Christer N A Quinn

Towards Smarter Buildings

An IoT Maturity Index Approach

Master's thesis in MSUMA
Supervisor: Niels Peter Østbø
June 2021

Master's thesis

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Abstract

The Internet of Things (IoT) has the capacity to transform the Architect, Engineering, Construction and Facility Management (AEC/FM) industry and take it into a new era of buildings, Smart Buildings. Smart buildings control systems distinguish themselves from traditional building automation systems (BAS) in terms of advanced analysis and data monitoring. The IoT enables data collection on any aspect of the building's function, such as the major operational components, power consumption, predictive maintenance, occupancy sensing, amongst many others (Minoli, Sohraby et al. 2017).

Though smart buildings are expected to have a significant impact in the future, this thesis seeks to find the status of buildings today. This thesis uses IoT as an indicator to index the technological maturity of commercial buildings towards smarter buildings. It aims to identify which technologies are of interest in the industry and who the technological drives are.

Through semi-structured interviews with domain experts, the research identified that both the public and the private sector considers it challenging to be on the bleeding edge of technology due to cost and risk associated with this. However, the public sector has made the furthest progress towards smarter buildings, whilst the private sector lags behind. Due to the cost of development and implementation of new technology, current industry trends are focused on technologies that reduce the operational costs of buildings. As the main drivers, vendors and public sector continue to push the technological boundaries, another step is taken towards smart buildings.

Sammendrag

Tingens Internet (IoT) har potensialet til å transformere bygge-, anleggs- og eiendomsnæringen (BAE) og ta den inn i en ny epoke av bygg, smarte bygg. Smarte bygningsstyringssystemer skiller seg fra tradisjonelle bygningsautomatiseringssystemer (BAS) når det gjelder avansert analyse og dataovervåking. IoT muliggjør datainnsamling om ethvert aspekt av bygningens funksjon; for eksempel de viktigste operasjonelle komponentene, strømforbruk, prediktivt vedlikehold, tilstedeværelsesdetektor, blant mange andre.

Det forventes at smarte bygninger vil ha en betydelig innvirkning i fremtiden, denne oppgaven undersøker intelligensstatusen til bygninger i dag. Denne oppgaven bruker IoT som en indikator for å indeksere den teknologiske modenheten til kommersielle bygninger mot smartere bygninger. Det tar sikte på å identifisere hvilke teknologier som er av interesse i bransjen og hvem de teknologiske driverne er.

Gjennom semistrukturerte intervjuer med fageksperter identifiserte forskningen at både offentlig og privat sektor anser det som utfordrende å være på den nyskapende siden av teknologi på grunn av kostnader og risiko forbundet med dette. Imidlertid har offentlig sektor kommet lengst mot smartere bygninger, mens privat sektor henger etter. På grunn av kostnadene ved utvikling og implementering av ny teknologi, er dagens bransjetrender fokusert på teknologier som reduserer driftskostnadene til bygninger. Leverandører og offentlig sektor fortsetter som bransjens hoved drivere for å fremme gode løsninger for fremtidens bygg.

Preface

The following thesis concludes a two-year study programme in Sustainable Manufacturing at the Department of Manufacturing and Civil Engineering, NTNU Gjøvik. The thesis is written on behalf of NTNU without the cooperation of an external partner company. The thesis is based on a research carried out by the author in the spring of 2021, with the guidance of Associate professor Niels Peter Østbø.

With my background in electrical engineering, currently working in the building industry, this research project has allowed me to combine my interest for sensory electronics and building automation. This research has been a valuable learning experience for myself, and already, the results of this research have proved useful in a professional capacity.

I want to express my gratitude to all who agreed to be interviewed for this thesis and contributed their time and valuable insight.

I would also like to express my gratitude towards Associate professor Niels Peter Østbø for his supervision, insights, and interesting discussions throughout the entire process.

Most of all, I would like to thank my wife and child for their incredible patience, and their support of me through this entire process, who have made countless sacrifices to help me get to this point.

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Terms and Abbreviations

AEC/FM	*Architecture/Engineering/Construction (*AEC*) and Facilities Management (FM)*
AI	*Artificial intelligence*
AIMI	*Acatech Industrie 4.0 Maturity Index*
BAS	*Building Automation System*
BIM	*Building Information Model*
BSRIA	*Building Services Research and Information Association*
IMI	*IoT Maturity Index*
IoT	*Internet of Things*
IT	*Information Technology*
LOD	*Level of Detail*
OT	*Operative Technology*
PM	*Property Manager*
PoE	*Power over Ethernet*

1 Introduction

1.1 Background

A long time ago, commercial buildings such as offices, museums, schools, and hospitals, amongst others, were built in such a way to provide the basic necessities such as electricity, heat, lighting and water for their occupants and stakeholders. Buildings have played an essential role for the survival of humans in providing safety and comfort for their emotional, physical and social needs. In particular, the occupants' overall well-being significantly impacts their productivity (Lawal and Rafsanjani 2021). This highlights the need for automation in commercial buildings (Totonchi 2018, Lawal and Rafsanjani 2021).

Automation in buildings utilising Internet of Things (IoT) is able to provide the bleeding-edge solution for improving visual and thermal comforts, security, monitoring building resource use, and enhancing efficiency (Metallidou, Psannis et al. 2020, Lawal and Rafsanjani 2021). Though some IoT applications are applied in commercial buildings, there is still a need for more IoT applications and operations to fully understand the potential of this technology (Lawal and Rafsanjani 2021). Though IoT has many advantageous use cases for commercial buildings, BSRIA research reports that commercial buildings are slow to adopt and utilise IoT technology (Building Services Research and Information Association 2021).

Considering the implications of utilising IoT to its full potential in commercial buildings, it becomes imperative to identify the current state in which it is being utilised. Many studies indicated that IoT applications are being used in various buildings, including schools, hospitals, offices, outdoor settings, sports venues, residential buildings, train stations, and airports (Zafari, Papapanagiotou et al. 2015, Yu, Xie et al. 2017). The studies explore commercial-building sensors, including motion detectors for lights, heating, CO2, desks and rooms usage/activity, tracking chips on moveable objects etc. The IoT applications predominantly mentioned in literature are used in optimising building services, location-based and monitoring user flows. Others include monitoring space use, building energy simulation, telecare, user detection, social sensing applications, and emergency response applications.

Application and objectives are closely linked. Thus, location-based user applications often seek to support users by improving comfort or finding ways, while optimising building services that helps conserve energy. Applications used to monitor user flows and space are usually applied to support users and optimise costs and resources (Coates, Hammoudeh et al. 2017).

When the type of application and the sensors used were compared, some studies noted diversity in sensing approaches. Some applications, including building services optimisation and location-based user applications, were reported to favour specific sensing approaches involving Wi-Fi and multiple sensors. Other studies noted the predominance of a single sensor. A significant segment of the literature looked at multiple sensing methods. In applications that optimise building services, sensors were used to measure indoor environment aspects, including temperature, CO2, and acoustics (Akkaya, Guvenc et al. 2015). In some studies, the data collected on these aspects were supplemented by user feedback and space utilisation data to support informed decision making (Zafari, Papapanagiotou et al. 2015).

At the current state, the academic application for IoT in smart buildings far exceeds the current smart buildings being built today; as buildings are at its earliest stages of adopting IoT to the industry (Jia, Komeily et al. 2019). To promote the application and objectives of IoT to building developers of the future generation, systems and approaches need to not only focus on improving the robustness and feasibility of the system, but also follow market trends in order to meet the stakeholders' needs (Jia, Komeily et al. 2019). Many of the above studies described above are IoT case studies of pilot projects and don't give a true representation of real-world usage in normal instances. Thus, the premiss for this thesis.

1.2 Objectives and Scope

The primary objective of this thesis is to explore the use of technology in commercial buildings at its current state, as buildings technologically advance towards smart buildings, using an IoT maturity index as an indicator. The secondary objectives of this thesis is to identify which technologies and systems are desirable in the industry; as well as who are the technological drivers of the industry. The research questions are as follows:

- Using an IoT maturity index approach, what is the current level of technological maturity in commercial buildings, towards smart buildings?
- Which IoT technologies and systems are desirable in the industry?
- Who are the technological drivers moving towards smart buildings?

This research paper is limited to researching the above questions. The data gathering for this research is from semi-structured interviews. The research and the interview candidates are Norwegian, their experience is also based on their work experience in Norway. Therefor this research is limited to commercial buildings in Norway, though the information may be transferable internationally. The interview candidates may bring up subjects outside the boundaries of this research scope. Subjects that the interview candidates discuss outside the scope may be mentioned; but will not be discussed in deph.

One of the questions the researcher considered before beginning the research; is, why should this be researched and who would find this research of interest. This research is intended for professionals, typically engineers, consultants, vendors and property managers (PM) that are concerned with technical solutions within the buildings industry. From an academic perspective, this research would hold value for the work that is done in designing the framework for measuring maturity, as well as giving the current status of building maturity in 2021.

1.3 Structure

The thesis is divided into six chapters. The remaining chapters are structured as follows:

2. **Methodology:** Describes some theoretic background behind research, as well as describing how the research problems introduced in section 1.2 was solved.

3. **Theory:** Presents relevant theory and background information useful for understanding the premiss of this thesis

4. **Results:** Presents the results and findings from the research conducted

5. **Discussion and analysis:** Discusses the results as they relate to the research questions

6. **Conclusion:** Contains the concluding remarks and presents suggestions for future work.

2 Methodology

As described by Leedy, research is the systematic process of collecting, analysing, and interpreting information (data) to increase our understanding of a phenomenon (Leedy and Ormrod 2010). Different methods of research have different strengths and weakness. Therefore a research method must be selected based on what one intends to accomplish within the research limitations (Dalland 2000).

2.1 Reliability and validity of research

The quality of the research is determined by the validity and reliability of the research. The quality of research also affects the extent to which one can learn something about the phenomenon that is studied and the probability that one can obtain statistical significance in the data analysis and the text to which one can draw a meaningful conclusion from the data (Leedy and Ormrod 2010).

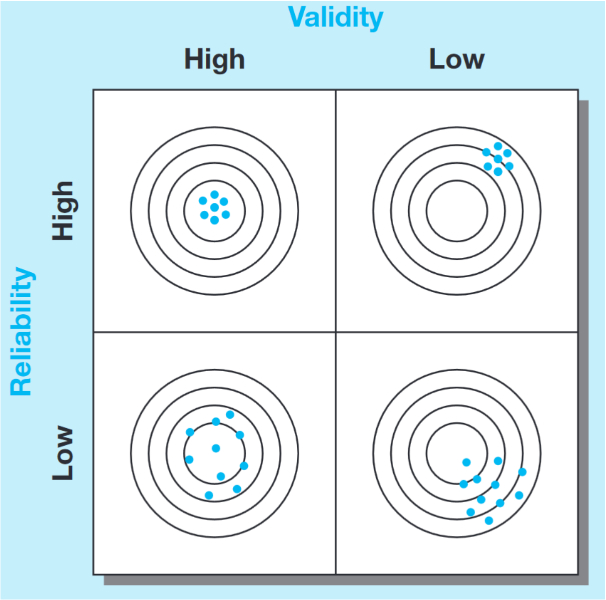


Figure 1: Illustration of reliability and validity in research (Cooper and Schindler 2014)

Validity can be explained as the extent an instrument measures what it is intended to measure. As an example, using a thermometer to measure the temperature outdoors. Using the wrong tool, or a tool not adequately suited for the task may give invalid results (Leedy and Ormrod 2010). Furthermore, Bryman (2016) describes two forms of validity, internal and external validity. External validity refers to the degree to which findings can be generalised across social settings. Internal validity refers to whether there is a good match between the researchers' observation and the ideas or knowledge being transferred (Bryman 2016).

Reliability concerns itself with the consistency with which a measuring instruments yields a particular result when the entity measured is not changing. Using the example above, imagine that the same thermometer randomly varied by +/- 5 degrees centigrade, even though the true temperature was constant, this would mean the thermometer is unreliable (Leedy and Ormrod 2010). Furthermore, Bryman (2016) describes two forms of reliability, internal and external. External reliability concerns itself with the degree of which the research can be replicated by another research and return the same results. Internal reliability concerns itself with when there is more than one researcher; they can observe the phenomena individually, then discuss the results and verify if they agree on the observation (Bryman 2016).

Validity and reliability both take different forms, depending on the research problem and the phenomenon being studied. However, both are equally important for a successful research (Leedy and Ormrod 2010).

2.2 Literature search

Prior to this thesis, a scientific literature review of IoT concept, features, and technologies was conducted. The review was thought to only consider articles from the Architecture/Engineering/Construction (AEC) and Facilities Management (FM) AEC/FM. However, due to the origins of IoT, there was an abundance of articles unrelated to the research topic which needed to be filtered out from the search results.

The initial search phrase used was "Internet of Things" and was limited to title, abstract and keywords. Later this was changed to IoT, which gave a similar result mass. Then, the term "IoT" was combined with the search phrase "commercial buildings" using Boolean operators; then, to further narrow the search, "maturity" was added.

Table 1: Search Query test

Search string	Scopus	Web of Science
Internet of things	107 555	38798
IoT	82725	51269
Iot & Commerical Buildings	1330	161
Iot & Commerical Buildings & Maturity	22	0

However, the search still included articles from unrelated industries, fortunately the results were of a small enough capacity that it was manageable to select useful articles based on their titles. Although time-consuming, this proved to be very beneficial as it allowed for a deeper review of the concept of IoT.

As this early literature revealed, there wasn't an abundance of current research papers about technological maturity in commercial buildings. It was therefore determined to do this research thesis on an IoT approach to measure the maturity of commercial buildings.

2.3 Research method

2.3.1 Qualitative and Quantitative research

The research method is the general approach the researcher takes in carrying out the research project. To some extent, this approach dictates the particular tools the researcher selects (Leedy and Ormrod 2010).

Research methods are often described as either quantitative or qualitative. A q*uantitative* research strategy emphasises quantification in the collection and analysis of data, whereas a qualitative approach is considered the research strategy that emphasises words rather than quantification (Bryman 2016).

Quantitative research involves looking at amounts (quantities) of one or more variables. Typically, quantitative research tries to measure variables in some way in order to gather empirical data to support their research. This is can be done either by using existing commonly accepted measurements (e.g. ruler, thermometer, scale) or by carefully designing their own method of measurement (e.g. tests, questionnaires, rating scales), such as if trying to measure psychological characteristics or behaviours, happiness (Leedy and Ormrod 2010).

In comparison, qualitative research looks at *softer* data, such as characteristics or qualities that are not easily reduced to numerical values. Typically, a qualitative research aims at examining the many variations and complexities of a particular phenomenon. Qualitative research is often used in studies that are related to complex human situations, e.g. when needing to research peoples perspectives on complex situations, explain their behaviours or values (Leedy and Ormrod 2010). Furthermore, Bryman (2016) describes qualitative research as concerned with the generation of theories, rather than the testing of theories.

2.3.2 Qualitative semi-structured interviews

For this research, a qualitative approach was chosen to collect data rather than a quantitative approach. This is because the research topic was better described as a social construct rather than a numeric one. Within qualitative research, Leedy et.al (2010) describe that there are three main methods of data collection; observation, artefact/document collection and interviews(Leedy and Ormrod 2010).

For this research, the researcher will interview experts within the domain of this study to find their perspective on the complexity of buildings. Bryman (2016) describes 12 different types of interviews! The researcher will not go into detail on the 12 types of interviews, other than to state that they were considered, and it was determined that semi-structured interviews were best suited for this research.

A semi-structured interview is a form of questioning where the interviewer has a series of questions prepared in the general form of an interview schedule/guide. However, the interviewer may deviate from the schedule, and ask questions in a different sequence to how the interview is planned. This interview methodology also gives the interviewer some leeway to ask other questions not in the interview guide for further in-depth questioning in response to what the candidates answer (Bryman 2016). The interview guide for this thesis can be found in Appendix A

Due to the geographical location of this research, as well as the interview candidates; the interviews were performed in Norwegian. As Norwegian is the mother tongue of the researcher and coincidentally all of the interview candidates, it was deemed most appropriate and natural that the interviews were in Norwegian. This is also to reduce any misunderstandings, potentially compromising the validity or reliability of this research.

2.3.3 Quality of data

The quality of data can be evaluated based on its reliability, validity as well as forms of bias (Leedy and Ormrod 2010). The reliability of data is associated with the level to which any research will reveal similar information if they follow the same approach. Establishing reliability in a qualitative semi-structured interview is often challenging. This becomes even more difficult to ensure due to the anonymity of the interview candidates. Furthermore, the validity of the research is characterised as the degree to which the research is measuring what is supposed to be measured. Which again, is also challenging when conducting a qualitative semi-structured interview.

Another concern that Bryman (2016) highlights as an issue related to the reliability and validity of interviews is trustworthiness. As interviews are social experiments, there is always a concern that the candidate is not entirely truthful (either intentional or unintentional).

However, some actions were applied in attempts to improve the validity and reliability of this research. The research interviewed as many subjects as possible that were considered viable for the research. This would increase the amount of data, and discrepancies could more easily be identified. All interviews were recorded, making it possible for other researchers to verify and replicate the study in the future. This is also made possible with a well-documented report!

