inhabitants and users. This is intelligent Buildings become truly intelligent by automatically adapting to their inhabitants and their usage behaviour. This is what makes a true smart building. The communication between the different units that can be installed in a building, e.g. energy systems, ventilation and shading, makes it possible to increase the comfort of the occupants and drastically reduce energy consumption. Smart Buildings technologies and the automation of "physical movements" are the pillars of the digitalization of buildings.

Environmental Issues

Buildings definitely have an enormous share in global energy consumption. Especially in countries with poor building fabric. In Germany we underestimate the savings potential of renewable energy sources enormously. However, a zero-energy building not only has renewable energy sources, such as photovoltaics or air heat pumps, but also becomes a low-energy building through the interaction of efficient energy generation and storage. In addition, the building fabric is crucial. With insufficient insulation, even the best systems can only achieve low energy savings.

Stakeholder Value

Residents: The most important technologies, which are most in demand, are those which either improve the comfort of the residents in the long term or which are particularly cost-saving. Accordingly, it can be said that renewable energy systems are in great demand. These have an enormous savings potential and can, if combined with intelligent ventilation, improve the living comfort.

Office: For office buildings those technologies are interesting which improve the working conditions of the employees. Also, here the indoor climate is most important. Other systems that can be used to control the parking management or measure the flow of people are useful but do not improve the working conditions. Important are then again systems around predictive maintenance, which monitor the air conditioning systems or elevator systems and prevent a total failure.

Residents & Office: Overall there is a demand for technologies that improve security, i.e. intelligent door systems and sensors that detect open doors or locks. Important to mention is the demand for systems that have no explicit connection to the cloud storage or that do not evaluate data collected on external servers. We see here a clear countermovement to systems like Amazon Alexa or Google. There is of course less demand for special solutions which address very customer-specific problems, are not really practical or do not achieve cost reductions.

Technologies:

Photovoltaics, Air ventilation, Smart Shading, Smart Meter, Battery Storage, quality building fabric, Heat Pumps, Healthcare

Challenges & Outlook

The way we live, work and live together will change, that is clear. This is mainly promoted by digitalization. Buildings and people are already communicating with each other. In the near future, they will automatically adapt to our behaviour, so we will hardly ever give orders anymore. The environment and the protection of resources remain one of the most important areas in which digital technology can improve buildings. Intelligent energy generation, energy distribution and storage are essential here. The consumption of resources in the construction of buildings and the recyclability of buildings will become a central issue. A particular impact can be expected in this respect. Production technologies which allow wood constructions, buildings which can be converted, or modular buildings will make a difference and save resources.

How will the way we live in our houses change, especially in urban space?

There will be an increase in the mixed use of buildings in urban areas. Work space and living space will merge, which is naturally intensified by the current situation with the corona virus. Home office will become the rule. In urban areas, one will increasingly see living, working and local supply combined in one building. An efficient use of space is made possible by digital technologies, which will also change mobility in the inner cities.

Interview Stefan Boettle

Stefan Boettle is CEO of CIP Generalplaner Stuttgart GmbH. He has over 40 years' experience in Architecture, Planning and Construction Methods. He was chosen to provide insights from the perspective of an architect and general planner. With CIP he planned and build hotels, office buildings and residential complexes in Europe with a focus on DACH. (Date/Time: (13.6.2020; 34:43 min))

Digital Buildings

Resources can be saved through intelligent energy systems and intelligent ventilation systems. In addition, sensors are used to regulate the room climate in such a way that ideal working conditions are created. Furthermore, different usage data can be analyzed. We work together with manufacturers who, for example, analyze the use of space with Dashboards. Offices can determine which rooms they use frequently and which not. Office space can be adapted to achieve an optimal degree of utilization. This leads to cost savings, which is the general goal of smart building technologies. Smart building technologies digitize buildings fundamentally and lead to an optimal use of space, energy and manpower.