Another measure that was implemented, was to anonymise the candidates both name and place of work. Due to the nature of this research, the research deemed it unlikely that the domain expert would intentionally be truthless. However, it is worth noting the information provided by the domain expert is their subjective observation of a phenomenon, and they are explaining this to a researcher. Therefore, the researchers understanding of the topic is at best, what Leedy describes as *secondary data (Leedy and Ormrod 2010).* Therefore, there is room for misinterpretation and misunderstandings.

Another concern when interviewing candidates is *bias.* As described by Leedy, Bias is any influence, condition or set of conditions that singly or in combination distort the data. Furthermore, Leedy describes that bias can creep into a research project in a variety of subtle and undetected ways, that even the researchers' personality may affect the outcome of an interview (Leedy and Ormrod 2010). Bias, in general, is very difficult to overcome; however, the researcher was aware of this concern and made attempts to minimise this by studying interview guides and running practice interviews with people who were not part of the research group.

2.3.4 Framework for measuring maturity

Due to the nature of this research, a method of *measuring maturity* was required. Maturity is uncommon to measure; therefore, there are no standard tools available for this. Part of the literature research as presented in section 0

Literature search, was seeking for a framework that was suitable for this research, non were found.

However, the literature research described in section 0 did reveal other frameworks that were useful. It was determined to combine concepts from different frameworks to make a maturity index customised for measuring the maturity level of buildings based on IoT devices (IMI). The IMI was a combined from two other frameworks.

The first was the framework Model Maturity Index (MMI) used for rating BIM level of detail and building progression as part of the framework (Fløisbonn, Skrei et al. 2018). It is at this point worth noting that the MMI is a framework designed by multiple Norwegian consultancy companies for Norwegian consultancy companies; therefore the framework as depicted in Figure 3 is also in Norwegian.

The second was the Acatech Industrie 4.0 Maturity Index (AIMI), a framework used to develop Industry 4.0 in smart factories (Zeller, Hocken et al. 2018).

Naturally, when designing one’s own framework for measurement, validity and reliability is of concern. In order to improve the consistency of measurements, three tables for “Technologies at each stage” was created to improve the reliability and validity of the measurements. This can be viewed in more detail in section 3.4 below. With this intent, the framework is designed with the best intentions of measuring the maturity of buildings, towards smarter buildings using IoT as the reference of measurement. Whether this is a good indicator or not will have to be researched at a later time, using a different framework for comparison.

3 Theory

3.1 What is the Internet of Things?

Internet of Things, Industrial Internet of Things and Industry 4.0, three buzzwords as we roll into the 21st century. Though these three words have a generally accepted meaning, as implied by Firouuze et. Al, the definition is ambiguous (Firouzi, Chakrabarty et al. 2020). Several companies have defined the internet of things in their own terms, and reviewing these definitions are important and meaningful.

> IBM defines the Internet of Things as "the Internet of Things is the concept of connecting any device (so long as it has an on/off switch) to the Internet and to other connected devices. The IoT is a giant network of connected things and people – all of which collect and share data about the way they are used and about the environment around them" (Clark 2016). IBM also writes that IoT refers to "the growing range of Internet-connected devices that capture or generate an enormous amount of information every day" (Firouzi, Chakrabarty et al. 2020).

> SAP defines the Internet of Things as "The vast network of devices connected to the Internet, including smart phones and tablets and almost anything with a sensor on it – cars, machines in production plants, jet engines, oil drills, wearable devices, and more. These "things" collect and exchange data."(SAP 2016).

> Kapersky summarises IoT as "The Internet of Things refers to all devices, even those out-of-the-ordinary devices, that can connect to the Internet. Almost anything with an on/off switch these days can potentially connect to the Internet, making it part of the IoT."(Kapersky 2018).

> Finally, in 2014 ISO defined IoT as "An infrastructure of interconnected objects, people, systems and information resources together with intelligent services to allow them to process information of the physical and the virtual world and react."(International Organization for Standardization 2014).

The term "Internet of things" was first coined by Kevin Ashton in 1999, working in supply chain optimisation at Procter & Gamble (P&G) (Ashton 2009). Due to rapid development of technology and their convergence, the definition of IoT is quickly evolving (Firouzi, Chakrabarty et al. 2020). Thus, there is no single definition available for Internet of Things that is accepted by all users. In fact, there are many groups, including researchers, academicians, innovators, developers and corporations that define the term from their perspective, as shown above. However, the key fundamental characteristics repeat themselves within the different definitions (Madakam, Lake et al. 2015).

3.1.1 Key fundamentals of IoT

Things or Devices – Things in IoT are objects connected to a network. These can be intelligent/smart objects, or merely a simple sensor connected to a network (either wired or wireless). In order to be an IoT device it typically must meet these criteria: the device must have a processing unit, power source, sensor/actuator, networked connection and a tag/address so it can be uniquely identified (Firouzi, Chakrabarty et al. 2020).

Connectivity – Connectivity is crucial for IoT, as this is the empowerment behind enabling IoT devices to be connected to the internet or other networks (Firouzi, Chakrabarty et al. 2020-9).

Data – One of the primary products of IoT is vast amounts of data, Big Data. Data is the first step towards intelligence and action. Information sent from an IoT device often include sensory data, location data, status or diagnostics data (Firouzi, Chakrabarty et al. 2020).

Intelligence – Intelligence is another crucial aspect to utilise the full potential of IoT, by extrapolating IoT data (Firouzi, Chakrabarty et al. 2020). As an example, the combination of artificial intelligence (AI), machine learning, data analysis, and IoT data can improve user experience, avoid unplanned downtime (predictive maintenance), increase operational efficiency, improve risk management and even reduce risk (Schatsky, Kumar et al. 2017).

Action – This refers to the devices ability to perform actions as a result of intelligence, either by the device itself, or the stakeholders in the IoT ecosystem (Firouzi, Chakrabarty et al. 2020).

Ecosystem – The ecosystem consists of the IoT devices themselves, the protocols they use, the platforms of which they run on, the stakeholders interested in the data, as well as the goals and of the interested parties (Firouzi, Chakrabarty et al. 2020).

Diversity – Devices in the IoT are expected to be made up of different devices, working on different platforms and on different networks. Thus, all devices should be interoperable (Firouzi, Chakrabarty et al. 2020).

Security and Privacy – Security and privacy are fundamentally a part of IoT as sensitive as well as personal data is transmitted between devices within a system as well as online. This demands data sovereignty, secure networks, secure endpoints, and a scalable data security plan to keep all of this information safe (Firouzi, Chakrabarty et al. 2020).

3.1.2 Common understanding of IoT

Above describes a compilation of aspects that major players in the market define as essential for IoT. These aspects can be divided into four major components: data, things, people and process. In an ideal ecosystem, all four components must work together in unison to achieve IoT connectivity.

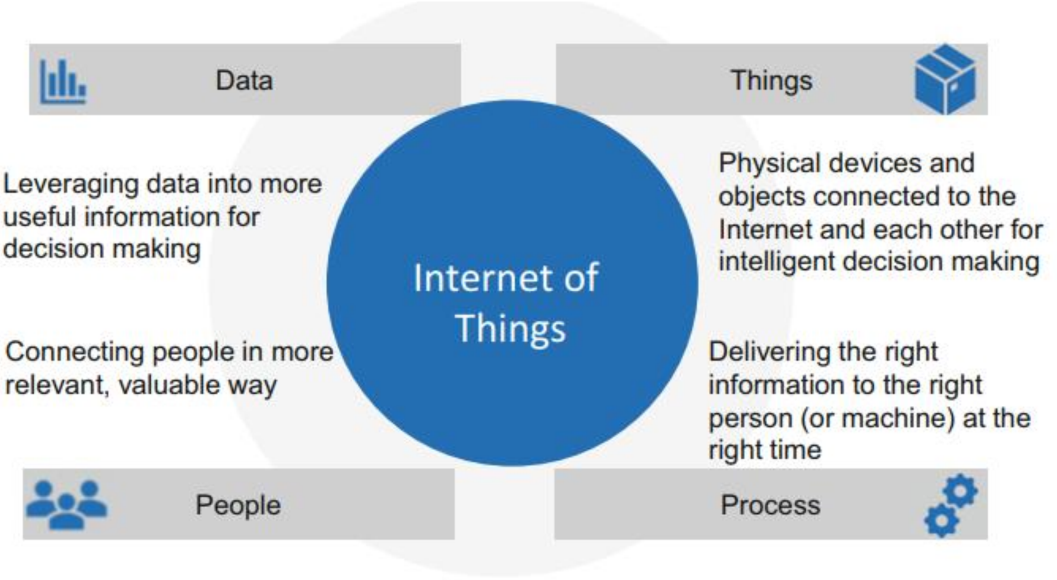


Figure 2: IoT Components (Firouzi, Chakrabarty et al. 2020)

Data – With devices connectivity to a network, data is produced. Data is the first step towards action and intelligence. Information, or data sent between IoT devices often include environmental data, diagnostic, location, or report of their status as well as the data they are designed to gather. The IoT device can also often receive data. This data can be anything from software upgrades, commands, or update scheduled tasks – to mention a few. With a large number of IoT devices producing lots of data, it is easy to understand that the size of data also will be enormous. For this data to have any real value, the data must either be stored for later analysis, or analysed immediately. The relevance of the data is a contributing factor as to whether the data is analysed immediately or is stored for later analysis. Analysis of data can either be done close to the device (e.g. a server/PC/smartphone etc.) or the data can be communicated to an offsite centralised location, such as a cloud (Firouzi, Chakrabarty et al. 2020).

Things - Things refers to the physical devices that operate as part of the IoT. The device must be part of the IoT network in order to interact within the ecosystem. The device must have the ability to connect to another device or to a network. This could be with a specialised communication protocol such a Bluetooth or zigbee, or a more general protocol such as Internet Protocols (IP). In order to be a device in the IoT, the device must have a processing unit, power source, sensor/actuator, network connection and a tag/address so that it can be uniquely identified (Gilchrist 2016, Firouzi, Chakrabarty et al. 2020). The IoT device must also be able to produce some form of data. Most frequently this is sensor data which the device can collect by itself. Some examples include: temperature, humidity, pressure, CO2, light etc. The device may also be commanded to perform an action, this can be moving an actuator or control motor, or turn off/sleep. The devices must be engineered to survive the environmental conditions they are installed in (Firouzi, Chakrabarty et al. 2020).

Process - Process in the IoT ecosystem is where the benefits of intelligent automation, decision making, control and efficient procedures are realised. The methods and techniques can always become more efficient with the right information at the right time. Analysing the gathered data from the sensors and delivering this information to the appropriate stakeholders or systems is the main idea of the processes of IoT (Firouzi, Chakrabarty et al. 2020). This is the stage which separates triggers and lookup tables, from intelligent automation.

People - The final component of the IoT ecosystem is People. Within the IoT ecosystem people are affected by IoT in at least one of two ways: (1) agent of change, which must work to make the IoT function and/or (2) the beneficiary of its outcomes. Some level of analysis and interpretation is required to be performed by people for the data to have any value. Ultimately, it is people who create and maintain the IoT, and it requires their actions to make and utilise its potential. For any IoT devices, whether consumer or commercial information, people need to be aware of their personal data(Firouzi, Chakrabarty et al. 2020).

3.1.3 Comparison of Consumer IoT, Commercial IoT and Industry 4.0

Much IoT hype has focused on consumer-oriented devices, including smart home gadgets or wearables (Plageras, Psannis et al. 2018). However, there are many other significant ways in which IoT applies. Thus, this leads to an exploration of industrial IoT and commercial IoT alongside consumer IoT to establish the distinction among them. Despite the hype on consumer IoT, major applications exist in the Industrial Internet of Things (IIoT) (Sadowski and Spachos 2018). The Industrial Internet of Things refers to the intelligent industrial operations enabled by machines, computers and people utilising advanced data analysis to change business outcomes. The Industrial IoT involves the integration of IT and operational technology and related to Industry 4.0. Typical use cases of IIoT include smart lighting, smart grid applications, intelligent machine use, agricultural use cases, industrial control applications, smart cities, condition monitoring, smart traffic solutions, and oil refinery applications. These applications help with business efficacy, continuity, and cost reductions among other benefits (Barker 2020).

The Consumer Internet of Things (CIoT) is the most mentioned form of IoT (Casado-Vara, Martin-del Rey et al. 2020). It includes devices that attract significant attention on many websites and news outlets that cover technology. Connected, smart home applications, wearables, and smartwatches are some of the prominent examples of CIoT devices. The network of consumer applications and technology fascination play a pivotal role in the increasing focus on the IoT. The consumer allure aspect supersedes every real-life possibility as they are implemented. The CIoT market is driven by novel technology fascination as manufacturers push the market and adoption implies new business possibilities with data's significant role. While some applications, such as fitness and personal health, are popular, there is still room for real growth (Minoli, Sohraby et al. 2017).

Commercial Internet of Things is mostly about commercial real estate and smart buildings. While the location is still crucial in real estate, information-based applications can add value for customers and provide new sources of revenue (Jia, Komeily et al. 2019). The Internet of Things (IoT) is helping companies shift focus beyond cost reduction. IoT applications can enable commercial building owners to grow margins and improve tenant relationships, ensure efficient building operations, and provide additional revenue creation opportunities. More buildings are now fitted with smart thermostats that intuitively adjust light, humidity, and temperature based on one’s preferences and climatic conditions. Commercial IoT is likely to have a more significant impact on the industry, as it could be uniquely positioned for technology implementation using building automation systems (BAS) enabled by IoT to enhance the efficiency of building performance and improve building user experience by leveraging sensor-generated data (Elsisi, Tran et al. 2021).

Some common elements have been identified in these different types of IoT. The connectivity and network aspect are common to all, including a network of things, devices, sensors, etc., depending on the source (Qolomany, Al-Fuqaha et al. 2019). A dimension of networks and connectedness must exist in any IoT platform, whether commercial, industrial, or customer. Various IoT network and connectivity standards and protocols apply, in most cases coming in a combination. All IoT aspects need essential “things” to keep the network working. They have technology that makes them more capable of “doing something,” such as measuring moisture levels, sensing movement, obtaining location data, or capturing anything that may be transformed into data. IoT device management is crucial. For example, in consumer applications, it is possible using cloud platforms with IoT device proprietary vendor solutions. Data is a pivotal part of the reason why any IoT exists. IoT cannot exist without (substantial) data. Other commonalities include security and privacy issues, communication, intelligence, and automation regardless of scope (Casado-Vara, Vale et al. 2018).

3.2 What is a smart building?

Today, it is no longer enough for people to build homes and offices merely to shelter and keep them warm. Thanks to technological advances, a building can deliver everything occupants need while making it efficient, minimise costs and decrease the building's environmental impact (Spachos, Papapanagiotou et al. 2018). This balance will be critical to business. A smart building uses technology to share information about what happens in the building to optimise the performance within systems. This information can then help automate various processes such as heating, ventilation, air conditioning, and security. Smart buildings help deliver useful services that enhance occupants' productivity and safety at minimal cost and negligible environmental impact. They optimise and minimise energy consumption, and are able to operate using clean, renewable energy. Thus, occupant security and quality of life are made top priorities. This implies physical security (connected fire alarm and suppression systems as well as health security (high-quality water and air). Smart buildings' equipment and systems should be connected with the ability to communicate through the IoT and data analysis software to optimise operations. The generated data can be used to monitor performance, track assets' physical location, identify potential operational issues, and enhance preventive maintenance activities (Plageras, Psannis et al. 2018).

For any building owner or occupant, overheads can present a significant cost. However, although these are unavoidable business expense, the expenditure level can be wasteful when it is not intelligently used. For example, people may leave lights on in unused rooms. Smart building emerged to avoid this kind of wasteful resource use, to enhance energy efficiency and cut cost. In smart buildings, core systems are connected. Thus, water pumps, meters, lighting, fire alarms, power, etc. are all connected, making a building's systems communicate with each other. Sensors are a pivotal part of smart buildings, helping in data collection and informing decisions regarding where resources should be allocated. Information is gathered and analysed constantly and in real-time by installed systems. The persistent monitoring enables automated adjustments to manage conditions in a building. Smart buildings generate substantial valuable data regarding their use, something regular buildings simply cannot do (Sadowski and Spachos 2018).