Environmental Issues

Around half of the global emissions can be attributed to buildings. Although smart building technologies are initially being used in the western world, they have the great potential to increase efficiency worldwide. Take the example from the hotel business. The targeted switching off of heating in unused hotel rooms could save up to 15% of energy costs without changing other conditions. However, the mere retrofitting of smart building technologies generates only comparatively small increases in efficiency. Much more important is the efficiency standard of the building fabric itself. According to this, smart technologies enable resources to be saved. But high building efficiency classes can only be achieved in combination with modern building fabric. Additionally, the construction method and the ability to recycle the building and its fabric play an important role in the overall efficiency record of the building.

Stakeholder Value

Smart building technologies are used in different areas and generate different added value depending on the area of application. A pleasant indoor climate through an advanced air conditioning system is increasing the well-being in the private home. But an increase in productivity in the office through an optimal indoor climate of only 10 percent exceeds the cost savings through optimal energy or space utilization. Therefore, technologies that are capable of increasing productivity are extremely important for office tenants. Smart building technologies like parking management systems, in-building guidance systems or screens monitoring room occupants are increasing productivity of the workforce noticeably. A adequate work environment is increasing productivity and creativity

Technologies:

Parking Management; Air Conditioning, Data Monitoring (Dashboards), good building fabric, Technologies that safe resources, Smart Meter

Challenges & Outlook

Buildings in the future will be built with a high extend of flexibility. Residential, office and supply buildings will be integrated into one building. Buildings will be planned and built economically friendly and modular, meaning with prefabricated elements. Through technology smart buildings will further develop from smart buildings to cognitive buildings, that adapt to the to the needs of the occupants without the need of intervening. The biggest challenge is to protect these buildings from being attacked by cyber criminals. Buildings are part of are critical infrastructure, especially regarding hospitals, banking towers or big corporations. To ensure the error-free functioning of the future infrastructure of smart buildings within a smart city it is crucial to develop strong security systems.

Is there are defined role for smart buildings within a smart city?

Smart buildings will assume a special task in the smart city. By linking the individual buildings with each other, it will be possible to exchange information. Micro-grids enable the generation and storage of energy in the network of the individual buildings. Depending on the type of building, there are different requirements for the building at different times. Buildings will cooperate with each other to exchange resources

Interview Rüdiger Junghans

Rüdiger Junghans is Head of Business Development of Loxone Switzerland. Loxone (Loxone Electronics GmbH) is a leading Austrian Smart Home automation company and is providing various smart home technologies in the areas of energy saving, lightning, shadowing and security as well as smart home server. Rüdiger is an expert in smart building technology and has been involved in the development of smart home systems over the years and was able to analyse different technology trends in the context of loxone's business development. Date/Time: (13.6.2020; 53:25 min)

Digital Buildings

Incredibly important. With the energy revolution, climate change and e-mobility in particular, it is impossible to imagine life without this topic. This creates a need to automate things and load management requires the control of energy.

Environmental Issues

Buildings have a great steak in energy consumption. smart building technology is a new field with which green and environmentally friendly buildings can be constructed. However, it is also important that the building fabric is correct. A poorly insulated building cannot become a low-energy house with the best systems. With Loxone, we first recommend the installation of smart building technologies, which are particularly cost-effective and save a lot of energy. Through effective shading you can efficiently influence the indoor climate, whether in residential or office buildings. Energy optimization through heating systems is supported by Loxone through AI systems. Here the AI learns how different rooms are designed and used through inertial measurement. This allows the system to guess what temperature is desired at what time and to control heating systems accordingly, which results in a gain in efficiency.

Stakeholder value

Basically, everything that results in energy saving and is reflected in a cost saving is in great demand. Shading is enormously important for the energy management of Loxxone. In addition, automatic lighting is in great demand, which greatly improves the comfort of living. Here too, AI learns and automatically adjusts the lighting mood. Predictive maintenance topics are particularly relevant in the commercial sector. Here it is important that the daily work routine is not disturbed and can function. Heating systems can use Sensors to determine whether a system requires maintenance or whether there is damage that leads to higher power consumption. In the past, we trusted a data processing centre in Switzerland and successfully installed a control system with which it was possible to carry out maintenance work remotely.

Moreover, ventilation systems are extremely relevant for commercial properties, especially for meeting rooms. Sensors, which measure the humidity of air and other components, can control ventilation systems and provide better ventilation of the room. Because many systems are pre-installed as standard with Loxone, various security systems are also integrated. These include water damage sensors, window sensors, smoke sensors and can make safety announcements via built-in loudspeakers. The future trend is of course analysis of information from buildings via Sensors although it is already feasible. The gained information could then be used for different services for example cleaning services. However, at the moment no one is prepared to pay for a higher-level control system. Therefore, this technology cannot yet be implemented on a large scale. In summary, there are three areas. Everything that has to do with comfort is in demand. Everything that has to do with safety and everything that has to do with energy is in demand. Also, predictive approaches play a big role, which are able to read weather data and adapt energy systems accordingly.

Challenges & Outlook

The goal of smart building technology will be to create a system in which tenants hardly interact actively with the building, but rather that the building anticipates the needs of tenants. The goal of Loxone is to enable a building to independently control complicated settings of the building in the background, which cannot or do not want to be operated manually by the resident.

Loxone products take off exemplary 50k handles. What costs does building automation save in the different application areas?

This is not easy to answer across the board. It depends on the heating system. If I have an extremely sluggish heating system I can hardly optimize it. Here I only have a saving of 15%. But we have already implemented projects with our technology where we could achieve a saving of 50%. We have achieved this with a zone based system with infrared panels. So it is also about saving costs in construction by using the right kind of sustainable technologies. You have to match energy systems and smart builidng technologies to the structure of the building.

In times of "Nest" and "Amazon Alexa" - How is Loxone positioned against American technology companies that are pushing into the market, what is the USP of Loxone?

Alexa and Google Nest use a different way of communication. They use voice control. This makes sense for handicapped accessible living, in old people's homes or even for blind people. Loxone however tries to create an intelligent building that thinks independently for the residents and adjusts light, temperature and other things to suit them, without direct interaction. The resident can intervene at any time and adjust the system. Loxone also differs from Alexa in that Alexa is a cloud solution. Loxone is exactly not, it is a local solution. Our customers prefer exactly this feature. The control over your data. There is no evaluation from outside. Alexa and Co are a consumer solution, we move in the professional area.

Especially in urban areas, buildings are increasingly developing into multifunctional objects (mixed use - living, working, living, local supply, doctor) - Does Loxone see potential here and has a corresponding business model for this scenario?

Mixed-use properties will remain the trend in the large city centres. Here too, we have a solution for combining different types of building use and can also meet special customer requirements. For example, residents could see how many people are currently in the supermarket. However, this is a stand-alone solution. On the whole, it does not yet make sense.

However, we do provide the residents with other useful information. Maintenance work in the house, events in the region and we can display garbage collection plans and updated city transport timetables.

API's enable third-party collaboration via the Loxone technology platform - How important is openness/flexibility in the smart building area?

Open interfaces are important in the development process and vary in their nature. However, depending on the interface, we open the system to the cloud. This brings advantages but also the disadvantages. Closed systems such as for patient data from nursing homes or hotels with internal booking software are attractive examples of how smart building systems can be linked with software in different application areas.

Interview Marion Greiner

Marion is interested in buying a Smart Home and wants to contribute to environmentally conscious and smart building with a Green Home. Marion was interviewed to investigate the consumer's view on the topic of "smart building". (Date/Time:18.8.2020; 27:25 min)

Digital Buildings

Our environment is becoming increasingly digitalised. It is therefore only understandable to install technologies that increase the comfort of living. Not everything in the house has to happen automatically. My house should not send me messages all the time either. However, it makes sense if some adjustments to the house take place in the background, especially if you are saving heating costs, increasing security and improving your well-being. Digital technologies make it possible to make the modern house think for its inhabitants.

Environmental Issues

Yeah, definitely. Depending on the season, houses consume a lot of heating energy and electricity. Poor insulation, as in old buildings, increases the consumption even more. With an intelligent heating system which adapts itself in the background, heating costs can be reduced. If there are no people in the house, or if windows are open, radiators should switch off automatically. Smart technologies have great potential to save costs and reduce the consumption of resources.