Smart buildings increase occupants' productivity. Sanitation, air quality, physical comfort, security, and lighting can be provided at an optimum level to allow residents to perform well. Smart buildings also reduce energy consumption as they are greener, more cost-effective and more energy-efficient. They use sensors and cameras to gather data on building utilisation. This information is convertible into insightful decision making. Space use can be enhanced by looking at actual data, as the building is able to produce actionable, living intelligence. Smart buildings also enable significant operational savings, including those that can be made regarding daily expenditure and equipment maintenance. Moreover, there are potential savings from identifying underutilised resources and unused spaces that allow for growth. Smart buildings leverage IoT devices such as online connectivity, sensors, and software to monitor characteristics of buildings, analyse information, usage patterns and trends (Barker 2020). Thermal sensors and other devices can measure data without using people's identifiable images. The insights generated can help to optimise the operations and environment of buildings. Smart technology enhances one's control over a building. However, it transcends advanced command and control mechanisms. For example, a building management system can be programmed to operate an HVAC system in a building based on predefined temperature levels at certain times. Smart building technology, on the other hand, offers greater control over how the HVAC can be operated. It can even instruct the building management system to switch the HVAC on and off as required by making real-time measurements of CO2 levels. Furthermore, smart building analysis can incorporate weather data and information from utility companies to complement the building's HVAC operating data to allow the residents to strategies on how to reduce operating costs particularly on days when temperatures are high. This amount of control over the HVAC system enables residents to save energy and reduce costs without compromising their comfort. Smart building systems work together with a building management system and enable occupants to understand their building by monitoring its operations in real-time, providing an analysis of the building data, and automating functions strategically to allow the full optimisation of operations (Casado-Vara, Martin-del Rey et al. 2020).

Smart buildings are distinct from traditional control solutions in terms of advanced analysis and data monitoring. The IoT enables data collection on any aspect of the building's function. For instance, IoT sensors can be attached to all equipment in the building in addition to the major operational components to monitor the quality of power, carry out predictive maintenance, measure energy, or conduct occupancy sensing. They can be put on any relevant location, such as water pipes, machinery, walls, doors, windows, refrigeration units, ceilings, air ducts, desks, and appliances, depending on what needs to be measured. The more detailed data is available about the building, the easier it will be to make targeted and meaningful improvements. Smart buildings are also differentiated by their ability to do advanced analysis involving statistical algorithms and machine-learning capacities. These can penetrate the details of the building’s characteristics and integrate data streams from the building’s exterior and interior, such as weather and utility information to establish the most effective approach to achieving one’s goals. Eventually, one will see the impact of the steps being taken, the working measures, and what should be adjusted to achieve success (Minoli, Sohraby et al. 2017).

Smart building technology provides various applications in a building, depending on one’s objectives. The overall premise remains that the system will offer relevant surveillance to all areas of operation, gather data, analyse the information, and present tangible insights that can help in making improvements. If meeting sustainability requirements is a challenge, IoT platforms can assist in monitoring the prevailing energy consumption patterns. This data will then be analysed to produce targeted recommendations for minimising energy consumption. It can also help reduce water consumption and improve indoor air quality. Besides, it can be pivotal in reducing the building’s environmental impact by integrating renewable energy technologies into the energy system (Elsisi, Tran et al. 2021).

To minimise energy consumption, sensors that monitor the building can provide insight into how energy is being used. Smart building data can be applied to increase efficiency, helping optimise building and equipment utilisation by reducing overall consumption. To ensure continuous critical equipment functioning, one can apply sensors to measure things about their operation, including the refrigerant temperature, compressor vibrations, humidity level, to detect imminent failure. When incoming data indicates the deviation of one operational aspect from the norm, it shows imminent failure. Usually, one IoT can help preclude a breakdown before it occurs. IoT platforms can help in data collection and analysis to allow measures that meet the laid down standards for indoor air quality, energy efficiency, and water consumption. Smart building systems can help inspect, report, and review performance over the building's lifetime to maintain long-term certification, such as the Building Research Establishment Environmental Assessment Method (BREEAM) or Leadership in Energy and Environmental Design (LEED) (Qolomany, Al-Fuqaha et al. 2019).

Smart buildings provide meaningful services such as illumination, sanitation, air quality, thermal comfort, and physical security, which make occupants productive. This requires adding intelligence throughout a building's useful life. The role played by IoT cannot be overstated. It is used to connect various independently operating subsystems and share information. Smart buildings transcend the building equipment in them. Connection to the smart power grid and interaction with occupants and operators enable buildings to develop new visibility and actionable capabilities (Casado-Vara, Vale et al. 2018).

Smart buildings are set to connect to an intelligent future. Going beyond making energy savings and achieving sustainability goals, they extend the life of equipment and affect the security of all financial and human resources. They allow innovation by providing information accessibility (Sadowski and Spachos 2018). Buildings become virtual power generators by integrating multiple power sources from existing grid networks to provide a reliable power supply. Subsequently, they allow operators to eliminate electric load and sell it into the market. They are a vital element of a future where IT and human ingenuity work together to create a robust, low-carbon economy. As a result, the carbon footprint is reduced since power is generated by renewable energy sources and a network of information, matching demand with variable supply every minute. Businesses use data in new ways to operate at unprecedented efficiency levels. They maximise the intersystem connection whose components have been independent until the development of The Internet of Things (Plageras, Psannis et al. 2018). These benefits extend throughout a building's entire lifetime, during modelling, design, construction, renovation, and beyond. This vision will be possible thanks to the smart building, offering the roof overhead as well as the information infrastructure to realise an intelligent world. The Internet of Things will transform the building and take it to a different level and usher in a new era of how construction is done (Spachos, Papapanagiotou et al. 2018). As sensors become more powerful, the Internet of Things will be able to do even more incredible actions that will make buildings seem alive.

3.3 Framework developed for this research

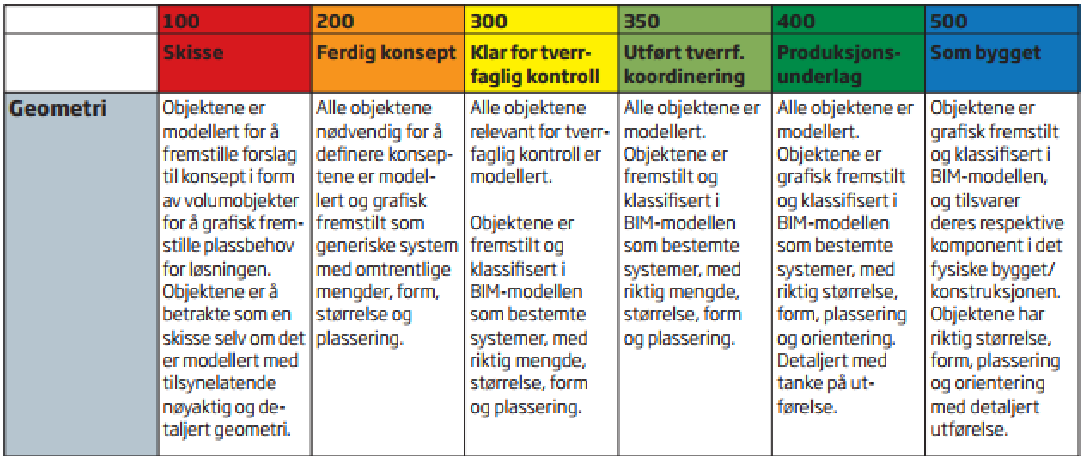
3.3.1 IoT Maturity Index (IMI)

The IoT Maturity Index (IMI) is a framework the researcher has created for analysis and use in this research work, with possible application in future work- to be discussed later. The first, Model Maturity Index (MMI), which is an index used in the construction industry to transfer the Building Information Model (BIM) level into a numeric value. The second is using the terminology from Acatech Industrie 4.0 Maturity Index (AIMI)

3.3.1.1 MMI

Model Maturity Index (MMI) is an already familiar system within the Norwegian AEC/FM sector (Fløisbonn, Skrei et al. 2018, Hæhre, Haugbotn et al. 2020). MMI addresses the issue of defining the terminology used for the BIM project. Further it describes the level of maturity of objects in a BIM model (both in regard to geometry as well as information content), and transfers this to a numeric value based on Level of Development (LOD). Thus, the IMI model utilises the concept of describing the maturity level by transforming it into a numeric value (Fløisbonn, Skrei et al. 2018).

In construction projects, MMI is used as a tool for engineering planning. The codes/LOD in the system are then used by each discipline to plan their own deliveries in relation to other disciplines in the project, as well as signal the need for BIM deliveries from other disciplines. This raises the quality of interdisciplinary controls and potentially saves the project time and incorrect planning (Fløisbonn, Skrei et al. 2018) Below, is a figure of an example of the BIM MMI, as the framework is of Norwegian origin, the figure description below is in Norwegian.



	100	200	300	350	400	500
	Skisse	**Ferdig konsept**	**Klar for tverrfaglig kontroll**	**Utført tverrf. koordinering**	**Produksjonsunderlag**	**Som bygget**
Geometri	Objektene er modellert for å fremstille forslag til konsept i form av volumobjekter for å grafisk fremstille plassbehov for løsningen. Objektene er å betrakte som en skisse selv om det er modellert med tilsynelatende nøyaktig og detaljert geometri.	Alle objektene nødvendig for å definere konseptene er modellert og grafisk fremstilt som generiske system med omtrentlige mengder, form, størrelse og plassering.	Alle objektene relevant for tverrfaglig kontroll er modellert. Objektene er fremstilt og klassifisert i BIM-modellen som bestemte systemer, med riktig mengde, størrelse, form og plassering.	Alle objektene er modellert. Objektene er fremstilt og klassifisert i BIM-modellen som bestemte systemer, med riktig mengde, størrelse, form og plassering.	Alle objektene er modellert. Objektene er grafisk fremstilt og klassifisert i BIM-modellen som bestemte systemer, med riktig størrelse, form, plassering og orientering. Detaljert med tanke på utførelse.	Objektene er grafisk fremstilt og klassifisert i BIM-modellen, og tilsvarer deres respektive komponent i det fysiske bygget/konstruksjonen. Objektene har riktig størrelse, form, plassering og orientering med detaljert utførelse.

Figure 3: BIM MMI Example (Fløisbonn, Skrei et al. 2018)

3.3.1.2 Acatech Industrie 4.0 Maturity Index

The Industrie 4.0 Maturity Index (AIMI) from Acatech is a well-recognised framework within the Industry 4.0 community. The AIMI a methodology for establishing manufacturing companies' current Industry 4.0 maturity stage and identifying areas where further action is required. This systematic identification of weaknesses and opportunities provides the basis for formulating an implementation strategy. In short, the AIMI offers manufacturing companies practical guidance for developing an individual Industrie 4.0 implementation strategy that is aligned with their business strategy (Schuh, Anderl et al. 2017).

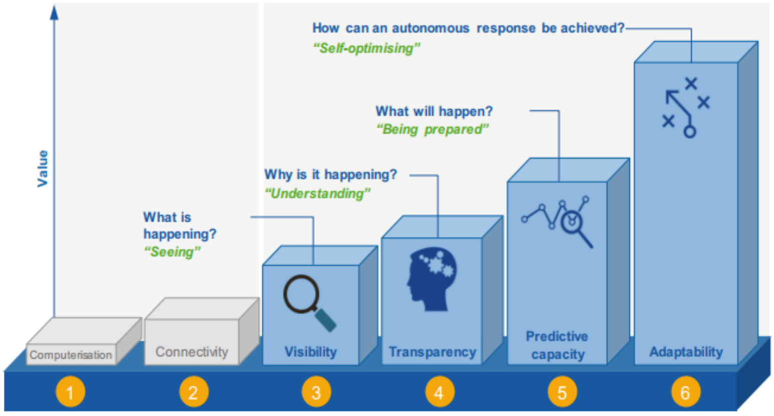


Figure 4: Acatech Industrie 4.0 Maturity Index (Schuh, Anderl et al. 2017)

Steps 1 and 2 of the AIMI model considers the digitalisation stage, whereas steps 3-6 considers the Industrie 4.0 stage. The conceptual structuring of AIMI is value-based increase for each stage. As value is not a factor in the framework for this research, the AIMI figure is restructured for the need of the research. Therefore, the stages of AIMI remain the same, however they are reconfigured into a "step based" progression system, as each stage builds the foundation for the next, as shown in Figure 5 below

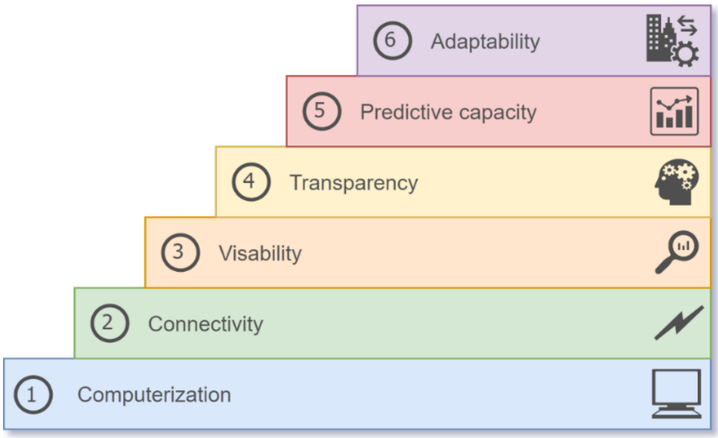
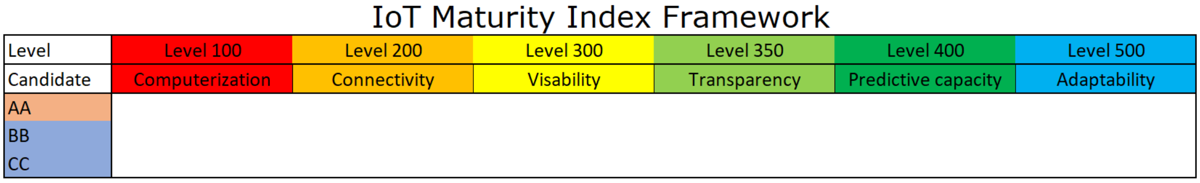


Figure 5: Building blocks of IMI, developed by the researcher based on maturity level premise of Acatech Industrie 4.0 Model

3.3.2 Proposed framework for IoT Maturity Index

Below presents the proposed framework for the IoT Maturity Index (IMI). The IMI utilises the terminology from AIMI, and the conceptual building blocks. There are 6 terms, and stages. Each level of technological maturity builds on its predecessor. Each of these 6 terms have been given a colour and numerical value, similar to the BIM MMI framework.



IoT Maturity Index Framework

Level	Level 100	Level 200	Level 300	Level 350	Level 400	Level 500
Candidate	Computerization	Connectivity	Visability	Transparency	Predictive capacity	Adaptability
AA						
BB						
CC						

Figure 6: IMI Maturity Index Framework

Below describes each category of the IMI framework in detail.

3.3.2.1 Computerization

Computerizations is the starting point for digitalisation and refers to the use of information technologies (Zeller, Hocken et al. 2018). At this stage different information technologies are used in isolation of one another within the company (Schuh, Anderl et al. 2017). In most companies, computerisations is already implemented (Zeller, Hocken et al. 2018). The terminology relates to basic use of IT equipment, however in regards to building use of IoT, very little is present.

A building that meets todays (TEK17) building standards can be categorised here. At this stage the building meets the basic expectations of various stakeholders may have. Technology at this point is typically manual switches with little to no sensory input, doesn’t produce data, as well as little automation (Powerhouse 2019).

3.3.2.2 Connectivity

At the connectivity stage, the isolated deployment of information technology is utilised by connected, networked components. However a complete integration between information technologies (IT) and operative technologies (OT) has not yet taken place. However interfaces to business IT are provided by parts of impended OT.

The connectivity stage, buildings on the foundation laid by computerisation, as shown in Figure 2Figure 5. At this stage there still a lot of technology that is unconnected, however there are a small number systems that are integrated to a control system using both proprietary and open communication protocols; as well as unstructured data, and little or no data storage. Typically, temperature and airflow is regulated by control systems using pre-set levels and operating times.

3.3.2.3 Visibility

Digital visibility is not only established with the help of sensors, but also by enabling recording of sensor data (Zeller, Hocken et al. 2018). Rather than only collecting data to enable a specific analysis or support a dedicated operation, they must instead be able to create an up-to-date model of all available IoT solutions. The combination of existing data sources with sensors in other building locations can deliver significant benefits (Schuh, Anderl et al. 2017).

The building, or rather system in the building is collecting data, which will make it possible to elevate the building to the next "intelligent" stage at a future point in time. Technical solutions within the building are now not only connected between sensor and actuator, but the data is also logged. The data can either be logged directly to a local server or the data/sensors is connected directly to a cloud service where the data is analysed or stored. All systems have two-way communication over open standardised protocols. Data can be available in real-time, as well as being logged for future use. There should be no unnecessary duplications of data (Powerhouse 2019).

3.3.2.4 Transparency

Stage three, visibility begins the process of creating a digital shadow of the building, thus the first stage of gathering large amounts of data (big data). The next stage is for the building control system and operators to understand why something is happening. In order to identify and interpret interactions in the digital shadow, the captured data must be analysed. The semantic linking and aggregation of data to create information and the corresponding contextualisation provide the process knowledge required (Schuh, Anderl et al. 2017). At this stage, the control system utilises more sensory data for its decision making, including the weather forecast. The control system can adjust or also open for input/feedback from individual users.