Stakeholder Value

When constructing a new smart building, it is important to consider which technologies will yield the most benefits. As you usually have a limited budget, you focus on applications that generate high cost savings. Intelligent heating systems, automatic shading and security technology and automatic lighting in order are relevant for me as primary technologies. It is also important for me that building related data does not get into the network. Alexa and Google Nest are not alternatives for me. I also want systems that can be updated at any time and offer interfaces to other systems.

Challenges & Outlook

For me, the challenges of modern houses in the future are as follows: Houses must support the modern lifestyle with the most modern technologies. The security of data must be of paramount importance if buildings are to communicate with each other in the near future. Buildings will have all kinds of interfaces to cars, mobile phones and other smart devices. These interfaces must be secure, only then can buildings deliver real added value.

How important are smart technologies for your future home. what expectations do you have?

My house should give me the best possible support in my life and do things in the background that I do not want to take care of. A sustainable lifestyle is important to me and therefore my house should be able to be run in a resource-friendly way. I want to get old in my house therefore the building technology should support me when I get older. The installation, modification and adaptation of smart systems should be user-friendly and safe.

Appendix 4: Contrasting juxtaposition of interview insights

Interview Partner	General	Digital Buildings	Environmental Issues	Smart Building Technologies/ Stakeholder Value	Technolgies	Challanges & Outlook
Markus Greitlinger (Green Architecture AG)	CEO of Green Architecture Bottighofen GmbH _Green Architecture plans/ realizes environmentally friendly buildings with smart building technology _Micro view on on the topic of "smart building"	_digitalization of buildings is an advancing process _intelligent Buildings become truly intelligent by automatically adapting to their inhabitants __to increase the comfort of the occupants and drastically reduce energy consumption	_Buildings definitely have an enormous share in global energy consumption _a zero-energy building not only has renewable energy sources, important is interaction of efficient energy generation and storage and the right building material	_renewable energy resources are in great demand, technologies that safe cost and increase comfort _technologies that improve working productivity in office buildings, indoor climate, predictive maintenance	Photovoltaics, Air ventilation, Smart Shading, Smart Meter, Battery Storage, quality building fabric, Heat Pumps, Healthcare, predictive maintenance	_ new ways of communication with buildings _environemental issues and resource protection _intelligent energy generation, distribution, storage _new production technologies, converting buildings, modular buildings
Stefan Boettle (CIP General Planer GmbH)	Stefan Boettle is CEO of CIP Generalplaner Stuttgart GmbH _ 40 years' experience in Architecture, Planning and Construction Methods. _planned and build hotels, office buildings and residential complexes in Europe with a focus on DACH _Macro View on on the topic of "smart building"	_digitalization of buildings is an is enabling resource saving _usage data will be evaluated and analysed to use space more efficient _digitalisation will enhance use of space, energy, manpower	_half of global emmissions because of buildings _retrofitting of technologies only with right building fabrics _construction method is important	_indoor climate to enhance productivity in office builindgs, _parking management systems to intregrate electric cars into the grid	Parking Management; Air Conditioning, Data Monitoring (Dashboards), good building fabric, Technologies that safe resources, Smart Meter, security systems, Micro Grids,	_buildings in the future highly flexible _ residential and office buildings will be integrated into one building _securtiy systems will be crucial
Rüdiger Langhans (Loxone Building Automation AG)	Rüdiger Langhans is Head of Business Development of Loxone Switzerland _Loxone (Loxone Electronics GmbH) is a leading Austrian Smart Home automation company providing various smart home technologies _Macro View on on the topic of "smart building"	_digitlisation will enhance energy revolution, climate change and e-mobility in particular, crucial for the industry _This creates a need to automate things and load management requires the control of energy	_Buildings have a great steak in energy consumption _Loxone recommends installation of smart building technologies cost-effective and save a lot of energy	_everything that results in energy saving and cost saving is in great demand _Shading is enormously important for the energy management of Loxxone. _ automatic lighting is in great demand, which greatly improves the comfort of living	_effective shading; adaptable indoor climate; Energy optimization through heating systems; Loxxone through AI systems (Dashboards); Air ventilation, control systems, Intelligent Lighting; water damage sensors, window sensors, energy, safety and comfort technologies	_smart building technology will be to create a system in which tenants hardly interact actively with the building, but rather that the building anticipates the needs of tenants
Marion Greiner (Customer Green Architektur AG)	Marion is interested in buying a Smart Home; environmentally conscious _consumer's view on the topic of "smart building".	_Digital technologies make to make modern buildings think for its inhabitants _install technologies that increase the comfort of living; adjustments to the house take place in the background _ especially if you are saving heating costs, increasing security and improving your well-being.	_houses consume a lot of heating energy and electricity _Poor insulation, as in old buildings, increases the consumption even more With an intelligent heating system which adapts itself in the background, heating costs can be reduced _Smart technologies have great potential to save costs and reduce the consumption of resources	_important to consider which technologies will yield the most benefits. As you usually have a limited budget, you focus on applications that generate high cost savings _important to have data security _ I also want systems that can be updated at any time and offer interfaces to other systems.	_Intelligent heating systems, automatic shading and security technology and automatic lighting, technology that supports healthcare _home server; important building related data must not get into the web (Alexa and Google Nest are no alternatives)	_Houses must support the modern lifestyle with the most modern technologies _The security of data must be of paramount importance if buildings are to communicate with each other in the near future _Buildings will have all kinds of interfaces to cars, mobile phones and other smart devices

Appendix 5: Questionnaire – The Building of the next century

Q1 Introduction to Smart Building devices

Smart Buildings are intelligent buildings that are using adaptable control systems, regenerative materials, and intelligent construction. To achieve the optimal combination of overall comfort and energy consumption, smart buildings use computer and IoT technologies. Smart Building Technologies vary from intelligent power systems using solar power to sensors that adapt light conditions, dashboards for occupants and technology that supports elderly people to live longer independently. In the following survey I would like to ask you for your opinions and views on various smart building technologies.

Q2 What is your primary relationship to buildings as mentioned below?

Options:

Tenant (1), Investor/ Landlord (2), Facility Manager (3), Homeowner (4)

Q4 Building technologies are improving real estate in various areas. These improvements can have a social, economic, ecologic, or comfortable character. Please distribute 100 points depending on how important improvements in the four different attributes to are you?

Options:

social improvements (1), economic improvements (2), ecological improvements (3)

comfort improvements (4)

Q5 Please "drag and drop" the characteristics of smart building technologies according to which ones seem most important to you. (From 1 - Most important to 12 - least important)

Options:

Increase return on investment (1), Increase property value (2), improve occupancy productivity (3), increase occupant comfort (4), Reduces cost of operation (5), reduce energy consumption (6), minimize environmental impact (7), comply with policy and legislation (8), improve organizations/personal image (9), Improves life in the community (10), increases occupants safety (11), Improve occupants health (12)

Q6 Innovation of Energy Distribution - Smart Grid / Smart Meter

An intelligent power grid or smart grid is able to buffer increased fluctuations. Smart meters are intelligent electricity meters that can measure the amount of electricity available in the public electricity networks. They can indicate when electrical energy is available at low cost and thus provide incentives for appropriately programmed household appliances to be connected to the grid at precisely that time. Washing machines, dryers or hot water boilers could start up selectively when there is a lot of wind and solar power on the grid - and electric cars could charge their batteries at exactly that time. If the grid is not providing enough power, energy intense appliances are switched off.

Please evaluate if the properties listed below do apply to the Building Technology "Smart Meters".

***Format of Evaluation**

	Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither agree nor disagree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
Increase return on investment (1)	○	○	○	○	○	○	○

Increase property value (2), improve occupancy productivity (3), improve occupancy productivity (3), increase occupant comfort (4), Reduces cost of operation (5), reduce energy consumption (6), minimize environmental impact (7), comply with policy and legislation (8), improve organizations/personal image (9), Improves life in the community (10), increases occupants safety (11), Improve occupants health (12)

Q8 Production of Electricity - Solar power plants / Solartermal systems

Solar power plants or photovoltaics, use solar cells to generate electricity directly from the sun's radiation. Solar thermal or photothermic uses the heat of the sun's rays to heat up water, for example. Both systems make it possible to use the energy of the sun and to generate sustainable power and heat. Both systems make it possible either to be more independent of central power grids or to reduce the consumption of fossil fuels for heat generation.