3.3.2.5 Predictive capacity

Building on the transparency stage, the next development stage is predictive capacity. The process of analysis of the data (starting at stage 4), builds up the database for predictive capacity (level 5). This in turn enables simulation of different future scenarios. To this end, the digital shadow is projected into future-based scenarios and evaluated according to probability of occurrence. This enables companies to anticipate upcoming events, make decisions in time and take adequate reaction measures (Zeller, Hocken et al. 2018). Predictive capacity allows for the system to make simulations and suggestions to best handle new scenarios. As an example, utilising historical weather forecasts, and simulating the buildings respons to weather patterns. The building can also run multiple scenarios based on weather input to find the most optimal settings based on simulations. However, the BAS would require human authorisation before taking actions.

The building predicts future states based on direct and indirect data from its environment and users. The building gives recommendations or adjusts parameters accordingly. Different users get different information or guidance based on needs (Powerhouse 2019).

3.3.2.6 Adaptability

Predictive capacity is a fundamental requirement for automated actions and automated decision making. The goal of adaptability is for the system to utilise the data from the digital shadow to make automated decisions that have the best results, without human assistance. However, it is important to carefully consider the risks of fully automating approvals/systems (Schuh, Anderl et al. 2017).

At this point the building is self-learning and utilising historical data and machine learning to improve its prediction models as well as operational control. At this point the building is self-governed requiring little input from human interactions. The building communicates and interacts with the environment and other buildings (Powerhouse 2019).

3.4 Technologies at each stage

Below tables show various technologies expected to be found in a modern building, and its expected technological progression as it advances through the different IMI maturity stages. Buildings may have a mix of different technologies at different stages of development, dependent on the buildings functional requirements. The tables below are based on the technological development tables by Powerhouse (2019). The tables are not intended to include all technologies or systems one may find in a smart building, however, it is intended to give an indication of how various systems may develop between the different stages (computerisation – adaptability). These tables are useful tool to aid when using the IMI framework.

3.4.1 Enabling technologies

Table 2: Enabling technologies

	Computerisation	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Use of open standard communications between systems and possibility of exchanging data	Systems have manual interface with little communications. More use of actuators and controllers	System is based on both open and proprietary protocols	All systems have two-way communication over open standardised protocol (ex. BACnet)	Systems have open documented API which makes it simple to exchange data.	-	-
*Integration of control systems**	-	Some control systems are integrated one-to-one based on gateways (protocol converter)	All relevant control systems can be integrated to one system	Interactive management systems. Data is utilised across systems.	The control systems are predictive and shares data on expected future condition	The control systems are self-learning and improves its prediction models based on historical data
Availability of data, e.g. when using sensors and multi-sensors, paper towel usage, desk vacancy, parking etc.	-	A small number of sensors are used by several system.	No unnecessary duplication of sensors. Instant data is available for all current systems, also future.	Simplified and flexible sensor system achieved by widespread use of multi-sensors and easy integration of additional sensors when needed	The sensor system is designed for high reliability through self-testing sensors, easy renewal of sensors, and the use of redundant sensors if necessary.	Machine learning algorithms checks system quality and reveals system errors.
Collection of structured data and analysis of these	No data is produced or data is not stored	Small and unstructured collection of data	Collection of structured data in real time. Data structure must be documented and available. No unnecessary duplication of data	Structured collection and storage of historical data. Data can be easily made available to third parties.	Large amounts of data are used for prediction	Large amounts of data are utilised by self-learning systems to to increase the precision system control during ordinary operation.
Technical networks	No network, or poor disciplined network.	A separate network per	A common technical network for all	All devices connected will be	The network monitors data traffic	The technical network is

		technical system.	technical systems. The network can be segmented and supports access control with a centralised access register	assigned access to the correct segment based on the devices defined functions and needs. Traffic and condition of the network is monitored	and detects irregularities. The system alerts and handles deviations.	self-learning and self-securing.
Positioning of people and equipment in the building	The building offers no positioning services	The building offers no positioning services	The building is prepared for indoor use positioning based on Wi-Fi triangulation, bluetooth beacons or a combination of these. Necessary wireless access points (WAP) and beacons are installed.	Users are assisted with navigating the building based on their position. Movable equipment is tracked and position made available to users.	The building offers users positioning services that let them find colleagues and be found.	-

* Light, sunscreen, HVAC, BAS (Building Automation System), fire alarm, access control, burglary alarm, CCTV (Closed-circuit TV), AV (audio video), visitor registration systems, meeting room booking, lifts etc.

3.4.2 Indoor climate and working environment

A key purpose for measuring maturity is how the technology is used and how the BAS utilises the data available. This is also to ensure the building is more user friendly, intelligent controlled indoor climate and working environment, optimal temperature, air, light, noise and ergonomics to ensure high productivity from employees.

Table 3: Indoor climate and working environment

	Computerisation	**Connectivity**	**Visibility**	**Transparency**	**Predictive capacity**	**Adaptability**
Temperature regulation *Thermal environment*	Temperature is regulated by physically adjusting the temperature controller on the device.	Temperature is controlled by preset temperature levels and operating times.	The building system makes it possible to include other sources (e.g. presence and meeting room calendar) in temperature control. If the building has openable windows, these must have a sensor for opening sensing and outdoor air quality.	The building's systems have the opportunity to exchange information with the user in real time, eg about temperature in different zones. Cooling and the heating systems are controlled on a holistically with other systems and can e.g. take into account if windows are open.	Temperature is controlled rule-based in regards to information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from unique users and responders on these, e.g. by adjusting temperature or giving users personal guidance.	The system is controlled from a large range of inputs, including usage patterns, are self-learning and uses historical data to improve their prediction models to ensure the satisfaction of users.

Atmospheric environment	Airflow is controlled by preset operating times.	Airflow is controlled according to preset CO^2 levels and operating times. At this stage, the CO^2 monitor is connected directly to the HVAC	Airflow can be controlled based on multiple sources in real time (e.g. activity in room, and CO^2 levels). If openable windows, these must have a sensor for opening and outdoor air sensors	Users can influence the amount of air natural and/or mechanical. The cooling and heating systems are controlled holistically with other systems and can for example take into account if a windows open.	Airflow is controlled on rule-based information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from individual users and adjusts settings based on this, e.g. by adjusting temperature	The system is controlled from a large range of data, where sometimes usage pattern, is self-learning and uses historical data for to improve their prediction models to ensure satisfied users.
Daylight and lighting	Lighting is turned on and off using a switch.	Lighting is turned on and off based on presence (motion sensor) and/or operating times.	The light control system controls the light level by presence, daylight level and operating times. Measures for optimal utilisation of daylight taken into account in the design of the building. The lighting system is divided into appropriate zones and adapted for two-way communication in control system.	Amount of light and colour temperature can be controlled by several sources such as time of day and season.	The lighting system receives feedback from individual users and provides users with information and guidance.	Amount of light and color temperature controlled in addition based on users physiology and preferences, after the principle of human centric lightning.

3.4.3 Energy and resource optimalisation

	Computerisation	**Connectivity**	**Visibility**	**Transparency**	**Predictive capacity**	**Adaptability**
Energy consumption and device management (lighting and equipment)	No lighting automation	Lighting is controlled based on predefined operating times and sensors.	All lighting and relevant electrical equipment shall have the possibility of two-way communication.	The units are controlled energy efficiently and effectively based on multiple sensor/data inputs (e.g. presence, sunscreen and daylight level) in real time. Energy consumption is measured and logged.	The units are controlled energy efficiently and effectively based on predicted needs (e.g. based on expected use and weather forecast).	The units are controlled energy efficiently and effectively based using large amounts of operational data and machine learning.
Climate technical system and thermal energy supply	-	Climate technology system such as satisfies TEK17.	The climate technology system is holistically designed (combination of passive and active measures) and easily optimised in operation. All relevant devices (e.g. heat pumps, valves, fans and temperature sensors) and zones in the building shall have the possibility of two-way communication.	The system is controlled and operated optimally energy based on several data sources (e.g. actual weather conditions, usage pattern and building response) in real time.	The system is controlled and operated at optimal energy efficiency based on usage pattern, and weather forecasting services. The system prepares themselves on upcoming heat and cold periods based on fixed algorithms.	The building is self-learning and improves its algorithms for control and operation adapted to usage pattern, the weather forecast and the actual weather.

Building spatial awareness and optimalisation	-	-	-	The building detects low use of space (typical for public holidays), and suggests users to relocate to certain floors, in order to “shut down” floors to save energy.	Building prepares for shutting down part of the build on periods expected to have low occupancy, e.g. giving users feedback on floor (un)availability when booking meeting rooms or workspace.	The building is self-learning and improves its algorithms for control and operation adapted to usage pattern.
Building maintenance staff optimalisation	-	Sensor on toilet rolls etc.	Sensors are installed to indicate when maintenance is required. E.g. which workstations have been in use, refill paper towels in WC etc.	-	The building monitors floor/area activity and predicts and notifies maintenance staff before service is required. E.g. When paper towel, hand sanitiser, soap dispenser is nearing empty.	Building is self-learning and improves its algorithms for control and operation using patterns and historical data to predict the required amount of maintenance required at a monthly/quartering interval

The tables above are intended as a guidance to identify technologies and how the technologies progress through the various development stages. These tables are not intended to contain all systems found in building/smart buildings, but systems where IoT may have a function.

4 Results of interviews

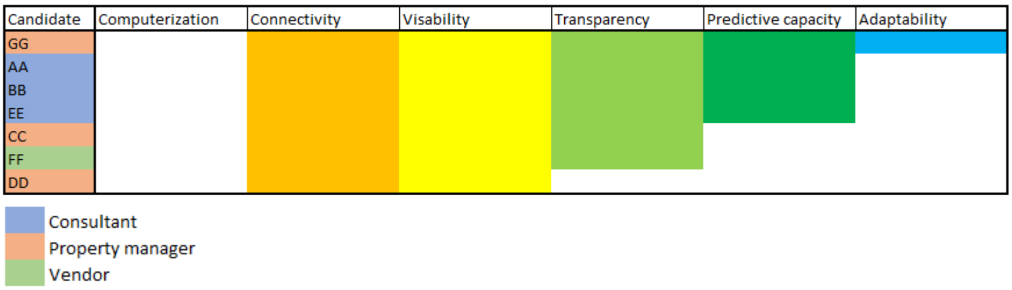
This section presents the results obtained from the seven interviews conducted with the domain experts, representing engineers from consulting, property managers, and vendors. As explained in section 2 Methodology, the interview candidates are experts within their fields. The interview candidates were carefully selected as a segment with a higher affinity for IoT within the AEC/FM sector.

4.1 Towards a common understanding

As an introductory question, the interviewees were asked what they associated with IoT. There was a common understanding of IoT, that any “thing or device” connected to the internet could be categorised as an IoT. Two out of seven candidates also associated data with IoT. At this stage of the interview, none of the candidates discussed process or people as components within IoT. Keep in mind, that at this stage of the interview it was still rather superficial question to grasp their understanding of the topic. The interviewed candidates were not pressed or further questioned about their association on the topic though a lot more details were revealed during the in-depth interviews.

4.2 IoT Maturity Index

The IoT Maturity Index (IMI) framework is introduced in section 3.3, as well as the terms and technologies required to achieve various levels of maturity. After the interviews, the recordings were reviewed and analysed to identify the technological maturity of buildings that their experience showed.



Candidate	Computerization	Connectivity	Visability	Transparency	Predictive capacity	Adaptability
🟧 GG		🟧	🟨	🟩	🟩	🟦
🟦 AA		🟧	🟨	🟩	🟩	
🟦 BB		🟧	🟨	🟩	🟩	
🟦 EE		🟧	🟨	🟩	🟩	
🟧 CC		🟧	🟨	🟩		
🟩 FF		🟧	🟨	🟩		
🟧 DD		🟧	🟨			

🟦 Consultant
🟧 Property manager
🟩 Vendor

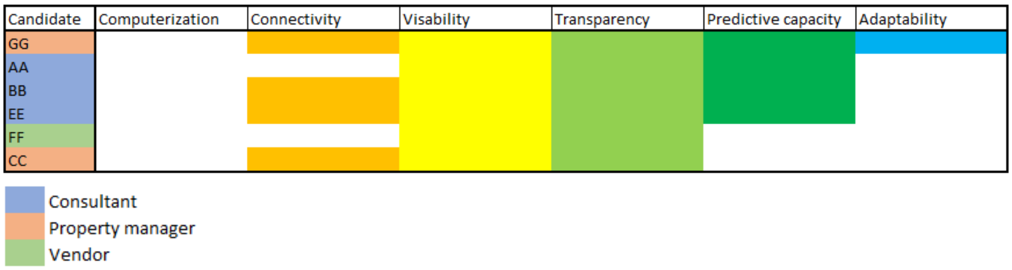
Figure 7: IMI results from the interview

As previously mentioned in 3.3.2 Proposed framework for IoT Maturity Index, computerisation is in many instances a minimum requirement dictated by today's building standards (TEK17), therefore contains little to no use of IoT device.

As seen in Figure 7, all interview candidates identify that they have worked in projects that meet the requirements for connectivity and visibility. While 6 out of 7 candidates identify indicators in the transparency stage, only 4 of 7 identify indicators for predictive capacity. Only 1 candidate had indicators for adaptability. At first glance, the results are remarkably high. However, during the interviews, it was identified a division/discrepancy between private and public sectors. Therefore, sections 0 and 0 presents the data findings from Figure 7 divided into more detail in relation to their sectors.

4.3 Public sector

Below shows the data representing the public sector only, removing any data representing the private sector in Figure 7.



Candidate	Computerization	Connectivity	Visability	Transparency	Predictive capacity	Adaptability
GG		🟧	🟨	🟩	🟩	🟦
AA			🟨	🟩	🟩	
BB		🟧	🟨	🟩	🟩	
EE		🟧	🟨	🟩	🟩	
FF			🟨	🟩		
CC		🟧	🟨	🟩		

🟦 Consultant
🟧 Property manager
🟩 Vendor

Figure 8: IMI results from public sector

A quick comparison reveals that two indicators from connectivity are removed. Further, looking more closely at the data at the different stages.

Connectivity:

The most common indicators were the use of motion detectors to regulate lights (on/off), 3/4 candidates identified this as an indicator. Two candidates specified the use of mixed propriety and open communications protocols.

Finally, indicators only represented by 1/4 candidates within the connectivity section was the utilising of some sensors used by multiple systems.

Visibility:

The most common indicators were the use of multiple sensor sources to regulate temperature as well as airflow. Typically this was the use of and/or combinations of motion detector, CO2 sensor, temperature sensor, and meeting room booking (through outlook).

Transparency:

The most common indicators were the use of multi-sensors that are easy to integrate, as well as open API. Additionally, there are indicators that units are controlled energy efficiently based on sensory inputs.

Predictive capacity

Four of the seven candidates revealed indicators within predictive capacity. The most common indicators within predictive capacity was the building preparing for warm/cold periods as well as the use of control systems ability to share data between systems; three of the four candidates presented these indicators.

Furthermore, 2/4 candidates within predictive capacity presented indicators for user preferred climate settings in meeting rooms. As well as predicting when certain apparel would require service from maintenance staff, two of the four candidates presented these indicators.

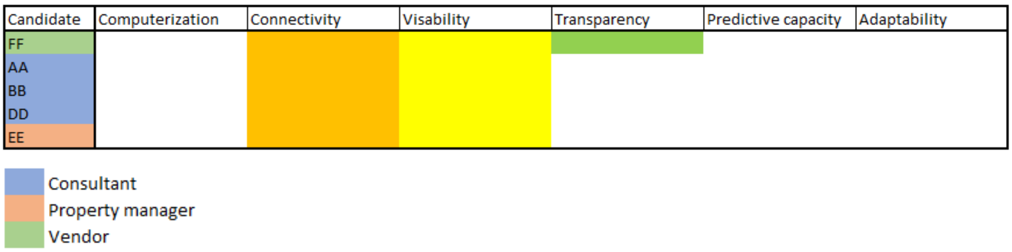
Finally, indicators only represented by 1/4 candidates within predictive capacity were quality and reliability of sensors, as well as building preparing to shutdown certain areas of the building when low occupancy.

Adaptability

Only 1 of the 7 candidates had indicators in the adaptability category. The indicators lay in the categories of self-learning control system, including analysis of large amounts of data to optimise heating/cooling in regards to weather patterns. The control system also uses a range of data input to predict user patterns to ensure their satisfaction and machine learning to check and verify system errors.

4.4 Private sector

The figure below shows the data representing the private sector only, removing any data representing the public sector.



Candidate	Computerization	Connectivity	Visability	Transparency	Predictive capacity	Adaptability
🟩 FF		🟧	🟨	🟩		
🟦 AA		🟧	🟨			
🟦 BB		🟧	🟨			
🟦 DD		🟧	🟨			
🟧 EE		🟧	🟨			

🟦 Consultant
🟧 Property manager
🟩 Vendor

Figure 9: IMI results from private sector

A quick comparison between Figure 8 and Figure 9 shows that the technological progression between the two sectors is significantly different. Of the candidates interviewed, 5 had experience with IoT from the private sector. Only one candidate identified technological advancement passed the visibility in the private sector. Further, looking more closely at the data at the different stages.

Connectivity

Four of the five candidates discussed the use of mixed open and proprietary communication protocols. Furthermore, three candidates revealed that some control systems were integrated one-to-one using gateways. Again, three candidates also discussed the use of motion detectors to regulate lights.