Please evaluate if the properties listed below do apply to the Building Technology "Solar power plants /Solartermal systems".

***Format of Evaluation**

Q9 Power saving - Battery storage

The battery storage tank is used to store the solar power that could not be used directly in the household. Without the storage tank, the generated solar power must be directly consumed or fed into the public grid. Direct use is only partially possible since PV produces most of the electricity during the day. Demand is typically highest in the morning and towards evening. However, the feed-in tariff for solar power is significantly lower than the purchase price. Therefore, it does not make sense to feed electricity into the grid during the day and draw it from the grid in the evening. A storage solution can capture the generated power and safe it for later use therefore increasing the efficiency photovoltaic system. A car battery can perform a similar function here if it is not moved during the day, as is the case with commuters, for example.

Please evaluate if the properties listed below do apply to the Building Technology "Battery storage".

***Format of Evaluation**

Q10 Innovative Heating - Power to Heat using Ambient Air / Geothermal heat

A solution for the production of heat or cold (Air-conditioning) without the use of fossil energy are "Power-to-Heat" or "Power-to-Cold" solutions like the heat-pump system. Here, electricity is used to transfer heat from a heat-source (ambient air, geothermal heat) to the heat sink, here the interior area of the smart building. The devices are working with a mechanism similar to refrigerators. The exchange of ambient with used air from the building provides the building with a fresh air supply. Geothermal solutions can also be used for cooling during summer. However, for the heat-pump system to create heat, electricity is needed, which has to be taken form the grid, which makes it dependent of the general grid if alternative electrical supply is not available. Fossil resources like gas or oil, which are used widely in households, are saved.

Please evaluate if the properties listed below do apply to the Building Technology "Power to Heat / Ambient Air / Geothermal heat".

***Format of Evaluation**

Q11 Dashboard Information for Occupants

Smart Buildings can use information dashboards to show residents different information. In addition to house-related information such as the energy level available from solar cells and the general energy consumption, environment-related information such as schedules of public transport, waste disposal dates or dates for culture, childcare or other services can be displayed. In a housing estate, activities can be communicated that promotes the community spirit. In a company, dashboards can show employees and guests how busy the cafeteria is at the moment, which meeting rooms are free and help visitors find their way around the building.

Please evaluate if the properties listed below do apply to the Building Technology “Dashboard”.

***Format of Evaluation**

Q12 Smart Logistics and Mobility

Smart buildings can offer technologies that support modern logistics. The density in Cities is rising. Smart buildings can offer parking space more effectively using digital technologies. Smart Sensors in the parking areas can communicate free parking spaces dynamically. If parking spaces offer electrical charging, car batteries can be charged by the smart grid. The improved parking situation on the Roadside for logistic vehicles transporting packages or food delivery services (e.g Amazon Prime, Uber eats). With up to 60 % failed home deliveries the current situation is in need of improvement. Smart buildings offer unattended acceptance of parcels and groceries with smart lock technologies.

Please evaluate if the properties listed below do apply to the Building Technology “Smart Logistics and Mobility”.

***Format of Evaluation**

Q13 Predictive Maintenance Systems

In the field of facility management, predictive maintenance can significantly reduce maintenance costs and the frequency of repairs. Smart meters can detect increased power consumption and sensors can detect faulty operations in various systems. Especially in office buildings, failures of elevators or air conditioning systems cause high costs. If persons cannot move efficiently around the building and if rooms cannot be heated or ventilated, business stops. A facility management company can use predictive techniques to significantly reduce maintenance costs and minimise the risk of major equipment failures. Additionally equipment functionality is prolonged. Lifts, large heating systems and air-conditioning systems are installed in multi-storey residential buildings. Accordingly, predictive maintenance systems could also make sense in the private sector.

Please evaluate if the properties listed below do apply to the Building Technology “Predictive Maintenance Systems”.

***Format of Evaluation**

Q14 Water leakage and Fire detection sensors

Water leakage sensors can detect water that is coming from broken pipes, the floor heating or household appliances and warn residents or maintenance services to prevent severe damages to the building. Smoke and fire detectors warn residents to prevent fire development early and inform rescue services. Rescue services should be put on special alert if buildings are equipped with solar panels or battery storage systems. Solar panels and lithium ion batteries require advanced techniques to prevent the release of toxic substances.

Please evaluate if the properties listed below do apply to the Building Technology “Water leakage and fire detection sensors”.

***Format of Evaluation**

Q15 Security of the House/ Alarm Systems

Smart buildings make it possible to enter the building with a smart key, a cell phone or a password. 2-factor solutions can also be implemented, in which access must be confirmed on the cell phone in addition to the key. Furthermore, rooms, a certain floor or the entire building can be "alarmed" by presence sensors. If irregularities are detected, the alarm system can contact the resident / owner (notification / call). In case of a burglary, the alarm can play loud music, flicker the lights or the shades.

Please evaluate if the properties listed below do apply to the Building Technology “Security of the House/ Alarm Systems”.

***Format of Evaluation**

Q16 Intelligent heating and shading

Each of your rooms would always have their preferred temperature. Wouldn't that be nice? An intelligent heating and cooling control can always produce the desired temperature in every room, fully automating your heating plan and adapting it to your preferences.. calculates your exact heating demand and knows at which times you are at home or not. Heating and cooling the house can be influenced through intelligent shadings. Modern buildings often come with large windows, light entering through them is heating up the living area. This light can be used to heat up rooms, however intelligent shading can counteract and can support cooling. A pleasant indoor climate also supports a more productive way of working, which is essential for companies or for working in a home office.

Please evaluate if the properties listed below do apply to the Building Technology "Intelligent heating and shading"

***Format of Evaluation**

Q17 Healthcare: Building technology that is improving health

Smart Buildings can interact with different Smart Home devices and can help to supervise and help elderly people with a need of care. Sensors detect unusual behaviour, e.g. if the person of has fallen on the ground and is in the need for help, thereby informing nursing services or ambulance. Filter systems which are installed in the ventilation system can remove pollutants such as pollen or tobacco smoke as well as food odors from the air and thus improve the air quality and protect allergy sufferers.

Please evaluate if the properties listed below do apply to the Building Technology "Building technology that is improving health".

***Format of Evaluation**

Q18 Please list which smart building technologies are most valuable to you? (From 1 – Most important to 12 - least important)

Options:

Innovation of Energy Distribution: Smart Grid / Smart Meter (1); Production of Electricity: Solar power plants / Solartermal systems (2); Power saving: Battery storage (3); Innovative Heating: Power to Heat using Ambient Air / Geothermal heat (4); Dashboard Information for Occupants (5); Smart Logistics and Mobility (6); Predictive Maintenance (7); Water leakage and Fire detection sensors (8); Security of the House/ Alarm Systems (9); Intelligent heating and shading (10); Building technologies improving healthcare (11)

Q26 Cloud based vs Local servers

Smart home products are mostly based on cloud-based technologies. Alexa speakers, google products and other manufacturers store information on external servers and can improve services and products based on a high number of data points. However, there are also manufacturers that store all data on local servers and do not store data in cloud systems. Data here can not be abused in any case. Which system do you prefer ?

Options:

Cloudbased Products (Amazon Alexa, Google Nest) (1); Products that store information locally (Loxone) (2)

Q27 Smart building technologies vs. Smart building materials

Smart building technologies can reduce resource and energy consumption. However, the construction and demolition of a house also has an impact on the environment.

Would you consider the environmental impact of the construction and the demolition of a house, when thinking about a smart building ?

Options:

do not agree (1); somewhat agree (2); not sure (3); agree (4); totally agree (5)

Q28 Do you prefer wood houses or houses made out of brick an mortar ?

Options:

Wood (1); More wood then brick and mortar (2); in-between (3); More brick and mortar then wood (4); Brick and mortar (5); wood or brick and mortar (1)

Q29 Would you agree that the lifestyle of people is changing more frequently (i.e. Student life, working life, family, separation, retirement) today and therefore buildings should adapt to theses changes?

Options:

do not agree (1); somewhat agree (2); not sure (3); agree (4); totally agree (5)