Two out of five candidates discussed the use of temperature and co2 sensors with pre-set levels to regulate heating and airflow, as well as utilising some sensors across other systems.

Finally, only one of the five candidates discussed the use of data, which was unstructured.

Visibility

At the visibility stage of the IMI

Four of the five candidates indicated markers that

Four of the five candidates discussed the use of climate control with feedback to users. Additionally, 3/5 candidates discussed users ability to regulate temperature and airflow.

Finally, only one of the five candidates disused data management, specifically no data duplication and collection of structured data.

Transparency

One subject discussed an interactive control system, of which data is utilised across systems.

4.5 IoT technologies of interest – property managers perspective

From the interviews, the areas of interest within the use of IoT in commercial buildings were categorised into three categories: (1) energy efficiency, (2) resource efficiency and (3) user experience.

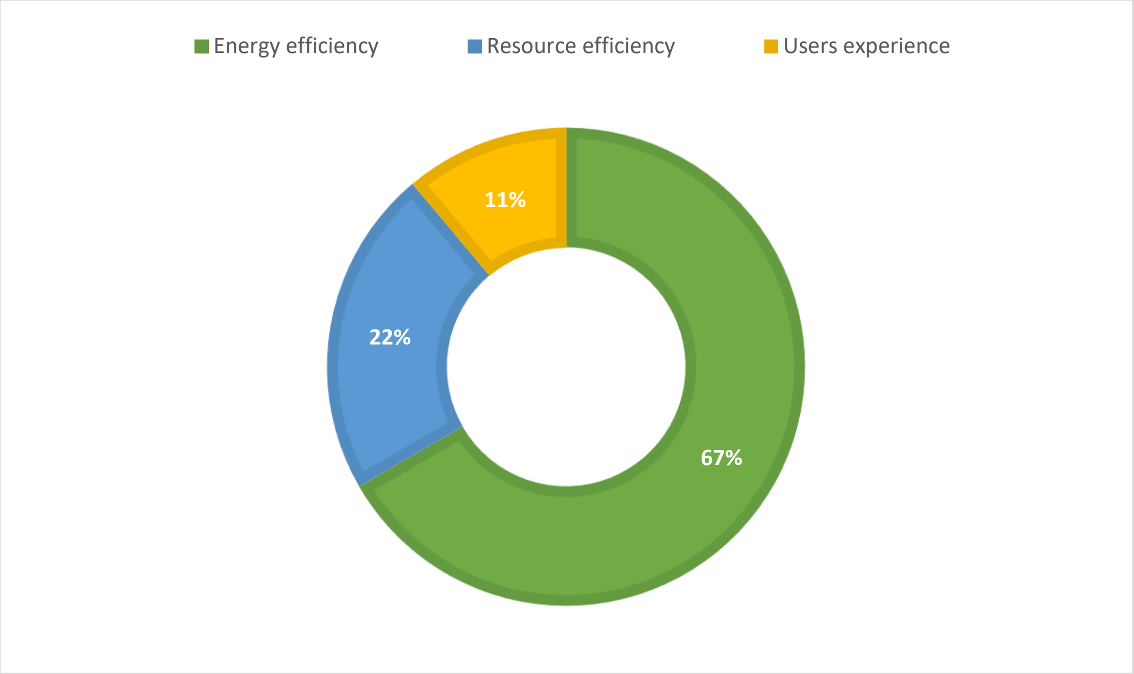


Figure 10: Technology areas of interest – PM perspective

The primary area of interest for use cases of IoT in commercial buildings lay within energy efficiency. Typically, these were technologies related to regulating heating/cooling, sunscreens, control system optimisation etc.

The secondary interest area was IoT technology for resource efficiency. This relates to the optimisation of buildings spatial allocation, as well as maintenance staff.

Finally, IoT devices that were directly related to users experience was the least prioritised in commercial buildings. These technologies gave users the possibility of feedback towards regulating heating/cooling, guidance/tracking, general ease of use features etc.

4.6 IoT technologies of interest – user perspective

The domain experts were asked if there were any IoT technologies or solutions they desired at their place of work. Their technological desires were categorized within the same three categories as described in section 4.5 above.

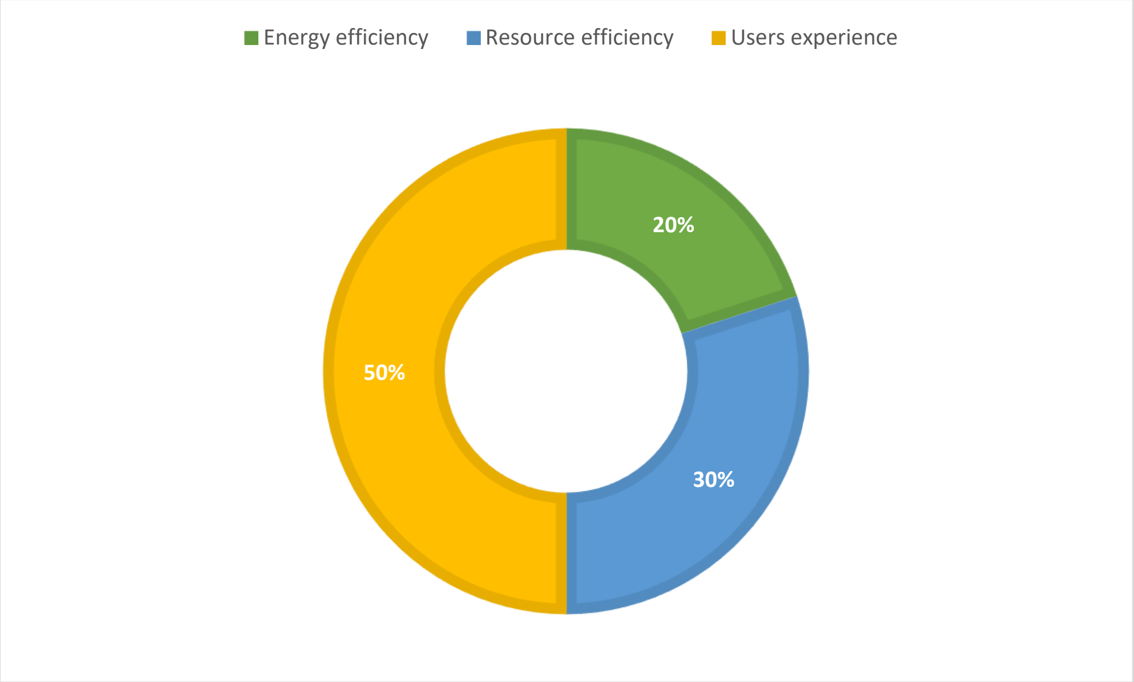


Figure 11 Technology areas of interest – user perspective

Of the 7 interview candidates, 5 mentioned IoT applications that were categorized within the user’s experience. These technologies were typically comfort and convenience related applications. Furthermore, 3 of the 7 candidates discussed IoT applications within resource efficiency. Typically, applications related this refers to maintenance and cleaning staff efficiency as well as personnel work efficiency. Finally, 2 of the 7 candidates mentioned IoT applications related to energy efficiency. Both candidates discussed user optimized temperature and airflow regulation.

4.7 Industry drivers

The domain experts were asked whom they believed to be the drivers to push IoT boundaries in buildings. As the interviews were semi-structured, there was no opposition to giving more than one answer. Therefore Figure 12 contains more answers than interview candidates.

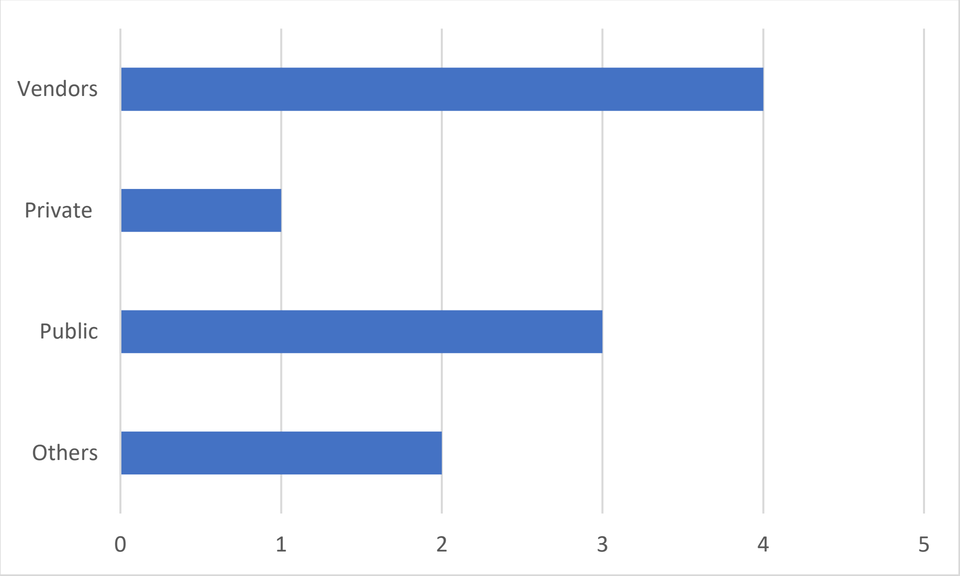


Figure 12: Drivers

As shown in Figure 12, a majority of the expectation is that vendors and the public sectors will be the main drivers in the technological advancement in buildings.

4.8 IoT Challenges

The domain experts were asked to identify challenges they perceive with the implementation and development of IoT solutions in buildings. Table 4 below shows the various challenges all interviewed candidates identified. Each of the challenges have been categorized within each of the IoT components, as described in Figure 2. Some of these challenges were discussed more than once by separate interview candidates. The number of times stated is represented under the "count" column.

Table 4: IoT Challenges

IoT Component	Count	Identified IoT challenges
Data	1	Open API, documented
	2	Data storage
	1	Data ownership
	1	Data security
People	3	Battery maintenance
	3	System complexity, challenging for maintenance personnel
	1	License costs
Things	1	More use of multi-sensors
Process	1	What data to use and how
	2	New data for analysis, resource-intensive

As shown in Table 4, 3 of the 7 candidates discussed maintenance of batteries and the complexity of systems would be a challenge with IoT in commercial buildings. Additionally, 2 out of 7 candidates stipulated challenges with data storage, as well as data analysis, to be too resource-intensive, as this would require manual labour.

5 Discussion & analysis

In the introduction, three research questions were presented. The first question, using an IoT maturity index approach, what is the current level of technological maturity in commercial buildings, towards smart buildings? The second question inquired which IoT technologies and systems are desirable in the industry? Finally, the last research question queried who are the technological drivers moving towards smart buildings?

5.1 Using an IoT Maturity Index approach, what is the current level of technological maturity in commercial buildings?

As there wasn’t an existing framework for measuring IoT maturity in buildings, the research designed a framework for this purpose. Section 3.3.2 goes into extensive detail on the proposed framework.

Following the interviews of the domain experts, due diligence was performed when analysing and categorizing their answers within the IMI framework. The initial analysis identified that the data had a skewed distribution across the categories from connectivity to adaptability, as shown in Figure 7. Though the distribution of data was spread from connectivity to adaptability, it was a positive observation that the maturity had extended past computerization, as computerization involves little or no IoT in the building. After further analysis, it was identified that the data could be segmented into two categories, commercial buildings for the public sector and commercial buildings for the private sector, which in return gave remarkably different results.

Beginning with the analysis of the private sector, when comparing Figure 7 to Figure 9, one can identify that the results are significantly different. Upon reviewing the results from private sectors, one finds that the vast majority fall within connectivity and visibility. From a perspective of smart buildings, at this stage, it contains very little or no IoT technology that signifies that this is a smart building. There is very little to no user noticeability of IoT technology in use at the connectivity and visibility stages. The technology at these stages consists of standard rule-based BAS, which is the minimum expectation from a commercial building. However, visibility starts to prepare the infrastructure of the building for greater connectivity, more data, and for future smart building applications. From this research, the domain experts indicated no use of IoT for artificial intelligence (AI) or predictive capacity in the private sector.

However, when reviewing the analysis of commercial buildings in the public sector, the results are very similar to the unsegmented results, as shown in Figure 8 and Figure 7. The main difference is that there are fewer IoT categorized within the connectivity stage;

additionally, there is more IoT technologies that transpire into visibility, predictive capacity as well as adaptability.

Using the IMI, one can identify that the public sector is advancing IoT utilisation in their buildings, even leaving the connectivity stage. When reviewing the details of the interviews as presented in Appendix B, the researcher identifies that there is only the use of motion detectors and some proprietary protocols remaining in the connectivity stage. The two are likely related. The delay in advancement may be because the technology is both cost-effective and energy-efficient. Regarding the progression path of lighting equipment, the following stages towards smart buildings entail lighting ergonomics and user customization. Progressing the light system to the next stage has little environmental or financial savings but high implementation costs. As shown in Figure 10, user experience is not a priority for property managers (PM) regarding smart building development. This may explain why lighting development is not a priority

Furthermore, the IMI identifies that the public sector is much further progressed towards smart buildings than the private sector. The BAS from the public sector use multi-sensors in a greater capacity than the private sector and utilise (when multi-sensors are not in use) input from multiple sensors in the BAS decision making. Similarly, new buildings built by the public sector in far greater capacity utilise predictive measures for energy efficiency. This entails using the weather forecast combined with expected energy costs the following day(s) to make the best financial and energy-efficient decision in preparing the building for extremely cold/hot days.

5.2 Which IoT technologies and systems are desirable in the industry?

The research identified that the desirable technologies in the industry may vary based on perspective. Therefore, section 0 is segmented into two perspectives, the perspective of the PM and the user's perspective.

When reviewing the IoT technologies and systems which are desirable from a PM perspective, energy efficiency is the dominating factor, as shown in Figure 10. Energy efficiency is both financial as well as environmentally beneficial. Though as also shown in Figure 10, IoT related to user experience is not prioritized. Throughout this research it is identified that the primary focus areas in smart buildings being built today is on energy efficiency. Though it is important to recognize that the development of the BAS, this also includes upgrading the infrastructure to accommodate the BAS of a smart building. This in turn makes future implementation of user experience as well as resource optimization IoT systems more attainable.

Furthermore, during interviews, it was identified that PM find its challenging to be on the bleeding edge of IoT development for building automation in most situations. There were two reasons for this: (1) there are high cost associated with the newest technology, high purchase price and technology quickly depreciates in cost once it matures. And (2) as with most newly developed technologies, there is a higher risk of failure and may require more support and employee training.

Some domain experts also identified that PM generally wants to avoid IoT that rely on batteries as a primary source of energy. Avoiding the use of batteries in IoT was especially true if there was a need for many such devices. The primary concern was the labour required to replace batteries, regardless of the expected battery life. PM were much more inclined to select a solution with a powered power source, either from the main outlet or Power over Ethernet (PoE). Even though the installation costs would be much higher, this was a preferable solution to avoid maintenance costs.

When considering the technologies of interest from the users perspective, there is a paradigm shift. The area of focus shifts from energy efficiency to technologies that improve users experience and comforts. Some users specified IoT technologies to assist with finding available parking and lockers, as well as previewing the cafeteria menu without leaving one’s workspace. These specified technologies are comfort related system, and though it has value for the users, it brings little value to the PM. Other technologies users identified was temperature and airflow regulation. Though these technologies are categorized under energy efficiency, users wanted the systems for their personal benefits rather than energy or environmental considerations.

As with most things, economy plays a large part in many decisions; this also holds true for building smart buildings. Domain experts recognise that the financial aspect plays a large part in building smart buildings, and PM are far more likely to accept a new system or technology presented as a system that will reduce the buildings' operating costs by optimising the buildings' energy consumption. However, systems such as optimising the building's resource (i.e. janitors, cleaning personnel etc.) and user experience are more challenging to document the costs and/or savings, thereby making the systems less appealing to a PM. Therefore, the IMI identifies systems related to energy optimising as further advanced than systems pertaining to user experience (exception is when users experience is part of the product, such as museums, shopping centres etc.) and resource optimization.

5.3 Who are the technological drivers moving towards smart buildings?

When queried, the domain experts identified the two main drivers of IoT to be the vendors and public sector, as shown in Figure 12. Naturally, vendors are at the front lines of driving technology further, as this is their product and livelihood. However, normal business concepts of need and demand still apply, and vendors still need to develop new products that are relevant to their market.

Furthermore, the domain experts also considered the public sector to be the drivers of IoT towards smart buildings. This claim is further supported by the results and analysis of the IMI; see sections 0 and 5.1 for more details.

The public sector is also the largest property manager in Norway (Byggeindustrien 2001). Therefore, it is also in their financial interest in finding ways to utilise the buildings' energy consumption more efficiently. In the public sector, the PM is both the owner and the occupant of the building. Therefore, operating costs affect them directly, whereas the occupant (tenant) would be responsible for the operational costs within the private sector. Due to the large amount of property owned by the public sector, a minor improvement in energy efficiency may yield large sums over the lifespan of the building. As the public sector accepts the latest developments in technology, they also undertake some of the development costs associated with this, making it easier for others to follow in the future.

Furthermore, the domain experts have identified that the private sector has many indicators in the visibility category of the IMI. This indicates that the private sector is preparing its infrastructure for the future implementation of IoT. Through logical deduction, there is a high likelihood that the private sector will follow the technological advancements when the technology matures and the costs of purchase and implementation declines.

6 Conclusion

In this thesis, the researcher has explored the use of IoT technology in commercial buildings to determine their current technological state as the building industry progresses towards smart buildings. Additionally, this thesis has researched which technologies and systems are desirable in the industry and the technological drivers of the industry.

To answer these research questions, semi-structured interviews were conducted with a total of 7 domain experts. It was determined to use semi-structured interviews, as this gave a possibility of structured questions and the opportunity for deeper prodding at the researchers' discretion. The data collected from the interviews were thoroughly reviewed then analysed.

To determine the level of maturity of buildings, the data was analysed using the IMI the researcher developed for this thesis. At this stage, it was identified a discrepancy between private and public sector. The data was further processed to recognise that the public sector had made significantly further progress towards smart buildings compared to the private sector. For the public sector, the technologies and systems ranged from connectivity to adaptability, which is the highest level on the IMI. Meanwhile, for the private sector, the technologies predominantly ranged from connectivity to visibility. At these stages, the private sector is preparing its infrastructure for future IoT implementation.

The IMI also uncovered that at this current stage of building smarter buildings, the majority of the technology is related to methods of energy efficiency. More specifically, energy efficiency within HVAC, temperature regulation and lighting, as these are the major operating costs that building owner/tenants can influence without inconvenience. Though smart buildings also cover aspects such as resource management and user experience, this research shows that current industry trends favour optimising the energy efficiency of buildings.

Furthermore, domain experts recognise both vendors and the public sector as the main drivers for smarter buildings. Vendors are expected to further develop and improve their products for better and more energy-efficient solutions. The public sector was also recognised as one of the main drivers for smarter buildings. Based on the data the IMI showed, the public sector is the main purchaser of the latest technological developments. If this is true, it is deduced that the public sector covers the R&D costs of new developments to some degree. This in turn makes the technologies more affordable for others PM's to follow in the future.

As technology and the building industry soars forward into the future, it is essential to recognize where we are today to try and predict and navigate to where we want to be tomorrow. This research intends to highlight the current progress buildings have undergone towards smart buildings and identify technologies that will be useful in the future. This research may deem useful in the building industry for engineers, consultants, vendors, and property managers, either for gaining new knowledge, verifying market trends, or giving managers the motivation to take the progressive technological step. After all, a building is no longer only a passive construction to shelter occupants from the elements, but a complexly engineered construction to accommodate our needs for comfort, safety, as well as physical and social needs. The advances in smart buildings automation utilising IoT can provide the bleeding-edge solution for improving visual and thermal comforts, security, monitoring building resource use, and enhancing energy efficiency.

6.1 Future work

There exist many opportunities to extend the elements of this study further. As part of this research, a framework for measuring maturity in buildings, based on IoT as an indicator was created. Furthermore, the index itself could be further developed and enhanced. Potentially, an index could be designed into a method of certifying a buildings intelligence. Much in the same way as how a Building Research Establishment Environmental Assessment Method (BREEAM) certification assesses the buildings sustainability and performance.

Furthermore, this research reveals that the public sector has advanced further than the private sector. Though the research has performed some deductive logic in order to explain why, further research is required to conclude the findings.

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Appendix A

A1. Intervjuguide

Informasjon til deltaker (deles med den som intervjues på forhånd)

Alle intervjuer vil utføres semistrukturert, dette vil innebære at det foreligger spørsmål kandidatene skal svare på, men det vil være mulig å gå mer I dybden underveis ut fra hva kandidaten svarer.

Mål for intervjuet

Innsikt i modenhet og funksjonelle krav, hvilke IoT løsninger som er viktige for byggherre/interessenter, og i hvilken grad IoT løsninger benyttes i næringsbygg.

Generelt om intervjuet

- Estimert tid: 45 min
- Type: semistrukturert intervju
- Stiller en rekke spørsmål, samt individuelle spørsmål underveis for avklaring eller utdyping av svar.
- Intervju vil være anonymt, men tilgjengelig på NTNU servere. Intervjukandidater vil bli informert dersom noen skal benytte opptakene etter avsluttet studie.
- Intervju vil være tatt opp, og gjennomføres via Microsoft Teams.

Introduksjon til intervjukandidater, ved interjustart

- Informerer om opptak, og om tillatelse for opptak

  Starter opptak

- Master oppgave i «Sustainable Manufacturing» ved NTNU Gjøvik
- Dette intervjuet skal brukes som en del av forskning i forbindelse med masteroppgaven.
- Hensikten med studiet er å kartlegge bruk og utnyttelse av IoT i næringsbygg samt behovet for byggherre/interessent/stakeholder.
- Dette intervjuet vil ikke være anonymisert, da opptak vil bli lagret hos NTNU. Veileder og sensur vil ha opptak tilgjengelig fram til studiet er avsluttet. Etter studiet er avsluttet vil opptak arkiveres hos NTNU. Opptakene vil være utilgjengelig for brukere. Dersom ditt opptak skal brukes ved en senere anledning vil du kontaktes på forhånd for samtykke. Dersom jeg skal sitere noe du sier i intervjuet, vil jeg kontaktet deg for tillatelse. Om ønskelig kan du få innsyn i de delene av oppgaven som omfatter ditt intervju før innlevering, og kopi av oppgave etter studiet avsluttes.
- Har du noen spørsmål angående anonymitet
- Har du noen spørsmål til intervjuet, eller studiet
- Da starter vi intervjuet

Intervjuspørsmål

Bakgrunn informasjon

- Tittel/rolle
- Hvor lenge har informant jobbet med dette?

Spørsmål:

Del 1 – Personlig mot ditt arbeidssted

- Hva forbinder du med IoT?
- Hvilken innstilling oppfatter du at ditt arbeidssted har til IoT, og i hvilken grad utnyttes dette?
- Hvilken IoT løsninger savner du på ditt arbeidssted?

Del 2 – Din erfaring fra arbeidslivet

- I hvilken grad erfarer du at byggherre/sluttbrukere utrykker ønsker for IoT løsninger i sitt næringsbygg?
- Hva er din erfaring med å presentere/selge/kjøpe IoT løsninger der byggherre ikke ønsker slike løsninger, evt. mottar IoT løsninger som en del av en "pakkeløsning" men har ingen intensjon om å benytte seg av løsningen?
- I hvilken grad en har i ettertid mottatt tilbakemelding fra brukere som i utgangspunktet ikke ønsket slike løsninger. (Positiv/Negativ)
- Hva er din erfaring med at byggherre/interessenter ønsker IoT løsninger som ikke er tilgjengelig på markedet/fra leverandør
- Hvilke områder kan du se for deg at IoT vil bli brukt I framtiden
- Hvilke utfordringer ser du med utviklingen og implementering av IoT løsninger
- Hvem ser du for deg vil drive denne utviklingen?
- Div. oppfølgingsspørsmål

Appendix B

B1 Results from AA

Blue = public sector, red = private sector, purple = both public and private sectors

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Use of open standard communications between systems and possibility of exchanging data	Systems have manual interface with little communications. More use of actuators and controllers	System is based on both open and proprietary protocols	All systems have two-way communication over open standardized protocol (ex. BACnet)	Systems have open documented API which makes it simple to exchange data.		
*Integration of control systems**		Some control systems are integrated one-to-one based on gateways (protocol converter)	All relevant control systems can be integrated to one system	Interactive management systems. Data is utilized across systems.	The control systems are predictive and shares data on expected future condition	The control systems are self-learning and improves its prediction models based on historical data
Availability of data, e.g. when using sensors and multisensors, paper towel usage, desk vacancy, parking etc.	No use of sensors	A small number of sensors are used by several system.	No unnecessary duplication of sensors. Instant data is available for all current systems, also future.	Simplified and flexible sensor system achieved by widespread use of multisensors and easy integration of additional sensors when needed	The sensor system is designed for high reliability through self-testing sensors, easy renewal of sensors, and the use of redundant sensors if necessary.	Machine learning algorithms checks system quality and reveals system errors.
Collection of structured data and analysis of these	No data is produced or data is not stored	Small and unstructured collection of data	Collection of structured data in real time. Data structure must be documented and available. No unnecessary duplication of data	Structured collection and storage of historical data. Data can be easily made available to third parties.	Large amounts of data are used for prediction	Large amounts of data are utilized by self-learning systems to to increase the precision system control during ordinary operation.

Technical networks	No network, or poor disciplined network.	A separate network per technical system.	A common technical network for all technical systems. The network can be segmented and supports access control with a centralized access register	All devices connected will be assigned access to the correct segment based on the devices defined functions and needs. Traffic and condition of the network is monitored	The network monitors data traffic and detects irregularities. The system alerts and handles deviations.	The technical network is self-learning and self-securing.
Positioning of people and equipment in the building	The building offers no positioning services	The building offers no positioning services	The building is prepared for indoor use positioning based on Wi-Fi triangulation, bluetooth beacons or a combination of these. Necessary wireless access points (WAP) and beacons are installed.	Users are assisted with navigating the building based on their position. Movable equipment is tracked and position made available to users.	The building offers users positioning services that let them find colleagues and be found.	

Climate control

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Temperature regulation *Thermal environment*	Temperature is regulated by physically adjusting the temperature controller on the device.	Temperature is controlled by preset temperature levels and operating times.	The building system makes it possible to include other sources (e.g. presence and meeting room calendar) in temperature control. If the building has openable windows, these must have a sensor for opening sensing and outdoor air quality.	The building's systems have the opportunity to exchange information with the user in real time, eg about temperature in different zones. Cooling and the heating systems are controlled on a holistically with other systems and can e.g. take into account if windows are open.	Temperature is controlled rule-based in regards to information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from unique users and responders on these, e.g. by adjusting temperature or giving users personal guidance.	The system is controlled from a large range of inputs, including usage patterns, are self-learning and uses historical data for to improve their prediction models to ensure satisfaction users.
Atmospheric environment	Airflow is controlled by preset operating times.	Airflow is controlled according to preset CO^2 levels and operating times. At this stage, the CO^2 monitor is connected directly to the HVAC	Airflow can be controlled based on multiple sources in real time (e.g. activity in room, and CO^2). If openable windows, these must have a sensor for opening and outdoor air sensors	Users can influence the amount of air natural and/or mechanical. The cooling and heating systems are controlled holistically with other systems and can for example take into account if a windows open.	Airflow is controlled on rule-based information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from individual users and adjusts settings based on this, e.g. by adjusting temperature	The system is controlled from a large range of data, where sometimes usage pattern, is self-learning and uses historical data for to improve their prediction models to ensure satisfied users.

Daylight and lighting	Lighting is turned on and off using a switch.	Lighting is turned on and off based on presence (motion sensor) and/or operating times.	The light control system controls the light level by presence, daylight level and operating times. Measures for optimal utilization of daylight taken into account in the design of the building. The lighting system is divided into appropriate zones and adapted for two-way communication in control system.	Amount of light and color temperature can be controlled by several sources such as time of day and season.	The lighting system receives feedback from individual users and provides users with information and guidance.	Amount of light and color temperature controlled in addition based on users physiology and preferences, after the principle of human centric lightning.

Energy and resource optimalisation

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Energy consumption and device management (lighting and equipment)	No lighting automation	Lighting is controlled based on predefined operating times and sensors.	All lighting and relevant electrical equipment shall have the possibility of two-way communication.	The units are controlled energy efficiently and effectively based on multiple sensor/data inputs (e.g. presence, sunscreen and daylight level) in real time. Energy consumption is measured and logged.	The units are controlled energy efficiently and effectively based on predicted needs (e.g. based on expected use and weather forecast).	The units are controlled energy efficiently and effectively based using large amounts of operational data and machine learning.
Climate technical system and thermal energy supply		Climate technology system such as satisfies TEK17.	The climate technology system is holistically designed (combination of passive and active measures) and easily optimized in operation. All relevant devices (e.g. heat pumps, valves, fans and temperature sensors) and zones in the building shall have the possibility of two-way communication.	The system is controlled and operated optimally energy based on several data sources (e.g. actual weather conditions, usage pattern and building response) in real time.	The system is controlled and operated at optimal energy efficiency based on usage pattern, and weather forecasting services. The system prepares themselves on upcoming heat and cold periods based on fixed algorithms.	The building is self-learning and improves its algorithms for control and operation adapted to usage pattern, the weather forecast and the actual weather.
Building spatial awareness and optimalisation				The building detects low use of space (typical for public holidays), and	Building prepares for shutting down part of the build on periods expected to have low	The building is self-learning and improves its algorithms for control

			🟥	suggests users to relocate to certain floors, in order to "shut down" floors to save energy.	occupancy, e.g. giving users feedback on floor (un)availability when booking meeting rooms or workspace.	and operation adapted to usage pattern.
Building maintenance staff optimisation		🟥	Sensors are installed to indicate when maintenance is required. E.g. which workstations have been in use, refill paper towels in WC etc.		The building monitors floor/area activity and predicts and notifies maintenance staff before service is required. E.g. When paper towel, hand sanitizer, soap dispenser is nearing empty.	Building is self-learning and improves its algorithms for control and operation using patterns and historical data to predict the required amount of maintenance required at a monthly/quartering interval

B2 Results from BB

Blue = public sector, red = private sector, purple = both public and private sectors

	Computerization	**Connectivity**	**Visibility**	**Transparency**	**Predictive capacity**	**Adaptability**
Use of open standard communications between systems and possibility of exchanging data	Systems have manual interface with little communications. More use of actuators and controllers	System is based on both open and proprietary protocols	All systems have two-way communication over open standardized protocol (ex. BACnet)	🟦 Systems have open documented API which makes it simple to exchange data.		
*Integration of control systems**		🟥 Some control systems are integrated one-to-one based on gateways (protocol converter)	All relevant control systems can be integrated to one system	Interactive management systems. Data is utilized across systems.	🟦 The control systems are predictive and shares data on expected future condition	The control systems are self-learning and improves its prediction models based on historical data
Availability of data, e.g. when using sensors and multisensors, paper towel usage, desk vacancy, parking etc.	No use of sensors	A small number of sensors are used by several system.	No unnecessary duplication of sensors. Instant data is available for all current systems, also future.	🟦 Simplified and flexible sensor system achieved by widespread use of multisensors and easy integration of additional sensors when needed	The sensor system is designed for high reliability through self-testing sensors, easy renewal of sensors, and the use of redundant sensors if necessary.	Machine learning algorithms checks system quality and reveals system errors.
Collection of structured data and analysis of these	No data is produced or data is not stored	Small and unstructured collection of data	Collection of structured data in real time. Data structure must be documented and available. No unnecessary duplication of data	🟦 Structured collection and storage of historical data. Data can be easily made available to third parties.	Large amounts of data are used for prediction	Large amounts of data are utilized by self-learning systems to to increase the precision system control during ordinary operation.

Technical networks	No network, or poor disciplined network.	A separate network per technical system.	A common technical network for all technical systems. The network can be segmented and supports access control with a centralized access register	All devices connected will be assigned access to the correct segment based on the devices defined functions and needs. Traffic and condition of the network is monitored	The network monitors data traffic and detects irregularities. The system alerts and handles deviations.	The technical network is self-learning and self-securing.
Positioning of people and equipment in the building	The building offers no positioning services	The building offers no positioning services	The building is prepared for indoor use positioning based on Wi-Fi triangulation, bluetooth beacons or a combination of these. Necessary wireless access points (WAP) and beacons are installed.	Users are assisted with navigating the building based on their position. Movable equipment is tracked and position made available to users.	The building offers users positioning services that let them find colleagues and be found.	

Climate control

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Temperature regulation *Thermal environment*	Temperature is regulated by physically adjusting the temperature controller on the device.	Temperature is controlled by preset temperature levels and operating times.	The building system makes it possible to include other sources (e.g. presence and meeting room calendar) in temperature control. If the building has openable windows, these must have a sensor for opening sensing and outdoor air quality.	The building's systems have the opportunity to exchange information with the user in real time, eg about temperature in different zones. Cooling and the heating systems are controlled on a holistically with other systems and can e.g. take into account if windows are open.	Temperature is controlled rule-based in regards to information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from unique users and responders on these, e.g. by adjusting temperature or giving users personal guidance.	The system is controlled from a large range of inputs, including usage patterns, are self-learning and uses historical data for to improve their prediction models to ensure satisfaction users.
Atmospheric environment	Airflow is controlled by preset operating times.	Airflow is controlled according to preset CO^2 levels and operating times. At this stage, the CO^2 monitor is connected directly to the HVAC	Airflow can be controlled based on multiple sources in real time (e.g. activity in room, and CO^2). If openable windows, these must have a sensor for opening and outdoor air sensors	Users can influence the amount of air natural and/or mechanical. The cooling and heating systems are controlled holistically with other systems and can for example take into account if a windows open.	Airflow is controlled on rule-based information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from individual users and adjusts settings based on this, e.g. by adjusting temperature	The system is controlled from a large range of data, where sometimes usage pattern, is self-learning and uses historical data for to improve their prediction models to ensure satisfied users.

Daylight and lighting	Lighting is turned on and off using a switch.	Lighting is turned on and off based on presence (motion sensor) and/or operating times.	The light control system controls the light level by presence, daylight level and operating times. Measures for optimal utilization of daylight taken into account in the design of the building. The lighting system is divided into appropriate zones and adapted for two-way communication in control system.	Amount of light and color temperature can be controlled by several sources such as time of day and season.	The lighting system receives feedback from individual users and provides users with information and guidance.	Amount of light and color temperature controlled in addition based on users physiology and preferences, after the principle of human centric lightning.

Energy and resource optimalisation

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Energy consumption and device management (lighting and equipment)	No lighting automation	Lighting is controlled based on predefined operating times and sensors.	All lighting and relevant electrical equipment shall have the possibility of two-way communication.	The units are controlled energy efficiently and effectively based on multiple sensor/data inputs (e.g. presence, sunscreen and daylight level) in real time. Energy consumption is measured and logged.	The units are controlled energy efficiently and effectively based on predicted needs (e.g. based on expected use and weather forecast).	The units are controlled energy efficiently and effectively based using large amounts of operational data and machine learning.
Climate technical system and thermal energy supply		Climate technology system such as satisfies TEK17.	The climate technology system is holistically designed (combination of passive and active measures) and easily optimized in operation. All relevant devices (e.g. heat pumps, valves, fans and temperature sensors) and zones in the building shall have the possibility of two-way communication.	The system is controlled and operated optimally energy based on several data sources (e.g. actual weather conditions, usage pattern and building response) in real time.	The system is controlled and operated at optimal energy efficiency based on usage pattern, and weather forecasting services. The system prepares themselves on upcoming heat and cold periods based on fixed algorithms.	The building is self-learning and improves its algorithms for control and operation adapted to usage pattern, the weather forecast and the actual weather.
Building spatial awareness and optimalisation			🟥	The building detects low use of space (typical for public holidays), and suggests users to relocate to certain floors, in order to "shut down" floors to save energy.	Building prepares for shutting down part of the build on periods expected to have low occupancy, e.g. giving users feedback on floor (un)availability when	The building is self-learning and improves its algorithms for control and operation adapted to usage pattern.

			🟥		booking meeting rooms or workspace.	
Building maintenance staff optimalisation		🟥	Sensors are installed to indicate when maintenance is required. E.g. which workstations have been in use, refill paper towels in WC etc.		The building monitors floor/area activity and predicts and notifies maintenance staff before service is required. E.g. When paper towel, hand sanitizer, soap dispenser is nearing empty.	Building is self-learning and improves its algorithms for control and operation using patterns and historical data to predict the required amount of maintenance required at a monthly/quartering interval

B3 Results from CC

Blue = public sector, red = private sector, purple = both public and private sectors

	Computerization	**Connectivity**	**Visibility**	**Transparency**	**Predictive capacity**	**Adaptability**
Use of open standard communications between systems and possibility of exchanging data	Systems have manual interface with little communications. More use of actuators and controllers	System is based on both open and proprietary protocols	All systems have two-way communication over open standardized protocol (ex. BACnet)	Systems have open documented API which makes it simple to exchange data.		
*Integration of control systems**		Some control systems are integrated one-to-one based on gateways (protocol converter)	All relevant control systems can be integrated to one system	Interactive management systems. Data is utilized across systems.	The control systems are predictive and shares data on expected future condition	The control systems are self-learning and improves its prediction models based on historical data
Availability of data, e.g. when using sensors and multisensors, paper towel usage, desk vacancy, parking etc.	No use of sensors	A small number of sensors are used by several system.	No unnecessary duplication of sensors. Instant data is available for all current systems, also future.	Simplified and flexible sensor system achieved by widespread use of multisensors and easy integration of additional sensors when needed	The sensor system is designed for high reliability through self-testing sensors, easy renewal of sensors, and the use of redundant sensors if necessary.	Machine learning algorithms checks system quality and reveals system errors.
Collection of structured data and analysis of these	No data is produced or data is not stored	Small and unstructured collection of data	Collection of structured data in real time. Data structure must be documented and available. No unnecessary duplication of data	Structured collection and storage of historical data. Data can be easily made available to third parties.	Large amounts of data are used for prediction	Large amounts of data are utilized by self-learning systems to to increase the precision system control during ordinary operation.

Technical networks	No network, or poor disciplined network.	A separate network per technical system.	A common technical network for all technical systems. The network can be segmented and supports access control with a centralized access register	All devices connected will be assigned access to the correct segment based on the devices defined functions and needs. Traffic and condition of the network is monitored	The network monitors data traffic and detects irregularities. The system alerts and handles deviations.	The technical network is self-learning and self-securing.
Positioning of people and equipment in the building	The building offers no positioning services	The building offers no positioning services	The building is prepared for indoor use positioning based on Wi-Fi triangulation, bluetooth beacons or a combination of these. Necessary wireless access points (WAP) and beacons are installed.	Users are assisted with navigating the building based on their position. Movable equipment is tracked and position made available to users.	The building offers users positioning services that let them find colleagues and be found.	

Climate control

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Temperature regulation *Thermal environment*	Temperature is regulated by physically adjusting the temperature controller on the device.	Temperature is controlled by preset temperature levels and operating times.	The building system makes it possible to include other sources (e.g. presence and meeting room calendar) in temperature control. If the building has openable windows, these must have a sensor for opening sensing and outdoor air quality.	The building's systems have the opportunity to exchange information with the user in real time, eg about temperature in different zones. Cooling and the heating systems are controlled on a holistically with other systems and can e.g. take into account if windows are open.	Temperature is controlled rule-based in regards to information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from unique users and responders on these, e.g. by adjusting temperature or giving users personal guidance.	The system is controlled from a large range of inputs, including usage patterns, are self-learning and uses historical data for to improve their prediction models to ensure satisfaction users.
Atmospheric environment	Airflow is controlled by preset operating times.	Airflow is controlled according to preset CO² levels and operating times. At this stage, the CO² monitor is connected directly to the HVAC	Airflow can be controlled based on multiple sources in real time (e.g. activity in room, and CO²). If openable windows, these must have a sensor for opening and outdoor air sensors	Users can influence the amount of air natural and/or mechanical. The cooling and heating systems are controlled holistically with other systems and can for example take into account if a windows open.	Airflow is controlled on rule-based information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from individual users and adjusts settings based on this, e.g. by adjusting temperature	The system is controlled from a large range of data, where sometimes usage pattern, is self-learning and uses historical data for to improve their prediction models to ensure satisfied users.

Daylight and lighting	Lighting is turned on and off using a switch.	Lighting is turned on and off based on presence (motion sensor) and/or operating times.	The light control system controls the light level by presence, daylight level and operating times. Measures for optimal utilization of daylight taken into account in the design of the building. The lighting system is divided into appropriate zones and adapted for two-way communication in control system.	Amount of light and color temperature can be controlled by several sources such as time of day and season.	The lighting system receives feedback from individual users and provides users with information and guidance.	Amount of light and color temperature controlled in addition based on users physiology and preferences, after the principle of human centric lightning.

Energy and resource optimalisation

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Energy consumption and device management (lighting and equipment)	No lighting automation	Lighting is controlled based on predefined operating times and sensors.	All lighting and relevant electrical equipment shall have the possibility of two-way communication.	The units are controlled energy efficiently and effectively based on multiple sensor/data inputs (e.g. presence, sunscreen and daylight level) in real time. Energy consumption is measured and logged.	The units are controlled energy efficiently and effectively based on predicted needs (e.g. based on expected use and weather forecast).	The units are controlled energy efficiently and effectively based using large amounts of operational data and machine learning.
Climate technical system and thermal energy supply		Climate technology system such as satisfies TEK17.	The climate technology system is holistically designed (combination of passive and active measures) and easily optimized in operation. All relevant devices (e.g. heat pumps, valves, fans and temperature sensors) and zones in the building shall have the possibility of two-way communication.	The system is controlled and operated optimally energy based on several data sources (e.g. actual weather conditions, usage pattern and building response) in real time.	The system is controlled and operated at optimal energy efficiency based on usage pattern, and weather forecasting services. The system prepares themselves on upcoming heat and cold periods based on fixed algorithms.	The building is self-learning and improves its algorithms for control and operation adapted to usage pattern, the weather forecast and the actual weather.
Building spatial awareness and optimalisation				The building detects low use of space (typical for public	Building prepares for shutting down part of the build on periods	The building is self-learning and improves

				holidays), and suggests users to relocate to certain floors, in order to "shut down" floors to save energy.	expected to have low occupancy, e.g. giving users feedback on floor (un)availability when booking meeting rooms or workspace.	its algorithms for control and operation adapted to usage pattern.
Building maintenance staff optimalisation		Sensor on toilet rolls etc.	Sensors are installed to indicate when maintenance is required. E.g. which workstations have been in use, refill paper towels in WC etc.		The building monitors floor/area activity and predicts and notifies maintenance staff before service is required. E.g. When paper towel, hand sanitizer, soap dispenser is nearing empty.	Building is self-learning and improves its algorithms for control and operation using patterns and historical data to predict the required amount of maintenance required at a monthly/quartering interval

B4 Results from DD

Blue = public sector, red = private sector, purple = both public and private sectors

	Computerization	**Connectivity**	**Visibility**	**Transparency**	**Predictive capacity**	**Adaptability**
Use of open standard communications between systems and possibility of exchanging data	Systems have manual interface with little communications. More use of actuators and controllers	System is based on both open and proprietary protocols	All systems have two-way communication over open standardized protocol (ex. BACnet)	Systems have open documented API which makes it simple to exchange data.		
*Integration of control systems**		Some control systems are integrated one-to-one based on gateways (protocol converter)	All relevant control systems can be integrated to one system	Interactive management systems. Data is utilized across systems.	The control systems are predictive and shares data on expected future condition	The control systems are self-learning and improves its prediction models based on historical data
Availability of data, e.g. when using sensors and multisensors, paper towel usage, desk vacancy, parking etc.	No use of sensors	A small number of sensors are used by several system.	No unnecessary duplication of sensors. Instant data is available for all current systems, also future.	Simplified and flexible sensor system achieved by widespread use of multisensors and easy integration of additional sensors when needed	The sensor system is designed for high reliability through self-testing sensors, easy renewal of sensors, and the use of redundant sensors if necessary.	Machine learning algorithms checks system quality and reveals system errors.
Collection of structured data and analysis of these	No data is produced or data is not stored	Small and unstructured collection of data	Collection of structured data in real time. Data structure must be documented and available. No unnecessary duplication of data	Structured collection and storage of historical data. Data can be easily made available to third parties.	Large amounts of data are used for prediction	Large amounts of data are utilized by self-learning systems to to increase the precision system control during ordinary operation.
Technical networks	No network, or poor disciplined network.	A separate network per technical system.	A common technical network for all technical systems. The network can be segmented and supports access control with a centralized access register	All devices connected will be assigned access to the correct segment based on the devices defined functions and needs. Traffic and	The network monitors data traffic and detects irregularities. The system alerts and handles deviations.	The technical network is self-learning and self-securing.

				condition of the network is monitored		
Positioning of people and equipment in the building	The building offers no positioning services	The building offers no positioning services	The building is prepared for indoor use positioning based on Wi-Fi triangulation, bluetooth beacons or a combination of these. Necessary wireless access points (WAP) and beacons are installed.	Users are assisted with navigating the building based on their position. Movable equipment is tracked and position made available to users.	The building offers users positioning services that let them find colleagues and be found.	

Climate control

	Computerization	**Connectivity**	**Visibility**	**Transparency**	**Predictive capacity**	**Adaptability**
Temperature regulation *Thermal environment*	Temperature is regulated by physically adjusting the temperature controller on the device.	Temperature is controlled by preset temperature levels and operating times.	The building system makes it possible to include other sources (e.g. presence and meeting room calendar) in temperature control. If the building has openable windows, these must have a sensor for opening sensing and outdoor air quality.	The building's systems have the opportunity to exchange information with the user in real time, eg about temperature in different zones. Cooling and the heating systems are controlled on a holistically with other systems and can e.g. take into account if windows are open.	Temperature is controlled rule-based in regards to information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from unique users and responders on these, e.g. by adjusting temperature or giving users personal guidance.	The system is controlled from a large range of inputs, including usage patterns, are self-learning and uses historical data for to improve their prediction models to ensure satisfaction users.
Atmospheric environment	Airflow is controlled by preset operating times.	Airflow is controlled according to preset CO^2 levels and operating times. At this stage, the CO^2 monitor is connected directly to the HVAC	Airflow can be controlled based on multiple sources in real time (e.g. activity in room, and CO^2). If openable windows, these must have a sensor for opening and outdoor air sensors	Users can influence the amount of air natural and/or mechanical. The cooling and heating systems are controlled holistically with other systems and can for example take into account if a windows open.	Airflow is controlled on rule-based information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from individual users and adjusts settings based on this, e.g. by adjusting temperature	The system is controlled from a large range of data, where sometimes usage pattern, is self-learning and uses historical data for to improve their prediction models to ensure satisfied users.

Daylight and lighting	Lighting is turned on and off using a switch.	Lighting is turned on and off based on presence (motion sensor) and/or operating times.	The light control system controls the light level by presence, daylight level and operating times. Measures for optimal utilization of daylight taken into account in the design of the building. The lighting system is divided into appropriate zones and adapted for two-way communication in control system.	Amount of light and color temperature can be controlled by several sources such as time of day and season.	The lighting system receives feedback from individual users and provides users with information and guidance.	Amount of light and color temperature controlled in addition based on users physiology and preferences, after the principle of human centric lightning.

Energy and resource optimalisation

	Computerization	**Connectivity**	**Visibility**	**Transparency**	**Predictive capacity**	**Adaptability**
Energy consumption and device management (lighting and equipment)	No lighting automation	Lighting is controlled based on predefined operating times and sensors.	All lighting and relevant electrical equipment shall have the possibility of two-way communication.	The units are controlled energy efficiently and effectively based on multiple sensor/data inputs (e.g. presence, sunscreen and daylight level) in real time. Energy consumption is measured and logged.	The units are controlled energy efficiently and effectively based on predicted needs (e.g. based on expected use and weather forecast).	The units are controlled energy efficiently and effectively based using large amounts of operational data and machine learning.
Climate technical system and thermal energy supply		Climate technology system such as satisfies TEK17.	The climate technology system is holistically designed (combination of passive and active measures) and easily optimized in operation. All relevant devices (e.g. heat pumps, valves, fans and temperature sensors) and zones in the building shall have the possibility of two-way communication.	The system is controlled and operated optimally energy based on several data sources (e.g. actual weather conditions, usage pattern and building response) in real time.	The system is controlled and operated at optimal energy efficiency based on usage pattern, and weather forecasting services. The system prepares themselves on upcoming heat and cold periods based on fixed algorithms.	The building is self-learning and improves its algorithms for control and operation adapted to usage pattern, the weather forecast and the actual weather.
Building spatial awareness and optimalisation				The building detects low use of space (typical for public	Building prepares for shutting down part of the build on periods	The building is self-learning and improves

				holidays), and suggests users to relocate to certain floors, in order to “shut down” floors to save energy.	expected to have low occupancy, e.g. giving users feedback on floor (un)availability when booking meeting rooms or workspace.	its algorithms for control and operation adapted to usage pattern.
Building maintenance staff optimalisation		🟥	Sensors are installed to indicate when maintenance is required. E.g. which workstations have been in use, refill paper towels in WC etc.		The building monitors floor/area activity and predicts and notifies maintenance staff before service is required. E.g. When paper towel, hand sanitizer, soap dispenser is nearing empty.	Building is self-learning and improves its algorithms for control and operation using patterns and historical data to predict the required amount of maintenance required at a monthly/quartering interval

B5 Results from EE

Blue = public sector, red = private sector, purple = both public and private sectors

	Computerization	**Connectivity**	**Visibility**	**Transparency**	**Predictive capacity**	**Adaptability**
Use of open standard communications between systems and possibility of exchanging data	Systems have manual interface with little communications. More use of actuators and controllers	System is based on both open and proprietary protocols	All systems have two-way communication over open standardized protocol (ex. BACnet)	Systems have open documented API which makes it simple to exchange data.		
*Integration of control systems**		Some control systems are integrated one-to-one based on gateways (protocol converter)	All relevant control systems can be integrated to one system	Interactive management systems. Data is utilized across systems.	The control systems are predictive and shares data on expected future condition	The control systems are self-learning and improves its prediction models based on historical data
Availability of data, e.g. when using sensors and multisensors, paper towel usage, desk vacancy, parking etc.	No use of sensors	A small number of sensors are used by several system.	No unnecessary duplication of sensors. Instant data is available for all current systems, also future.	Simplified and flexible sensor system achieved by widespread use of multisensors and easy integration of additional sensors when needed	The sensor system is designed for high reliability through self-testing sensors, easy renewal of sensors, and the use of redundant sensors if necessary.	Machine learning algorithms checks system quality and reveals system errors.
Collection of structured data and analysis of these	No data is produced or data is not stored	Small and unstructured collection of data	Collection of structured data in real time. Data structure must be documented and available. No unnecessary duplication of data	Structured collection and storage of historical data. Data can be easily made available to third parties.	Large amounts of data are used for prediction	Large amounts of data are utilized by self-learning systems to to increase the precision system control during ordinary operation.
Technical networks	No network, or poor disciplined network.	A separate network per technical system.	A common technical network for all technical systems. The network can be segmented and supports	All devices connected will be assigned access to the correct segment based on the devices defined functions and needs.	The network monitors data traffic and detects irregularities. The system alerts and handles deviations.	The technical network is self-learning and self-securing.

			access control with a centralized access register	Traffic and condition of the network is monitored		
Positioning of people and equipment in the building	The building offers no positioning services	The building offers no positioning services	The building is prepared for indoor use positioning based on Wi-Fi triangulation, bluetooth beacons or a combination of these. Necessary wireless access points (WAP) and beacons are installed.	Users are assisted with navigating the building based on their position. Movable equipment is tracked and position made available to users.	The building offers users positioning services that let them find colleagues and be found.	

Climate control

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Temperature regulation *Thermal environment*	Temperature is regulated by physically adjusting the temperature controller on the device.	Temperature is controlled by preset temperature levels and operating times.	The building system makes it possible to include other sources (e.g. presence and meeting room calendar) in temperature control. If the building has openable windows, these must have a sensor for opening sensing and outdoor air quality.	The building's systems have the opportunity to exchange information with the user in real time, eg about temperature in different zones. Cooling and the heating systems are controlled on a holistically with other systems and can e.g. take into account if windows are open.	Temperature is controlled rule-based in regards to information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from unique users and responders on these, e.g. by adjusting temperature or giving users personal guidance.	The system is controlled from a large range of inputs, including usage patterns, are self-learning and uses historical data for to improve their prediction models to ensure satisfaction users.
Atmospheric environment	Airflow is controlled by preset operating times.	Airflow is controlled according to preset CO^2 levels and operating times. At this stage, the CO^2 monitor is connected directly to the HVAC	Airflow can be controlled based on multiple sources in real time (e.g. activity in room, and CO^2). If openable windows, these must have a sensor for opening and outdoor air sensors	Users can influence the amount of air natural and/or mechanical. The cooling and heating systems are controlled holistically with other systems and can for example take into account if a windows open.	Airflow is controlled on rule-based information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from individual users and adjusts settings based on this, e.g. by adjusting temperature	The system is controlled from a large range of data, where sometimes usage pattern, is self-learning and uses historical data for to improve their prediction models to ensure satisfied users.

Daylight and lighting	Lighting is turned on and off using a switch.	Lighting is turned on and off based on presence (motion sensor) and/or operating times.	The light control system controls the light level by presence, daylight level and operating times. Measures for optimal utilization of daylight taken into account in the design of the building. The lighting system is divided into appropriate zones and adapted for two-way communication in control system.	Amount of light and color temperature can be controlled by several sources such as time of day and season.	The lighting system receives feedback from individual users and provides users with information and guidance.	Amount of light and color temperature controlled in addition based on users physiology and preferences, after the principle of human centric lightning.

Energy and resource optimalisation

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Energy consumption and device management (lighting and equipment)	No lighting automation	Lighting is controlled based on predefined operating times and sensors.	All lighting and relevant electrical equipment shall have the possibility of two-way communication.	The units are controlled energy efficiently and effectively based on multiple sensor/data inputs (e.g. presence, sunscreen and daylight level) in real time. Energy consumption is measured and logged.	The units are controlled energy efficiently and effectively based on predicted needs (e.g. based on expected use and weather forecast).	The units are controlled energy efficiently and effectively based using large amounts of operational data and machine learning.
Climate technical system and thermal energy supply		Climate technology system such as satisfies TEK17.	The climate technology system is holistically designed (combination of passive and active measures) and easily optimized in operation. All relevant devices (e.g. heat pumps, valves, fans and temperature sensors) and zones in the building shall have the possibility of two-way communication.	The system is controlled and operated optimally energy based on several data sources (e.g. actual weather conditions, usage pattern and building response) in real time.	The system is controlled and operated at optimal energy efficiency based on usage pattern, and weather forecasting services. The system prepares themselves on upcoming heat and cold periods based on fixed algorithms.	The building is self-learning and improves its algorithms for control and operation adapted to usage pattern, the weather forecast and the actual weather.
Building spatial awareness and optimalisation				The building detects low use of space (typical for public holidays), and	Building prepares for shutting down part of the build on periods expected to have low	The building is self-learning and improves its algorithms for control

				suggests users to relocate to certain floors, in order to “shut down” floors to save energy.	occupancy, e.g. giving users feedback on floor (un)availability when booking meeting rooms or workspace.	and operation adapted to usage pattern.
Building maintenance staff optimalisation			Sensors are installed to indicate when maintenance is required. E.g. which workstations have been in use, refill paper towels in WC etc.		The building monitors floor/area activity and predicts and notifies maintenance staff before service is required. E.g. When paper towel, hand sanitizer, soap dispenser is nearing empty.	Building is self-learning and improves its algorithms for control and operation using patterns and historical data to predict the required amount of maintenance required at a monthly/quartering interval

B6 Results from FF

Blue = public sector, red = private sector, purple = both public and private sectors

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Use of open standard communications between systems and possibility of exchanging data	Systems have manual interface with little communications. More use of actuators and controllers	🟥 System is based on both open and proprietary protocols	All systems have two-way communication over open standardized protocol (ex. BACnet)	🟦 Systems have open documented API which makes it simple to exchange data.		
*Integration of control systems**		Some control systems are integrated one-to-one based on gateways (protocol converter)	All relevant control systems can be integrated to one system	🟪 Interactive management systems. Data is utilized across systems.	The control systems are predictive and shares data on expected future condition	The control systems are self-learning and improves its prediction models based on historical data
Availability of data, e.g. when using sensors and multisensors, paper towel usage, desk vacancy, parking etc.	No use of sensors	A small number of sensors are used by several system.	🟥 No unnecessary duplication of sensors. Instant data is available for all current systems, also future.	🟦 Simplified and flexible sensor system achieved by widespread use of multisensors and easy integration of additional sensors when needed	The sensor system is designed for high reliability through self-testing sensors, easy renewal of sensors, and the use of redundant sensors if necessary.	Machine learning algorithms checks system quality and reveals system errors.
Collection of structured data and analysis of these	No data is produced or data is not stored	Small and unstructured collection of data	🟪 Collection of structured data in real time. Data structure must be documented and available. No unnecessary duplication of data	Structured collection and storage of historical data. Data can be easily made available to third parties.	Large amounts of data are used for prediction	Large amounts of data are utilized by self-learning systems to to increase the precision system control during ordinary operation.
Technical networks	No network, or poor disciplined network.	A separate network per technical system.	A common technical network for all technical systems. The network	All devices connected will be assigned access to the correct segment	The network monitors data traffic and detects irregularities.	The technical network is self-learning and self-securing.

			can be segmented and supports access control with a centralized access register	based on the devices defined functions and needs. Traffic and condition of the network is monitored	The system alerts and handles deviations.	
Positioning of people and equipment in the building	The building offers no positioning services	The building offers no positioning services	The building is prepared for indoor use positioning based on Wi-Fi triangulation, bluetooth beacons or a combination of these. Necessary wireless access points (WAP) and beacons are installed.	Users are assisted with navigating the building based on their position. Movable equipment is tracked and position made available to users.	The building offers users positioning services that let them find colleagues and be found.	

Climate control

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Temperature regulation *Thermal environment*	Temperature is regulated by physically adjusting the temperature controller on the device.	Temperature is controlled by preset temperature levels and operating times.	The building system makes it possible to include other sources (e.g. presence and meeting room calendar) in temperature control. If the building has openable windows, these must have a sensor for opening sensing and outdoor air quality.	The building's systems have the opportunity to exchange information with the user in real time, eg about temperature in different zones. Cooling and the heating systems are controlled on a holistically with other systems and can e.g. take into account if windows are open.	Temperature is controlled rule-based in regards to information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from unique users and responders on these, e.g. by adjusting temperature or giving users personal guidance.	The system is controlled from a large range of inputs, including usage patterns, are self-learning and uses historical data for to improve their prediction models to ensure satisfaction users.
Atmospheric environment	Airflow is controlled by preset operating times.	Airflow is controlled according to preset CO^2 levels and operating times. At this stage, the CO^2 monitor is connected directly to the HVAC	Airflow can be controlled based on multiple sources in real time (e.g. activity in room, and CO^2). If openable windows, these must have a sensor for opening and outdoor air sensors	Users can influence the amount of air natural and/or mechanical. The cooling and heating systems are controlled holistically with other systems and can for example take into account if a windows open.	Airflow is controlled on rule-based information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from individual users and adjusts settings based on this, e.g. by adjusting temperature	The system is controlled from a large range of data, where sometimes usage pattern, is self-learning and uses historical data for to improve their prediction models to ensure satisfied users.

Daylight and lighting	Lighting is turned on and off using a switch.	Lighting is turned on and off based on presence (motion sensor) and/or operating times.	The light control system controls the light level by presence, daylight level and operating times. Measures for optimal utilization of daylight taken into account in the design of the building. The lighting system is divided into appropriate zones and adapted for two-way communication in control system.	Amount of light and color temperature can be controlled by several sources such as time of day and season.	The lighting system receives feedback from individual users and provides users with information and guidance.	Amount of light and color temperature controlled in addition based on users physiology and preferences, after the principle of human centric lightning.

Energy and resource optimalisation

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Energy consumption and device management (lighting and equipment)	No lighting automation	Lighting is controlled based on predefined operating times and sensors.	All lighting and relevant electrical equipment shall have the possibility of two-way communication.	The units are controlled energy efficiently and effectively based on multiple sensor/data inputs (e.g. presence, sunscreen and daylight level) in real time. Energy consumption is measured and logged.	The units are controlled energy efficiently and effectively based on predicted needs (e.g. based on expected use and weather forecast).	The units are controlled energy efficiently and effectively based using large amounts of operational data and machine learning.
Climate technical system and thermal energy supply		Climate technology system such as satisfies TEK17.	The climate technology system is holistically designed (combination of passive and active measures) and easily optimized in operation. All relevant devices (e.g. heat pumps, valves, fans and temperature sensors) and zones in the building shall have the possibility of two-way communication.	The system is controlled and operated optimally energy based on several data sources (e.g. actual weather conditions, usage pattern and building response) in real time.	The system is controlled and operated at optimal energy efficiency based on usage pattern, and weather forecasting services. The system prepares themselves on upcoming heat and cold periods based on fixed algorithms.	The building is self-learning and improves its algorithms for control and operation adapted to usage pattern, the weather forecast and the actual weather.
Building spatial awareness and optimalisation				The building detects low use of space (typical for public holidays), and suggests users to relocate to certain floors, in order to	Building prepares for shutting down part of the build on periods expected to have low occupancy, e.g. giving users feedback on floor (un)availability when	The building is self-learning and improves its algorithms for control and operation adapted to usage pattern.

				“shut down” floors to save energy.	booking meeting rooms or workspace.	
Building maintenance staff optimalisation		Sensor on toilet rolls etc.	Sensors are installed to indicate when maintenance is required. E.g. which workstations have been in use, refill paper towels in WC etc.		The building monitors floor/area activity and predicts and notifies maintenance staff before service is required. E.g. When paper towel, hand sanitizer, soap dispenser is nearing empty.	Building is self-learning and improves its algorithms for control and operation using patterns and historical data to predict the required amount of maintenance required at a monthly/quartering interval

B7 Results from GG

Blue = public sector, red = private sector, purple = both public and private sectors

	Computerization	**Connectivity**	**Visibility**	**Transparency**	**Predictive capacity**	**Adaptability**
Use of open standard communications between systems and possibility of exchanging data	Systems have manual interface with little communications. More use of actuators and controllers	System is based on both open and proprietary protocols	All systems have two-way communication over open standardized protocol (ex. BACnet)	Systems have open documented API which makes it simple to exchange data.		
*Integration of control systems**		Some control systems are integrated one-to-one based on gateways (protocol converter)	All relevant control systems can be integrated to one system	Interactive management systems. Data is utilized across systems.	The control systems are predictive and shares data on expected future condition	The control systems are self-learning and improves its prediction models based on historical data
Availability of data, e.g. when using sensors and multisensors, paper towel usage, desk vacancy, parking etc.	No use of sensors	A small number of sensors are used by several system.	No unnecessary duplication of sensors. Instant data is available for all current systems, also future.	Simplified and flexible sensor system achieved by widespread use of multisensors and easy integration of additional sensors when needed	The sensor system is designed for high reliability through self-testing sensors, easy renewal of sensors, and the use of redundant sensors if necessary.	Machine learning algorithms checks system quality and reveals system errors.
Collection of structured data and analysis of these	No data is produced or data is not stored	Small and unstructured collection of data	Collection of structured data in real time. Data structure must be documented and available. No unnecessary duplication of data	Structured collection and storage of historical data. Data can be easily made available to third parties.	Large amounts of data are used for prediction	Large amounts of data are utilized by self-learning systems to to increase the precision system control during ordinary operation.

Technical networks	No network, or poor disciplined network.	A separate network per technical system.	A common technical network for all technical systems. The network can be segmented and supports access control with a centralized access register	All devices connected will be assigned access to the correct segment based on the devices defined functions and needs. Traffic and condition of the network is monitored	The network monitors data traffic and detects irregularities. The system alerts and handles deviations.	The technical network is self-learning and self-securing.
Positioning of people and equipment in the building	The building offers no positioning services	The building offers no positioning services	The building is prepared for indoor use positioning based on Wi-Fi triangulation, bluetooth beacons or a combination of these. Necessary wireless access points (WAP) and beacons are installed.	Users are assisted with navigating the building based on their position. Movable equipment is tracked and position made available to users.	The building offers users positioning services that let them find colleagues and be found.	

Climate control

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
Temperature regulation *Thermal environment*	Temperature is regulated by physically adjusting the temperature controller on the device.	Temperature is controlled by preset temperature levels and operating times.	The building system makes it possible to include other sources (e.g. presence and meeting room calendar) in temperature control. If the building has openable windows, these must have a sensor for opening sensing and outdoor air quality.	The building's systems have the opportunity to exchange information with the user in real time, eg about temperature in different zones. Cooling and the heating systems are controlled on a holistically with other systems and can e.g. take into account if windows are open.	Temperature is controlled rule-based in regards to information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from unique users and responders on these, e.g. by adjusting temperature or giving users personal guidance.	The system is controlled from a large range of inputs, including usage patterns, are self-learning and uses historical data for to improve their prediction models to ensure satisfaction users.
Atmospheric environment	Airflow is controlled by preset operating times.	Airflow is controlled according to preset CO² levels and operating times. At this stage, the CO² monitor is connected directly to the HVAC	Airflow can be controlled based on multiple sources in real time (e.g. activity in room, and CO²). If openable windows, these must have a sensor for opening and outdoor air sensors	Users can influence the amount of air natural and/or mechanical. The cooling and heating systems are controlled holistically with other systems and can for example take into account if a windows open.	Airflow is controlled on rule-based information about future events, e.g. meeting room booking and weather forecast. The system receives and saves feedback from individual users and adjusts settings based on this, e.g. by adjusting temperature	The system is controlled from a large range of data, where sometimes usage pattern, is self-learning and uses historical data for to improve their prediction models to ensure satisfied users.

Daylight and lighting	Lighting is turned on and off using a switch.	Lighting is turned on and off based on presence (motion sensor) and/or operating times.	The light control system controls the light level by presence, daylight level and operating times. Measures for optimal utilization of daylight taken into account in the design of the building. The lighting system is divided into appropriate zones and adapted for two-way communication in control system.	Amount of light and color temperature can be controlled by several sources such as time of day and season.	The lighting system receives feedback from individual users and provides users with information and guidance.	Amount of light and color temperature controlled in addition based on users physiology and preferences, after the principle of human centric lightning.

Energy and resource optimalisation

	Computerization	Connectivity	Visibility	Transparency	Predictive capacity	Adaptability
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Building spatial awareness and optimalisation				The building detects low use of space (typical for public	Building prepares for shutting down part of the build on periods	The building is self-learning and improves

			🟦	holidays), and suggests users to relocate to certain floors, in order to “shut down” floors to save energy.	expected to have low occupancy, e.g. giving users feedback on floor (un)availability when booking meeting rooms or workspace.	its algorithms for control and operation adapted to usage pattern.
Building maintenance staff optimalisation		🟦	Sensors are installed to indicate when maintenance is required. E.g. which workstations have been in use, refill paper towels in WC etc.		The building monitors floor/area activity and predicts and notifies maintenance staff before service is required. E.g. When paper towel, hand sanitizer, soap dispenser is nearing empty.	Building is self-learning and improves its algorithms for control and operation using patterns and historical data to predict the required amount of maintenance required at a monthly/quartering interval

Christer N A Quinn

Towards Smarter Buildings

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Norwegian University of
Science and Technology